Journal of Forestry Research (2011) 22(3): 403–408
DOI 10.1007/s11676-011-0110-y

ORIGINAL PAPER

Distribution pattern and conservation of threatened medicinal and aromatic plants of Central Himalaya, India

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Received: 2010-04-07; Accepted: 2010-08-26

Abstract: A study was conducted to examine the distribution pattern of four rhizomatous medicinal and aromatic plant species (MAPs) viz., *Angelica glauca*, *Pleurospermum angelicoides*, *Rheum emodi* and *Arnebia benthamii* in different forest stands in Central Himalaya. Results show that *A. glauca* and *P. angelicoides* had a higher (50%) frequency at Chipkoan, Garpak and Phagati forest, *R. emodi* had a higher (60%) frequency at Rishikund, Suki and Himtoli, and *A. benthamii* had a higher (70%) frequency at Suki and Khambdhar The densities of *A. glauca* (0.6 plants·m^{-2}) and *P. angelicoides* (0.5 plants·m^{-2}) were higher at Chipkoan and Garpak sites than at other micro-sites, while densities of *R. emodi* (0.8 plants·m^{-2}) and *A. benthamii* (1.0 plants·m^{-2}) were higher at Suki and Khambdhar sites. *A. glauca* had highest total basal covers (TBC) (1.2 cm^2·m^{-2}) at Chipkoan, *P. angelicoides* had highest TBC (0.92 cm^2·m^{-2}) at Lati kharak site, *A. benthamii* had the highest TBC (6.48 cm^2·m^{-2}) at Khambdhar, and *R. emodi* had highest TBC (4.53 cm^2·m^{-2}) at Rishikund. For the four studied species, *A. glauca* showed a contagious distribution, *P. angelicoides* and *R. emodi* showed the random and *A. benthamii* showed the regular type of distribution.

Keywords: alpine ecosystem; Himalaya; medicinal and aromatic plants; traditional knowledge; Uttarakhand

Foundation project: This work was supported by financial assistantships from NATP-PB, NBPGR, Pusa Campus New Delhi.
The online version is available at http://www.springerlink.com

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Responsible editor: Hu Yanbo

Introduction

Among many biological hotspots around the world, the Himalaya and Western Ghats in the Indian sub-continent are the biodiversity rich areas. Himalaya covers only 18% of the Indian sub-continents; however. it accounts for more than 50% of Indian forest, of which 40% are endemic species (Maikhuri et al. 2000; Kala 2005). It is well known that the distribution pattern of plant species is mainly governed and regulated by altitude as well as edaphic and climatic factors (Bongers et al. 1999; Nautiyal et al. 2001; Kala 2004; Kharkwal et al. 2005, 2007) and their population is especially affected by human activities due to various reasons (Niggemann et al. 2009). Himalayan forests extend from the lower mountain slopes with nearly tropical to temperate timberline (Singh and Singh 1992). The alpine region of the Himalaya has a variety of medicinal plant species. However, exploitation through legal or illegal means has ultimately resulted in the decline of the population of many valuable medicinal and aromatic plants (MAPs) that are of ecological and economic significance.

Moreover, a large number of medicinal plants have become threatened due to their small population size, narrow distribution area, habitat specificity, destructive mode of harvesting, heavy livestock grazing, high value of utilization, climate change, habitat loss, present development activities and genetic drift (Kala 2000; 2005). Although extensive research has been carried out on many medicinal plants of this region (Samant 1993; Purohit et al. 2001; Kumar and Ram 2005; Misra et al. 2008; Kala 2006, 2010), there is relatively less information available about the distribution pattern of large number of MAPs. In this regard, the present study was initiated to investigate the distribution pattern and conservation measures of four rhizomatous species (*Angelica glauca* Edgew., *Pleurospermum angelicoides* (DC.) C.B. Clarke, *Rheum emodi* Wall. ex Meissn., and *Arnebia benthamii* Wall. ex G. Don.) in the Dhauli Ganga catchment of Nanda Devi Biosphere Reserve in Central Himalayan region of India.

Materials and methods

Study area

The study was conducted in Dhauli Ganga catchment (30°16' to 30°32' N and 79°44' to 80°02' E) of Nanda Devi Biosphere Reserve (NDBR), which lies in Chamoli district of Uttarakhand (Central Himalaya). The area is dominated by crystalline rocks and the soils are loam to sandy loam. The study area is dominated by the Bhotiya; a tribal community belonging to an Indo-Mongoloid ethnic group (Fig. 1).

Climate

The daily minimum and maximum temperatures were recorded from March 2000 to March 2003. Monthly minimum temperature ranged from 2.2°C to 16°C, and the monthly maximum-temperature ranged from 15.3°C to 27.2°C. June and August were the warmest months of the year, with an average temperature of 27°C. Average rainfall is about 937 mm/year and about 43% of annual rainfall occurs over a short period of two months (July–August), with a strong monsoon influence (Fig. 2).

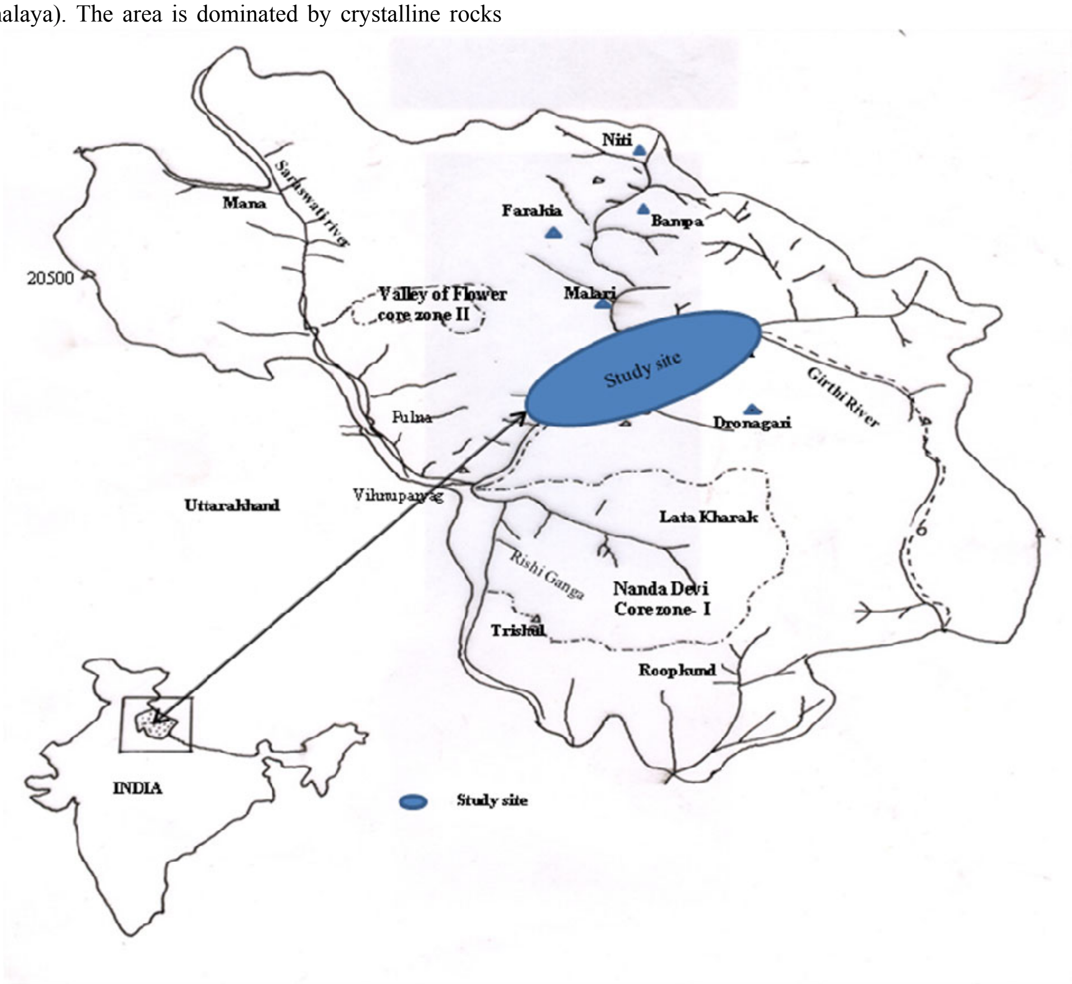

Fig. 1 Location map of the study site in the Nanda Devi Biosphere reserve (Not to Scale), India

Survey

Specimens were collected with the help of ‘Flora of Chamoli’ (Naithani 1984) and information on the botanical work of the Nanda Devi National Park (Hajra, 1983). Plant species were identified at the herbarium of Botany Department of HNB Garhwal University. Plant specimens were collected, preserved and identified following the techniques reported by Gaur (1999) and Naithani (1984) and specimens were deposited in the herbarium.

Considering the importance of these endangered taxa in the Himalayan region, complete and in-depth quantitative field surveys were conducted on population estimation in different localities. The survey was undertaken in a wide transverse range covering more than 45 km in the study area (from Raini to Malari in Chamoli District) in Uttarakhand. Five prominent sites between elevations of 2 000 and 3 500 m a.s.l. were analyzed for each species (Table 1). Approximately 100 m × 100 m forest stands were selected in the area. In each forest stand, 10 quadrats (1 m × 1 m size each) were laid randomly following the methodology of Kershaw (1973). Analytical features of the population such as percent frequency, density and total basal cover were calculated using the standard methods of Misra (1968). The ratio of abundance to frequency (A/F), a relative measure to present the distribution of species in a community, was calculated according to the methods of Curtis and Cottom (1956) as: A/F <0.025 (regular), between 0.025 and 0.05 (random), and > 0.05 (contagious) distribution. Importance Value Index (IVI) of each species was calculated for the determination of dominance and ecological success of a species (Curtis and McIntosh 1950). The plant species diversity was determined using Shannon-Weiner information index (Shannon and Weaver 1963). The community similarity coefficient of the stands was calculated on the basis of IVI following the methods of Jaccard (1912). Niche width for each species was computed using the equation given by Levins (1968). The degree of presence (P) of a species was determined following Braun-Blanquet (1932) method.

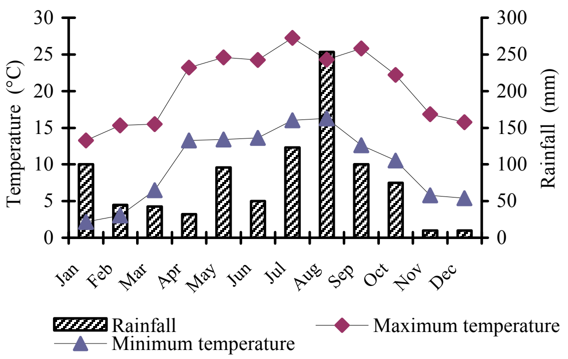

Fig. 2 Climatic data for the study area, based on average rainfall and temperature (minimum and maximum)

Table 1. Site characteristics of the selected population

Sites	Altitude (m a.s.l.)	Aspects	Slope (°)	Habitat
Khambdhar	3900	North West	40-50	Rocky terrain, moist grassy slopes.
Himtoli	3700	South West	50-55	Steep slopes very moist grassy slopes.
Rishikund	3900	North West	45-60	Rocky slope on Northwest facing slopes.
Tolma forest	3200	North West	40-45	Mixed forest (Cedrus, Betula spp).
Suki	3300	North West	50-55	Dry rocky crevices
Chipkoan	3500	South East	50-60	Moist rocky, grass dominated
Garpak	3200	South East	45-55	Moist rocky grass dominated
Phagati forest	3500	South East	50-55	Moist laden moist rocky, boulders
Lati kharak	3700	South East	50-60	Gentle slope in moist with Cedrus forest

Results

Occurrence and availability

The distribution of species in the study areas was found mostly habitat specific (Table 2). *A. glauca* grows well in moist and shady areas especially in alpine slopes. The frequency of *A. glauca* ranged from 30% at Phagati forest site to 50% in all the study sites. The density of *A. glauca* was higher (0.6 plants·m^{-2}) at Chipkoan and Garpak sites. The species accompanied with *A. glauca* were *Veronica cana*, *Fragaria nubicola* and *Calamagrostis pilosula*. *F. nubicola* was a dominant species in all the sites, although, other species were also present as co-dominant species at different sites. *P. angelicoides* was mostly found growing in shady places of the forest. Frequency of *P. angelicoides* ranged from 30% at Lati kharak site to 50% at Chipkoan, Garpak and Phagati forest sites. Density of *P. angelicoides* was higher (0.5 plants·m^{-2}) at Chipkoan and Garpak sites. Common species growing along with *P. angelicoides* were *Sedum imbricatum, Thalictrum alpinum* and *Polygonum* spp (Table 3). *R. emodi* grows well in moist rocky places between boulders and stream (with 40°–50° steepness); the frequency of occurrence of this species was 40% at Tolma forest site and 60% at Suki, Himtoli and Rishikund sites. The density of *R. emodi* was the highest (0.8 plants·m^{-2}) at Suki site. The common species associated with *R. emodi* were *Danthonia cachemyriana*, *Ligularia arnicoides* and *Potentilla fulgens*. *D. cachemyriana* was found to be the most dominant species across all sites, although different species were present as co-dominant species at various sites (Table 3). For *A. benthamii*, frequency of occurrence was 20% at Tolma forest, 70% at Suki, and Khambdhar, and 30% at Himtoli and Rishikund sites. The density of *A. benthamii* was highest (1 plants·m^{-2}) at Khambdhar site. In general, species such as *D. cachemyriana*, *P. polystachyum* and *Fritillaria roylei* were dominant at all the investigated sites. A/F ratio presents the idea of distribution patterns of species in a community. *A. glauca* shows contagious distribution, *P. angelicoides* and *R. emodi* shows random and *A. benthamii* shows regular type of distribution. *A. glauca* exhibited the highest total basal cover (TBC) (1.2 cm^2·m^{-2}) at Chipkoan, *P. angelicoides* (0.92 cm^2·m^{-2}) at Lati kharak, *R. emodi* (4.53 cm^2·m^{-2}) at Rishikund and *A. benthamii* (6.48 cm^2·m^{-2}) at Khambdhar sites (Table 3).

The maximum IVI of *R. emodi* (25.63) , *A. benthamii* (65), *A. glauca* (28.02), and *P. angelicoides* (33.06) were found at Himtoli, Khambdhar, Garpak, and Chipkoan sites, respectively (Table 3). In the present study, the value of diversity index (H$^{'}$) ranged from 1.47 to 2.52 for all the four species (Fig. 3). The highest community similarity for *A. glauca* (81.8) and *P. angelicoides* (94.7) was both at Garpak site. Similarly, the highest similarity coefficient of *R. emodi* (90.9) and A. *benthamii* (90) was observed to occur at Khambdhar site (Table 4). Percent contribution to community basal cover for *R. emodi* ranged between 4.568 at Suki, to 16.566 at Khambdhar, similarly *A. benthamii* had community basal cover between 3.61 at Tolma forest and

81.18 at Suki,, *A, glauca* between 0.86 at Phagati forest and 2.11 at Lati kharak, and *P. angelicoides* between 0.151 at Phagati forest and 20.35 at Rishikund (Table 5).

Table 2. Characteristic of *Angelica glauca, Pleurospermum angelicoides, Arnebia benthamii* and *Rheum emodi*

Species	Habitat and occurrence	Altitude (m a.s.l)	Life span	Flower	Leaves	Root
Angelica glauca	Moist shady, sub-alpine slopes near, water springs and occur mostly in the shady canopy of *Betula utilis* forest	1800-3700	Perennial	Compound umbel yellowish or purple in colour	1-3 pinnate	Tuberous
Pleurospermum. angelicoides	Mostly forest; cover and shady slope.	2800-3500	Perennial	Compound umbel yellowish or purple in colour	Broad leaves bilaterally divided	Tuberous
Rheum emodi	Moist rocky places, between boulders and stream.	3500-5000	Perennial	Axillary panicles, dark purple or pale red and tall	orbicular or broadly ovate	Stout
Arnebia benthamii	Sub-alpine forest and shady slopes	3000-3900	Perennial	Flowers are pink to purple or maroon, in dense, terminal spikes; nutlets ovoid.	Narrow-lanceolate	Stout

Table 3. Phytosociological attributes of *Angelica glauca, Pleurospermum angelicoides, Rheum emodi*, and *Arnebia benthamii* in the study area.

Species	Phytosociological attributes						
	Sites	Frequency F (%)	Density (Plants m^{-2})	Abundance frequency ratio	Total basal cover ($cm^2 m^{-2}$)	Importance Value Index	Dominant associates
	Chipkoan	50	0.6	0.02	1.2	8.61	*C. pilosula, V. cana*
	Garpak	50	0.6	0.60	0.97	28.02	*F. nubicola, Cicerbita cyanea*
Angelica glauca	Phagati forest	30	0.3	0.03	0.60	8.01	*F. nubicola, P. arbuscula*
	Rishikund	50	0.5	0.02	0.64	13	*C. pilosula, V .cana*
	Lati kharak	50	0.2	0.05	0.57	9.36	*V. cana, C. pilosula*
	Chipkoan	50	0.5	0.02	0.36	33.6	*P. spp, S. imbricatum*
	Garpak	50	0.5	0.02	0.36	9.86	*P. spp, S. imbricatum*
Pleurospermum angelicoides	Phagati forest	50	0.3	0.03	0.21	5.74	*S. imbricatum, C. pilosula*
	Rishikund	40	0.4	0.02	0.02	7.88	*S. imbricatum, L. arnicoides*
	Lati kharak	30	0.3	0.03	0.92	12.27	*S. imbricatum, T. alpinum*
	Suki	60	0.8	0.02	2.88	14.56	*D. cachemyriana, P. fulgens*
	Khambdhar	50	0.6	0.02	4.33	24.34	*D. cachemyriana, F. roylei*
Rheum emodi	Himtoli	60	0.6	0.01	4.33	25.63	*D. cachemyriana, L. arnicide*
	Rishikund	60	0.7	0.019	4.53	16.09	*D. cachemyriana, P. fulgens*
	Tolma forest	40	0.4	0.025	2.88	17.55	*D. cachemyriana, P. fulgens*
	Suki	70	0.9	0.01	5.83	18.44	*P. polystachyum, A. margaritacea*
	Khambdhar	70	1.0	0.02	6.48	65.07	*D. cachemyriana, P. polystachyum*
Arnebia benthamii	Himtoli	30	0.4	0.44	2.88	38.56	*P. astrosanguinea, F. roylei*
	Rishikund	30	0.3	0.03	2.16	14.79	*D. cachemyriana, F. roylei*
	Tolma forest	20	0.2	1.44	1.44	8.63	*L. arnicoides, D. cachemyriana*

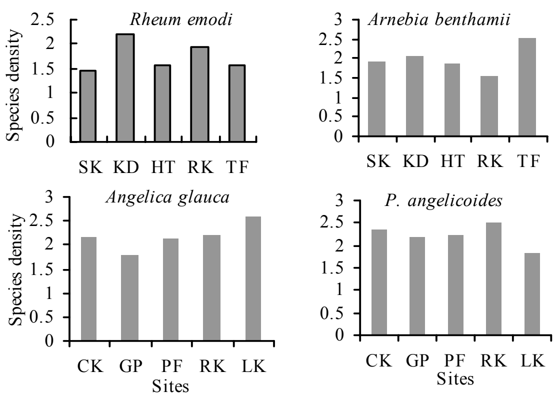

Fig. 3 Species diversity (H') for 1) *Rheum emodi,* 2) *Arnebia benthamii,* 3) *Angelica glauca* and 4) *Pleurospermum angelicoides*.
SK---Suki, KD---Khambdhar, HT---Himtoli, TF---Tolma forest, CK-Chipkoan, GP---Garpak, PF---Phagati forest, RK---Rishikund, LK---Lati kharak

Niche width value based on density value ranged from 1 to 8.2 among the different species. Niche width value was 1.68 for *A. glauca*, 3.7 for *A. benthamii*, 4.7 for *R. emodi*, and 2.2 for *P. angelicoides*, respectively. However, Percent presence (% P) of all the four species was very high which might be due to their specific natural requirements (Fig. 4).

Discussion

A. glauca showed contagious distribution and *P. angelicoides* and *R. emodi* presented the random and *A. benthamii* was the regular type of distribution, which is a common feature in alpine vegetation. These patterns are consistent to the previous observations (Singh and Yadav 1974; Saxena and Singh 1980). According to Odum (1971), contagious distribution is the most pervasive pattern in nature; random distribution is confined only in very uniform environments whereas regular distribution occurs in those areas where competition among several individuals exists. Contagious distribution depends on the local habitat, daily and seasonal weather change and reproductive process.

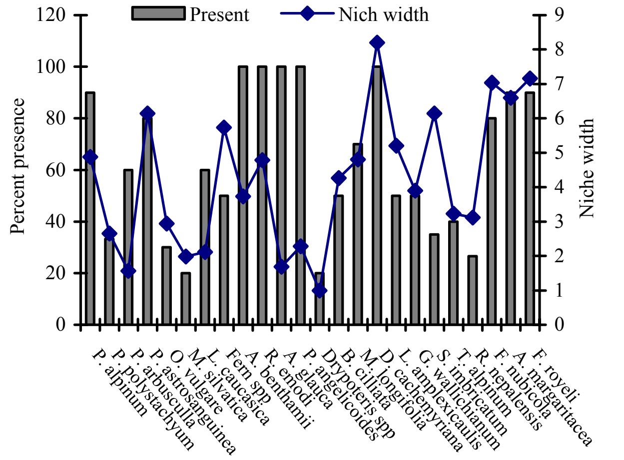

Fig. 4 Percent presence and Niche width of the species in the study area.

Table 4. Community similarity coefficients between different populations of *Rheum emodi*, *Arnebia benthamii*, *Angelica glauca*, and *Pleurospermum angelicoides* in the study area

Stands	Suki	Khambdhar	Himtoli	Rishikund	Tolma forest
R. emodi					
Suki	100	90.9	73.68	60	80
Khambdhar	–	100	73.68	60	80
Himtoli	–	–	100	58.82	70.5
Rishikund	–	–	–	100	55.5
Tolma forest	–	–	–	–	100
Stands	Suki	Khambdhar	Himtoli	Rishikund	Tolma forest
A. benthamii					
Suki	100	90	73.66	73.68	66.66
Khambdhar	–	100	82.35	70.58	73.68
Himtoli	–	–	100	75	77.77
Rishikund	–	–	–	100	66.66
Tolma forest	–	–	–	–	100
Stands	Chipkoan	Garpak	Phagati forest	Rishikund	Lati kharak
A. glauca					
Chipkoan	100	81.81	54.54	45.45	47.61
Garpak	–	100	55.55	44.44	47
Phagati forest	–	–	100	77.77	70.58
Rishikund	–	–	–	100	58.82
Lati kharak	–	–v	_	–	100
Stands	Chipkoan	Garpak	Phagati forest	Rishikund	Lati kharak
P. angelicoides					
Chipkoan	100	94.73	80.00	60.00	82.35
Garpak	–	100	73.68	52.63	75.00
Phagati forest	–	–	100	60	70.58
Rishikund	–	–	–	100	70.58
Lati kharak	–	–	–	–	100

Table 5. Contribution of the species community dominance/TBC a) *Rheum emodi* b) *Arnebia benthamii*, c) *Angelica glauca* and d) *Pleurospermum angelicoides*.

Sites	Community Density (Plants m^{-2})	% Contribution of the Species to community Density	Community total basal cover	Contribution of the species community dominance/TBC
Rheum emodi				
SK	594.8	0.1344	62.78	4.5868
KD	272.3	0.2203	26.167	16.5662
HT	442.0	0.13574	34.401	12.586
RK	401	0.1746	87.14	5.2048
TF	301.3	0.132	4.52	8.5624
Arnebia benthamii				
SK	827	0.1088	71.85	81.1899
KD	394.8	0.2532	12.232	52.972
HT	310.8	0.1287	9.592	30.1059
RK	421.7	0.0711	27.407	7.9030
TF	309.7	0.0645	39.934	3.6159
Angelica glauca				
CK	249.3	0.2406	78.6925	1.52492
GP	88.7	0.6764	6.184	1.5716
PF	166.8	0.1798	69.734	0.8604
RK	136.9	0.1158	31.0382	2.0619
LK	136.9	0.146	26.447	2.1179
Pleurospermum angelicoides				
CK	158	0.3164	145.199	0.2479
GP	146.2	0.3419	133.726	0.2692
PF	207.8	0.1443	142.613	0.151
RK	54.7	0.2585	111.919	20.3502
LK	72.4	0.4143	80.600	1.1445

Note: SK---Suki,, KD---Khambdhar, HT---Himtoli, TF---Tolma forest, CK-Chipkoan, GP---Garpak, PF---Phagati forest, RK---Rishikund, LK---Lati kharak

The higher IVI value indicates that most of the available resources are being utilized by that species and the residual resources are being trapped by another species as the competitors and associates (Kukshal et al. 2009). In the present study, the value of diversity index ranged from 1.4 to 2.5, which is within the range of general temperate forest from 1.16 for young stands to 3.4 for old stands (Knight 1975). Niche width is a measure of different resources used by an organism which further provides the role of species on a community and the degree of specialization of a species as its ability to exploit an environment range in space (Bisht and Kusumlata 1993). It was found that *D. cachemyriana* exhibits a broader niche width as compared to other species. According to Smith (1980, 1990) the species with wider niche are considered to be more generalized. MacArthur (1965) pointed out the utility of niche is to determine differences between individuals and species.

Song et al. (1997) stated that the distribution and diversity of plant species in a landscape depend on various factors (e.g., dispersal, ability, competition, environmental factors such as solar radiation, temperature and soil geological conditions) which may influence the landscape vegetational structure and would show significant effects on richness and diversity (Heydari and Madhavi 2009). However, some species are widely distributed across a range of elevations, 3000 m. a.s.l. Kala (2005) reported elevation as a strong feature for establishment of plant communities. The present findings are relevant to sustainable harvesting of species in their natural habitats. The observed parameters on population status and habitat preference would assist in understanding the ecology and development of a conservation plan with regard to *A. glauca*, *A. benthamii*, *R. emodi* and *P. angelicoides*. Considering the above facts, besides protecting these plants in their natural habitats, sustainable harvesting of these selected MAPs is required as per the demands of the local people so as to improve their socio-economic conditions.

Acknowledgements

The authors are thankful to Director, G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora, Uttarakhand for providing the facilities for this study; financial assistantships from NATP-PB, NBPGR, Pusa Campus New Delhi and NRF, Pretoria, South Africa are acknowledged.

References

Bisht NS, Kusumlata. 1993. Niche width and dominance diversity relations of woody species in a moist temperate of Garhwal Himalaya. *Journal of Hill Research,* **6**: 107–113.

Bongers F, Poorter L, Van Rompaey RSAR, Parren MPE. 1999. Distribution of twelve moist forest canopy tree species in Liberia and Cote d'Ivoire: response curves to a climatic gradient. *Journal of Vegetation Science,* **10**: 371–382.

Braun-Blanquet J. 1932. *Plant Sociology: The study of plant communities.* (Transl. G.D. Fuller & H.C. Conard). New York: McGraw-Hill Book Co., p. 439.

Curtis JT, Cottam G. 1956. *Plant Ecology Workbook Laboratory Field Reference Manual*. Minnesota: Burgess Publishing Co., p.193.

Curtis JT, McIntosh RP. 1950. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology,* **31**: 434–455.

Gaur RD. 1999. Flora of District Garhwal, North West Himalaya (With Ethnobotanical Notes). Transmedia, Srinagar, Garhwal, Uttaranchal, India.

Heydari M, Madhavi A. 2009. Pattern of plant species diversity in related to physiographic factors in Melah Gavan protected area, Iran. *Asian Journal of Biological Sciences,* **2**: 21–28.

Hajra PK. 1983. Contribution to the botany of Nanda Devi National Park, Howrah, Botanical Survey of India.

Jaccard P. 1912. The distribution of flora in alpine zone. *New Phytosociology,* **11**: 37–87.

Kala CP. 2000. Status and conservation of rare and endangered medicinal plants in the Indian trans-Himalaya. *Biological Conservation*, **93**: 371–379.

Kala CP. 2004. Pastoralism, plant conservation, and conflicts on proliferation of Himalayan Knotweed in high altitude protected areas of the Western Himalaya, India. *Biodiversity and Conservation,* **13**: 985–995.

Kala CP. 2005. Indigenous uses, population density and conservation of threatened medicinal plants in protected areas of the Indian Himalayas. *Conservation Biology*, **19**: 368–378.

Kala CP. 2006. Problems and prospects in the conservation and development of the Himalayan medicinal plant sector. *International Journal of Sustainable Development*, **9:** 370–388.

Kala CP. 2010. *Medicinal plants of Uttarakhand: Diversity livelihood and conservation.* Delhi, India: Biotech Books.

Kershaw KA. 1973. *Quantitative and dynamic plant ecology*. London: Edward Arnold, p. 308.

Kharkwal G, Poonam M, Rawat YS, Pangtey YS. 2005. Phytodiversity and growth form in relation to altitudinal gradients in the Central Himalayan (Kumaun) region of India. *Current Science,* **89**: 873–878.

Kharkwal G, Rawat YS, Pangtey YS. 2007. Distribution characteristics of the tree species in Central Himalaya, India. *International Journal of Botany,* **3**: 226–228.

Knight DH. 1975. A phytosociological analysis of species rich tropical forest on Barro-Colorado Island: Panama. *Ecological Monograph,* **45**: 259–284.

Kukshal S, Nautiyal BP, Anthwal A, Sharma A, Bhatt BP. 2009. Phytosociological investigation and life form pattern of grazing lands under Pine canopy in temperate zone, Northwest Himalaya, India. *Research Journal of Botany*, **4:** 55–69.

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

Levins R. 1968. Evolution in changing environments. Princeton University Press, Princeton, N.J. USA.

MacArthur RH. 1965. Patterns of species diversity. *Biological Review,* **40**: 510–533.

Maikhuri RK, Nautiyal S, Rao KS, Chandrasekhar K, Gavali R, Saxena KG. 2000. Analysis and resolution of protected area-people conflicts in Nanda Devi Biosphere Reserve, India. *Environmental Conservation,* **27**: 43–53.

Misra R. 1968. *Ecology workbook*. Calcutta: Oxford and IBH Publishing, p.244.

Misra S, Maikhuri RK, Kala CP, Rao KS, Saxena KG. 2008. Wild leafy vegetables: A study of their subsistence dietetic support to the inhabitants of Nanda Devi Biosphere Reserve, India. *Journal of Ethnobiology and Ethnomedicine*, **4**: 1–9.

Naithani BD. 1984. *Flora of Chamoli, I & II, Botanical Survey of India*, Howarh.

Nautiyal BP, Prakash V, Chauhan RS, Harish P, Nautiyal MC. 2001. Assessment of germinability, productivity and cost benefit analysis of *Picrorrhiza kurrooa* cultivated at lower altitude. *Current Science,* **81**: 579–585.

Niggemann M, Jetzkowitz J, Brunzel S, Wichmann MC, Bialozyt R. 2009. Distribution patterns of plants explained by human movement behaviour. *Ecological Modelling,* **220**: 1339–1346.

Odum EP. 1971. Fundamental of Ecology. 3rd ed., WB Saunders, Philadelphia, pp574.

Purohit A, Maikhuri RK, Rao KS, Nautiyal S. 2001. Impact of bark removal on survival of *Taxus baccata* L. (Himalayan yew) in Nanda Devi Biosphere Reserve, Garhwal Himalaya, India. *Current Science*, **81**: 586–590.

Samant SS. 1993. Diversity and status of plants in Nanda Devi Biosphere Reserve, In; Scientific and ecological expedition on Nanda Devi. Reports, Corps of Engineers (Army), New Delhi, India, pp. 45–53.

Saxena AK, Singh JS. 1980. Analysis of forest grazing lands vegetation in parts of Kumaun Himalaya. *Indian Journal of Range Management,* **1**: 13–32.

Shannon CE, Weaver W. 1963**.** *The Mathematical theory of communication*. Champaign, IL, USA: University of Illinois Press, p.367.

Singh JS, Singh SP. 1992. *Forest of Himalaya: Structure, Functioning and Impact of Man*. Nainital, India: Gyanodaya Prakashan,.

Singh JS, Yadav PS. 1974. Seasonal variation in composition, plant biomass and net primary productivity of tropical grasslands at Kurukshetra, India. *Ecological Monograph,* **44**: 351–376.

Smith RL. 1980. *Ecology and Field Biology*. New York: Harper and Row Publishers, p. 835.

Smith RL. 1990. *Student resource manual to accompany ecology and field biology*. Fourth edition, New York: Harper and Row Publisher, p. 114.

Song B, Chen J, Desanker PV, Reed DD, Bradshaw GA, Franklin DF. 1997. Modelling canopy structure and heterogeneity across scales: from crown to canopy. *Forest Ecology and Management,* **96**: 217–229.