Floristic diversity, community composition and structure in Nanda Devi National Park after prohibition of human activities, Western Himalaya, India

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The present study was carried out to assess floristic diversity, community composition and regeneration status of different forests in Nanda Devi National Park after prohibition of human activities in 1983 with a view to understand the impact of ban, and provide a basis for assessing subsequent changes on plant diversity and composition. The comparison of the present study with the earlier studies conducted in 1993 and 2003, indicated positive changes on plant diversity, forest composition and ecological conditions of the National Park. A total of 409 taxa belonging to 203 genera and 71 families (377 Angiosperms, 7 Gymnosperms and 25 Pteridophytes) were documented from the National Park. Two types of forest communities, i.e. Betula utilis *along timberline, and mixed forest of* Abies spectabilis *with* B. utilis *form the dominant forests inside the National Park. Proportionate distribution of individuals in seedling, sapling and tree layers showed considerable variation in the population structure of different communities. Maximum species richness was observed in Dibrugheta (128) followed by Dharansi (43) and Sarsopatal (34) among the studied alpine meadows of this National Park. The present results could be a pilot to strengthen conservation measures across the Protected Area Network by understanding the impact of the ban on anthropogenic activities, and is also useful for future assessment of floristic diversity and forest composition in the National Park.*

Keywords: Conservation, Nanda Devi National Park, tree regeneration, species diversity, western Himalaya.

RECENT global studies have demonstrated that biodiversity and ecosystem services continue to be lost, despite constant growth in the number of protected areas (PAs)[1]. It is accepted that the sole designation of an area as 'protected' does not imply that it is efficiently preserved; it also needs effective management practices[2]. Hence, the evaluation and assessment of PAs has become a priority for developing management and early vigilance strategies in the context of biodiversity conservation and global climate change[3]. The biodiversity-rich areas of Indian Himalayan Region (IHR) have been protected through an extensive Protected Area Network (PAN)[4]. These representative areas harbour rich diversity of both fauna and flora, thus acting as a reservoir of biodiversity in IHR covering 9.6% of the geographical area[4–6]. A systematic evaluation of representative biophysical values of PAs may be useful to address the issue of management and resource conservation in the IHR[7]. Tree species diversity is an important aspect of forest ecosystem that impacts the composition and plant diversity of forests[8,9]. Species composition and dynamics provide the necessary context for management planning and development of strategies for achieving sustainable management of forests, and also for interpreting Long-Term Ecological Research[10]. Long-term ecological studies are important to improve understanding about the relationship between vegetation and environment, and also for documenting responses of global climate change[11]. Further, these studies clearly demonstrate the path and process of changes in vegetation composition. Long-term monitoring of ecological changes in forest structure and composition becomes important for the successful implementation of REDD+ scheme in any area[12].

The Nanda Devi Biosphere Reserve (NDBR) is the second biosphere reserve designated by the Government of India and represents a distinctive combination of

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mountain ecosystems with unique floral and faunal diversity[13]. Recognition of its uniqueness and rich biodiversity, the reserve has been included in the World Network of Biosphere Reserves. Before 1982, the Nanda Devi peak inside Nanda Devi National Park (NDNP) was most popular among mountaineers and trekkers, after Mount Everest[14]. Tourism and mountaineering to the peak led to heavy destruction of biological resources, i.e. poaching of wild animals, tree felling by expedition parties, illegal collection of medicinal herbs, and accumulation of garbage inside the National Park (NP)[15]. Uncontrolled human activities in the NDNP area from the surrounding villages for a variety of resources, coupled with increased mountaineering activities, and the consequent environmental degradation led to the declaration of this area as a National Park in 1982 and was closed for human activities from 1983. Following complete closure, evaluation and assessment of biodiversity were made in 1993 and 2003.

The information collected and compiled in earlier expeditions on floristic diversity is available in the form of reports[16,17] limited only to the Forest Department of the state. The results of earlier expeditions indicated positive changes on plant diversity, richness, forest composition and ecological conditions of the park over the years. Maximum number of species showed either random or contiguous distribution in different forest communities. Such conditions reflect better forest health, which also reflects increase in species richness over the years. The present study provides a systematic information on the status of floristic diversity, community structure and regeneration pattern of different forests and highlights the major changes over the years (1993–2015) after the ban on anthropocentric activities inside NP.

Methodology

Study area

The present study was carried out in NDNP, which is one of core zones of NDBR in Uttarakhand, India (Figure 1). NDNP and NDBR encompass the transition zone between Greater and Trans-Himalaya and is renowned for its meadows with endemic and unique plants including high value medicinal plants and a variety of flora[15]. The biosphere reserve has been inscribed on the ‘World Heritage’ list by UNESCO for having unique floral and faunal diversity. After complete ban on human activities inside the NP by the Forest Department of the state, an ecological expedition is organized once in every ten years to assess the impact of the ban on biodiversity (floral and faunal) and plant species composition inside the NP. The present study was part of the ‘Decadal Biodiversity Monitoring Expedition 2015’ which was the third evaluation and assessment of biodiversity of NDNP twelve year after the earlier expedition in 2003. This expedition starts from Lata village in the buffer zone of NDBR and follows a fixed route, i.e. Belta-Khark, Lata-Khark, Dharasi, Dibrugheta, Deodi, Ramani, Bhitartoli, Bhujgarh, Patalkhan and ends at Sarsopatal meadow, the base camp for Nanda Devi Peak (Figure 1).

Floristic diversity, forest structure and regeneration pattern

Intensive field surveys using rapid sampling were carried out covering most of the habitats/sites of the NDNP. Plants were recorded and herbarium specimens of selected species were prepared as per standard protocol followed by Jain and Rao[18]. All the alpine meadows (Dharansi, Dibrugeta, Betartoli, Sarsaupatal) and forests (Dharansi-I, Dharansi-II, Dibrugeta, Parkhuriadhar-I, Parkhuriadhar-II, Trishul nala, Talla Deodi, Malla Deodi, Udyari Gufa, Ramari) along the track of Nanda Devi Peak (Rishi Gorge) were selected for detailed vegetation sampling following Samant and Joshi[16] and Adhikari[17]. Quadrat method was used to study plant species diversity, density and richness across different habitat types in the alpine meadows and forest community following Misra[19]. As mentioned in an earlier expedition, a total of 14 sites were selected between 3300 and 4400 m for vegetation sampling. Among these, 4 sites (each alpine meadow of NP) were used for analysing vegetation of alpine meadows, and 10 sites (each forest sites of NP) for tree species composition and regeneration status. For sampling of herbaceous vegetation in alpines, three 50 × 50 m plots were marked representing the major areas of the selected alpine meadow (Dharansi, Dibrugeta, Betartoli, Sarsaupatal), and 25 quadrats (1 × 1 m) randomly placed within each selected 50 × 50 m plot (a total of 75 quadrats of 1 × 1 m for each site).

Population structure and regeneration status of all the tree communities/stands in different forests were studied and analysed for various ecological parameters using quadrat method following Misra[19] and Mueller-Dombois and Ellenberg[20]. In each selected forest, three 100 × 100 m plots (one hectare) were laid systematically, and each 100 × 100 m plot was further divided into ten (10 × 10 m) quadrats for enumeration of tree species. Each 10 × 10 m quadrat was further subdivided into two quadrats (5 × 5 m) for observing shrubs and saplings density, and 5 quadrats (1 × 1 m) for seedlings and herbs. The basic CBH information of individual tree generated from each quadrat was used for development of population structures. The individuals in each tree species were grouped into seven arbitrary CBH classes (A: <10; B: 11–30; C: 31–60; D: 61–90; E: 91–120; F: >121–150; G: >150 cm) following Magurran[21,22]. Classes A and B represent seedlings and saplings respectively, and other classes (C–G) represent individual trees. The population

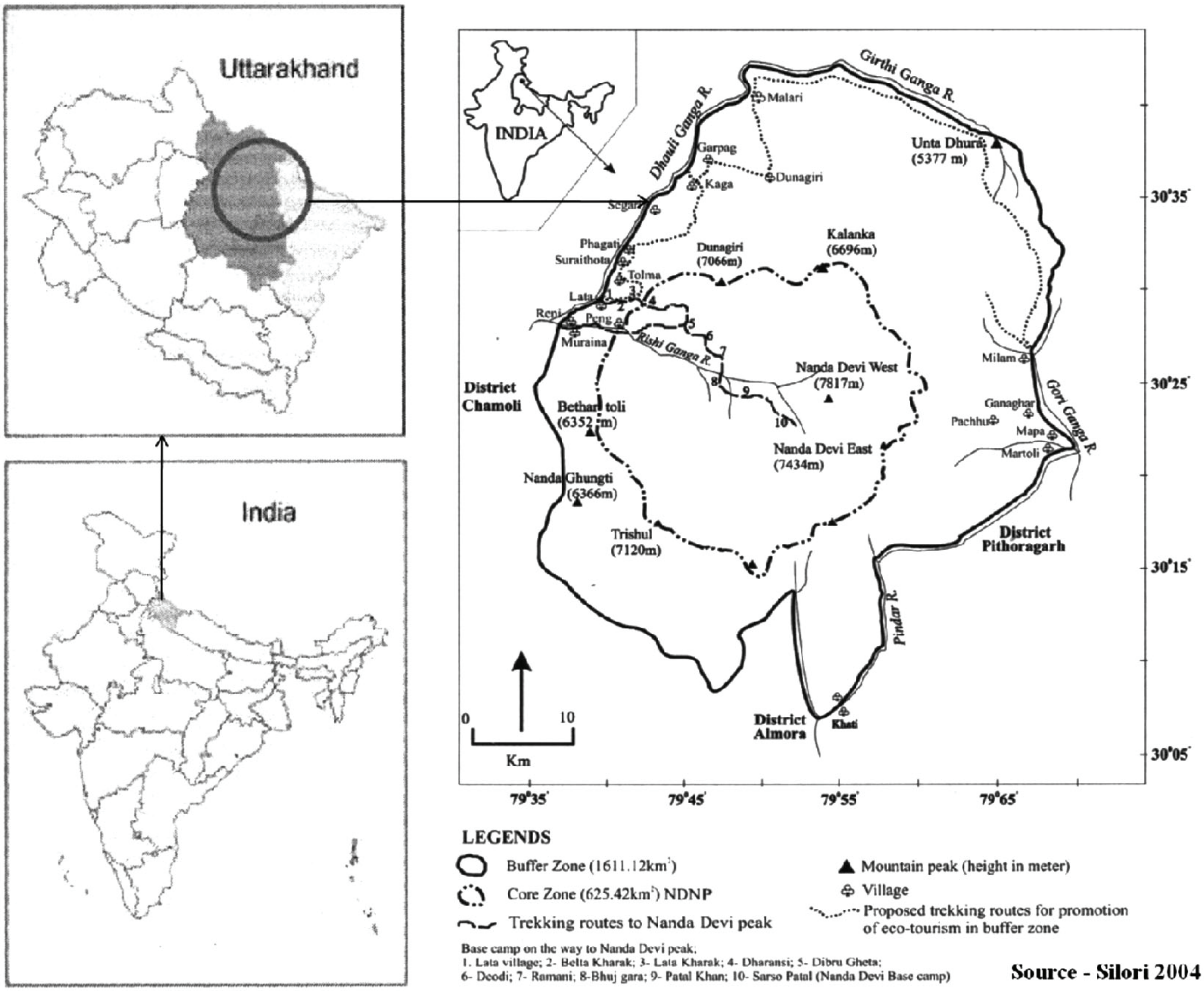

Figure 1. Map of the study area: Nanda Devi National Park within Nanda Devi Biosphere Reserve in Uttarakhand.

structure was studied by tallying species, individuals and basal area in four girth (gbh) classes, namely juvenile (>10 to <30 cm), young (>30 to <90 cm), elder (>90 to <180 cm) and mature (>180 cm). The regeneration status of dominant trees was assessed based on proportional distribution of density of individuals in each seedling, sapling and adult tree class[22,23]; good regeneration, if seedlings >saplings > trees; fair regeneration, if seedlings > or ≤ saplings ≤ trees; fair regeneration, if the species survives only in the sapling stage, but no seedlings (saplings may be <, > or = trees). Specific details of locations including latitude and longitude were recorded using global positioning system (GPS).

Results

The vegetation types in NP mostly comprised temperate forests, sub-alpine forests, alpine scrublands and alpine meadows. *Betula utilis* and *Abies spectabilis* form the dominant forest community between 3300–3900 m and 3300–3650 m respectively. *Rhododendron campanulatum* forms krummholtz zone and *R. anthopogon*, *R. lepidotum*, *Lonicera spinosa* and *Salix karelinii* were dominant species of the alpine scrubland. A total of 409 taxa belonging to 203 genera and 71 families were recorded from the National Park (see Supplementary Material). Among the 409 taxa, 377 are angiosperms, 7 are gymnosperms and 25 are pteridophytes. The angiosperms are distributed in 377 taxa and belong to 187 genera and 60 families; of these, the dicot plants are distributed in 320 taxa, belonging to 155 genera and 53 families and the monocot plants are distributed in 79 taxa, belonging to 39 genera and 10 families. Gymnosperms are distributed in 7 taxa, belonging to 4 genera and 3 families, while pteridophytes are distributed in 25 taxa, belonging to 12 genera and 8 families. Among the taxa, 354 were herbs, 50 shrubs and 5 taxa (*Betula utilis*, *Salix disperma*, *Acer acuminatum*, *Abies spectabilis* and *Pinus wallichiana*) were trees (see Supplementary Material). Asteraceae was the dominant family followed by Ranunculaceae and Rosaceae.

Among the studied forest sites, *Betula utilis* community was observed at 9 sites and *Abies spectabilis* was

Table 1. Composition and population density of tree communities in the National Park

Site	Altitude (m amsl)	Geographical location	Tree			
			Species	Density (Ind/hectare)	TBA (m^2/hectare)	A/F ratio[#]
Ramani	3300	N30°25′44.2″ E79°50′16.1″	*Betula utilis*	410	18.41	0.01**
			Abies spectabilis	200	21.92	0.05**
Talla Deodi	3350	N30°26′31.1″ E79 °49′01.2″	*Betula utilis*	760	15.70	0.10*
			Abies spectabilis	20	3.36	0.50*
Trishul Nala	3400	N30°25′42.4″ E79°49′45.2″	*Betula utilis*	800	8.02	0.13*
Dharansi-II	3550	N30°27′54.1″ E79°47′36.3″	*Abies spectabilis*	610	49.21	0.05**
			Betula utilis	200	6.93	0.04**
Parkhuriadhar-II	3550	N30°27′36.3″ E79°47′52.2″	*Abies spectabilis*	680	71.79	0.11*
Malla Deodi	3560	N30°26′37.4″ E79°49′3.1″	*Abies spectabilis*	670	24.12	0.09*
			Betula utilis	140	16.72	1.0*
Udyari Gufa	3600	N30°25′48.3″ E79°49′32.2″	*Betula utilis*	620	6.21	0.1*
Dibrugheta	3620	N30°27′46.7″ E79°47′55.5″	*Betula utilis*	640	32.03	0.05**
			Abies spectabilis	180	15.08	0.06*
Parkhuriadhar-I	3670	N30°27′24.2″ E 79°47′55.5″	*Abies spectabilis*	650	64.22	0.09*
			Betula utilis	170	23.61	0.06*
Dharansi-I	3900	N30°28′10.7″ E79°47′32.2″	*Betula utilis*	580	27.39	0.07*

Distribution pattern[#]. *Contiguous (>0.05), **Random (0.025–0.05), ***Regular (<0.025).

found in 7 sites. *Abies spectabilis* forms the dominant tree community at Dharansi-II, Parkhuriadhar-I, Parkhuriadhar-II and Malla Deodi, while *B. utilis* dominated at Ramari, Talla Deodi, Udyari Gufa, Dibrugeta, Trishul Nala and Dharansi-I forests. Based on density distribution of species, *Betula utilis* was observed as the most frequent species in the NP. *Pinus wallichiana* in small patches has also been observed on the south facing slopes between Parkhuriadhar-II and Deodi. The density of *A. spectabilis* and *B. utilis* ranged from 20 to 680 ind ha^{-1} and 140 to 800 ind ha^{-1} respectively (Table 1). Distribution of both species (*A. spectabilis* and *B. utilis*) was found random as well as contiguous in most of forest sites. The Total Basal Area (TBA) cover was in the range of 3.6–71.8 m^2/ha for *A. spectabilis* and 6.21–32.03 for *B. utilis* (Table 1). *Danthonia cachemyriana* was the most dominant species in all the sites followed by *Potentilla argyrophylla* and *Potentilla atrosanguinea* among herbs. Among the four alpine meadows, Dibrugheta shows maximum number of plant species (143) belonging to 55 families and 111 genera. The meadow also has maximum number of threatened and high value medicinal species with high population density. Out of 409 taxa recorded, 24 plant species were found under the threatened categories as per IUCN (2015). Among threatened species, the maximum density was found for *Arnebia euchroma* (1.6–2.8 ind/m^2) followed by *Angelica glauca* (1.2–2.6 ind/m^2) and *Arnebia benthamii* (0.8–1.4 ind/m^2) respectively, and the least was found for *Nardostachys jatamansi* and *Cypripedium elegans* (0.2–0.4 ind/m^2) in NP (Table 2). All tree species (*A. spectabilis*, *B. utilis*, *P. wallichiana*) and shrubs such as *Juniperus communis*, *J. indica* and *J. recurva* were under the threatened category.

The population structure of tree species in terms of proportion of seedlings, saplings and adults varied in all the study sites. *Abies spectabilis* showed maximum number of individuals in the seedling and sapling stages and decreasing numbers in the higher tree-size classes (Figure 2 *a*, *b*, *f*, *g*, *i*). The accumulation of sapling and decline towards seedling and higher tree-size were observed for *B. utilis*. Both tree species showed a greater proportion of individuals in seedling and sapling classes and a sharp decline toward higher tree-size classes (Figure 2 *c* and *e*). High accumulation of young tree, and sharp decline towards juvenile and mature tree, were also observed for mixed forest of NP (Figure 2 *d* and *h*). A very unusual trend was found for *B. utilis* forest of Dharansi-I site due to absence of seedlings (Figure 2 *j*). The regeneration of *B. utilis* was found good towards timberline ecotone in mixed forest of *A. spectabilis* at Talla Deodi, Malla Deodi and Parkhuriadhar-I sites, while it was found good for *A. spectabilis* at Ramari, Talla Deodi, Dharansi-II, Malla Deodi and Parkhuriadhar-II in a *B. utilis* dominated community (Figure 3). Poor regeneration of *A. spectabilis*

Table 2. Population density and altitudinal distribution of threatened plants in the National Park

Herb	Life form	Altitudinal range (m amsl)	Density range (Ind/m^2 – herbs; Ind/ha – tree and shrubs)	Threat status
Abies spectabilis	Tree	3500–3750	20–680	NT[39]
Aconitum heterophyllum	Herb	3450–3700	0.3–0.7	EN[39], CR[38]
Aconitum violaceum	Herb	3550–3600	0.5–1.4	VU[39, 38]
Allium stracheyi	Herb	4250–4300	1.2–2.3	VU[38]
Angelica glauca	Herb	3650–3800	1.2–2.6	EN[39, 38]
Arnebia benthamii	Herb	3560–3800	0.8–1.4	CR[38]
Arnebia euchroma	Herb	3900–4260	1.6–2.8	EN[38]
Betula utilis	Herb	3300–3900	140–800	EN[39]
Cypripedium elegans	Herb	3200–3700	0.2–0.4	EN[39]
Cypripedium himalaicum	Herb	3400–3850	0.3–1.2	EN[39]
Dactylorhiza hatagirea	Herb	3500–4050	0.6–1.6	CR[38]
Fritillaria roylei	Herb	3000–3650	0.6–1.2	EN[38]
Juniperus communis	Shrub	3600–3650	83–88	LC[39]
Jurinea macrocephala	Herb	3400–3950	0.6–1.8	EN[38]
Juniperus indica	Shrub	3600–3650	67–75	LC[39]
Juniperus recurva	Shrub	3600–3650	21–26	LC[39]
Malaxis muscifera	Herb	3560–3850	0.4–1.2	VU[39]
Meconopsis aculeata	Herb	3450–4250	0.2–0.8	EN[43]
Nardostachys jatamansi	Herb	3200–3550	0.2–0.3	CR[39,38]
Picrorhiza kurrooa	Herb	3600–4250	0.6–1.3	CR[38]
Podophyllum hexandrum	Herb	3400–3850	0.3–1.1	EN[38]
Polygonatum cirrhifolium	Herb	3520–3760	0.2–0.8	VU[38]
Polygonatum verticillatum	Herb	3580–3850	0.6–1.3	VU[38]
Rheum webbianum	Herb	3600–3850	0.6–1.22	VU[38]

NT, Near threatened; EN, Endangered; CR, Critically endangered; VU, Vulnerable; LC, Least concern; Ved[38], IUCN[39].

and *B. utilis* was observed for Dibrugeta and Dharansi-I sites. There were a good number of seedlings and saplings of *B. utilis* towards alpine meadows (20–50 m) at most sites, and *P. wallichiana* inside the national park at Parkhuriadhar-II and Dibrugeta sites. A total of 183 individuals of *P. wallichiana* (tree – 67; sapling – 107; seedling – 9) were recorded inside NP in the present study. Similar observation was also noticed for few shrubs species such as *Juniperus recurva*, *Rhododendron anthopogon*, *Cotoneaster microphylla*, etc.

Discussion

Biodiversity inventories are mostly used to determine the nature and distribution of forest biodiversity and resources for developing better management plans and resource conservation[24]. Understanding species composition, knowledge of the forest structure and regeneration pattern are necessary for effective forest conservation and management plans[25]. The distribution patterns for tree layers commonly showed contiguous growth among the studied sites followed by random. According to Odum[26], contiguous distribution is common in nature and formed as a result of small but significant variations in ambient environmental conditions, while random distribution is found in uniform environments[23,27,28]. The presence of adequate number of seedlings, saplings and young trees in any given population always indicates successful regeneration[29]. Maximum number of individuals in sapling stage and a sharp decline towards both higher tree classes and lower seedling classes resulting in hill-shaped curves, indicate that the rate of conversion of sapling to tree is not proportional as also indicated in an earlier study[30] from the region. Among the pure community forests, a decline from lower girth class to higher girth class was observed for Ramari, Talla Deodi, Malla Deodi, Udyari Gufa and Parkhuriadhar-I. Assemblage of individuals at sapling stage and a sharp decline toward the seedling and higher classes was apparent for Dharansi-II, Dibrugeta and Dharansi-I. The regeneration of *A. spectabilis* in *B. utilis* indicated development of mixed forests in future. *Betula utilis* forests seem to be quite young with good canopy cover, which may be due to exposure of the site to the light conditions as well as change in snow melting pattern with climate warming. Maximum tree density in mixed community of *Abies* and *Betula* was due to higher species richness as compared to single forest stand. The regeneration of *A. spectabilis* was found higher compared to *B. utilis* inside the forests of NP compared to buffer zone area of NDBR[31], indicating the positive impact of ban on human activities inside NP. Low density of sapling is an indicative of problems in conversion of seedlings to saplings at Dibrugeta, while absence of seedlings in *B. utilis* forests at Dharansi-I is possibly due to comparatively high CBH of *B. utilis* and dense shrub layer of

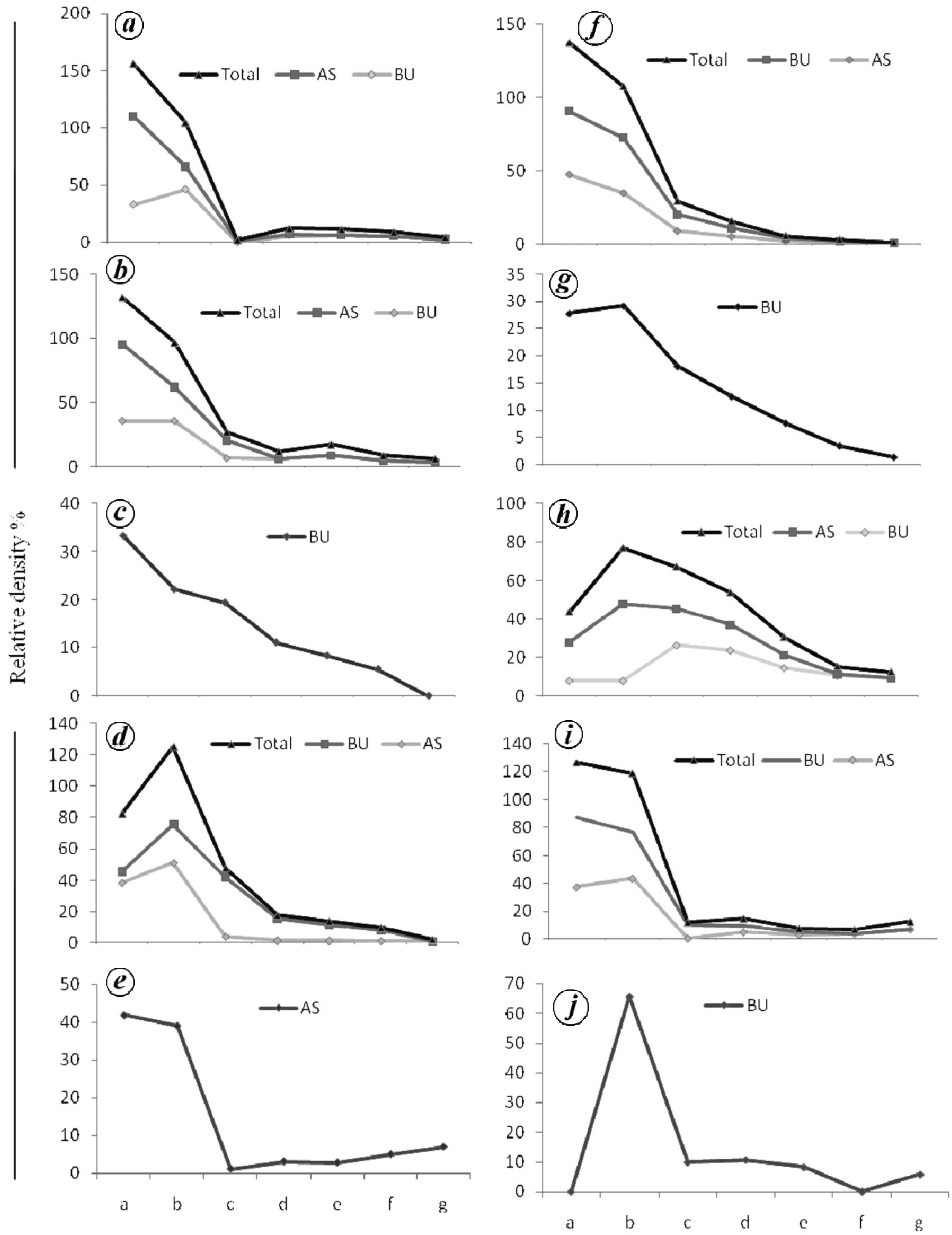

Figure 2. Population structure of all species: ***a***, Ramari; ***b***, Talla Deodi; ***c***, Trishul Nala; ***d***, Dharansi-II; ***e***, Parkhuriadhar-II; ***f***, Malla Deodi; ***g***, Udyari Gufa; ***h***, Dibrugeta; ***i***, Parkhuriadhar-I; ***j***, Dharansi-I. AS, *A. spectabilis*; BU, *B. utilis*.

Rhododendron campanulatum, resulting in low intensity of light reaching the soil, which may retain seed dormancy, as also reported in earlier studies[32,33] from the Central Himalaya.

The conversion rate of seedlings to saplings was good in *Abies* dominated forest, and is evident from the maximum number of saplings and trees. However, with respect to timberline, the seedlings and saplings were found higher for *B. utilis* at Ramari and Dibrugeta sites. The regeneration and conversion rate of seedlings to saplings along the timberline was found quite good in the present study compared to earlier studies[31,34] from the BR, and compared to reports of earlier expeditions[16,17]. The high density of *Betula* seedlings and saplings along the timberline indicated favourable climatic conditions, which help in establishment, growth and survival of seedlings beyond

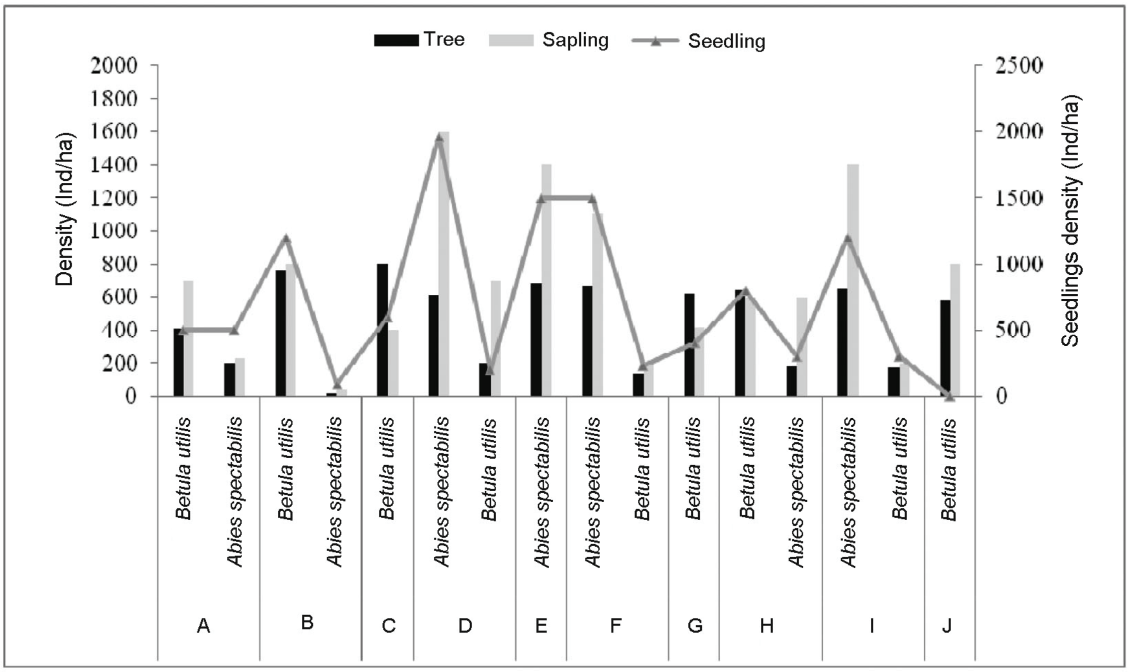

Figure 3. Regeneration pattern of different forest communities: A, Ramari; B, Talla Deodi; C, Trishul Nala; D, Dharansi-II; E, Parkhuriadhar-II; F, Malla Deodi; G, Udyari Gufa; H, Dibrugheta; I, Parkhuriadhar-I and J, Dharansi-I.

the canopy shelter, towards higher elevation as reported in earlier studies[11,17,34–36]. The population of *B. utilis* alongside the trails and trekking routes, indicated good regeneration in recent years. The density of new saplings is extensive, suggesting positive impact of the ban on human activities inside the park. The saplings of *B. utilis* were absent in Parkhuriadhar-I and Malla Deodi in 1993; however all the sites in 2003 and in the present study were represented by many saplings. Also the density of saplings in all the sites was observed to be higher compared to 1993–2003 (ref. 16). The regeneration of tree species at Parkhuriadhar-I, Malla Deodi and Parkhuriadhar-II was good compared to fair in 1993 and 2003. Seedlings were absent at Dharasi II in 1993 compared to low number of seedlings in 2003, while a good number of seedlings was observed in the present study. Total basal area of selected forest sites was found higher compared to 1993 and 2003 (ref. 16). TBA of *A. spectabilis* increased at all the sites and became almost double in 2003 (ref. 16), and was also found in the higher side in the present study. The richness of shrub species and their density increased during the last twenty years. The overall composition and health of the forests of the national park has improved compared to 1993 and 2003, indicating the positive impacts of the ban inside the NP.

The present study observed expansion and/or shift of *P. wallichiana* on south facing slopes of the NP due to open canopy and may be due to change in climatic conditions. Few individuals (seedlings and saplings) of *P. wallichiana* reported in 2003 by Adhikari[17], have now been developed into saplings and trees within a span of twelve years. The population of *Juniperus* spp., *Salix* spp., *Cotoneaster* spp., *Rhododendron lepidotum* and *R. anthopogon* has improved compared to 2003 (refs 16, 17). Establishment of small individuals of *Juniperus recurva* and *R. anthopogon* has been observed in various sites towards higher altitude, indicating impacts of climate change. Among others, *Cotoneaster microphyllus* has expanded its cover to almost double compared to 2003 (ref. 17) towards higher altitude in the Dibrugeta meadow. Establishment of *P. wallichiana* inside the national park and a good number of seedlings and saplings of *B. utilis* towards timberline ecotone in most sites indicated shifting of these species to higher altitudes. The study is consistent with Bharti[37], who showed increase in green biomass in the timberline ecotone of NDNP. In another study, Rai[34] reported a good number of seedlings and saplings beyond 10–15 m from the edge of timberline ecotone in Tungnath region of western Himalayas. However, shifting in altitudinal range of the species with climate warming required long-term ecological monitoring[11,35,36]. The diversity of *Juniperus* spp. was quite high inside NP compared to different valleys of western Himalaya including the cold desert of Lahaul valley[33]. The highest density of *J. communis*, *J. indica* and *J. recurva* in the Betartoli site, suggested that Betartoli site should be protected for conservation of threatened Gymnosperms. The overall density of shrubs such as *Juniperus communis*, *J. indica*, *J. recurva*, *Rhododendron anthopogon*, *Salix lindleyana*, *S. microphyllus* and *Lonicera* *spinosa* in NP was observed to be high compared to earlier studies[16,17].

The NP harbours many threatened plants; 24 species are in different threatened categories according to Ved[38] and IUCN[39]. There was no major difference in density of threatened plants as compared to earlier information[16] (1993–2003). Among the alpine meadows of NP, Dibrugheta represents 44.65% (348 species) of the total species of NDNP indicating priority for conservation of the meadow. This meadow is near the buffer zone villages (Lata, Tolma and Reni) that have been identified for special monitoring of illegal harvesting of medicinal plants from the region. Illegal harvesting and over-exploitation of medicinal plants have been reported[5,40] which have led the extinction of more than 150 species in the wild. Harvesting of medicinal plants such as *Allium humile*, *Allium stracheyi*, *Angelica glauca*, *Arnebia benthamii* from the surrounding alpine meadows of NP is a regular activity by local inhabitant community, particularly from Lata and Tolma villages, indicating a threat of illegal harvesting from outer regions (Dharasi and Dibrugeta meadows) of the NP. Collection of *Ophiocordyceps sinensis*; a 'caterpillar fungus', more commonly known as *Yartsa gunbu* and *Keera Jadi* from alpine meadows in recent decades is causing severe threat to the diversity of high value threatened plants in many alpine areas of the Himalayas[41–43]. Increasing market trend of the species[40,41] and unemployment in the region indicate that legal as well as illegal exploitation might have a negative impact on the diversity of other unique medicinal plants in the near future.

Conclusion

The present study provides positive impacts on plant diversity and forest composition as a result of complete ban on human activities inside NDNP for the last three decades. The information and database generated in the present study might be useful for future study, possibly after ten years to draw additional inferences. Considerable variation in composition and population structure was observed for different forest communities over the years inside NP. Among the mixed forests, a decreasing trend of individuals of *A. spectabilis* from lower girth class to higher, represents stability of the species at most sites. Occurrences of seedlings of *A. spectabilis* in most *B. utilis* communities and fewer *B. utilis* in *A. spectabilis* communities in some of the sites indicated long-term changes in these communities. The study also indicated shifting of species towards higher altitude which may be due to climate warming; however it needs to be monitored through remote sensing with field based observations. Dibrugheta meadows indicate the need for high priority for conservation of a repository of unique and rare medicinal plants. For proper conservation and better management of the park area, the following recommendations may be considered:

- Scientific study/expedition for biodiversity monitoring in NDNP needs to be undertaken every five years interval (instead of 10 year presently) for understanding closer change patterns in plant diversity and forest composition.
- Establishment of few permanent long-term monitoring sites as per globally accepted protocols to understand the relation between vegetation shifting and climate warming.
- Taking measures to prevent illegal harvesting of high value medicinal plants and collection of *Keeda Jadi* in the outer zone of NP.

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