Proc. Indian natn. Sci. Acad. B48 No. 1 pp 121-137 (1982)

Analysis of Forest Vegetation At and Around Naini Tal in Kumaun Himalaya

P K RALHAN, A K SAXENA and J S SINGH*

Department of Botany, Kumaun University, Naini Tal 263002

Certain forests at and around Naini Tal were quantitatively analysed. On the basis of IVI, a total of five forest types, viz., *Pinus roxburghii, Quercus floribunda, Q. lanuginosa, Q. leucotrichophora* and *Q. semecarpifolia* were recognized. The total tree basal cover ranged from 2686.7 to 6045.8 cm^2 100 m^{-2}. The composition of tree and shrub layers differed markedly among various types of forest. *Q. floribunda* forest supported the largest shrub population, while *P. roxburghii* and *Q. semecarpifolia* were the poorest in this regard. *P. roxburghii* forest indicated zero diversity, whereas *Q. floribunda* forest on basal cover basis and *Q. leucotrichophora* forest on density basis, had maximum diversity. Among the oak forests, *Q. floribunda* forest indicated relatively greater equitable share of resources among the various species. Generally, a total of four tree strata and a shrub stratum sheltering, in turn, a layer of herbs were recognizable in the present forests. The forests could be graded, as follows, in a decreasing order of soil protection potential: *Q. floribunda* (site 2) > *Q. leucotrichophora* > *Q. floribunda* (site 3) > *Q. lanuginosa* > *Q. semecarpifolia* > *P. roxburghii*. The trees in the oak forest were more wind stable, while in *P. roxburghii* they were specially susceptible to wind effect. With the exception of *Q. leucotrichophora* and *Q. semecarpifolia* in their respective forest types, the dominant species in all the forests had a stable population indicating good regeneration.

Key Words: **Himalayan forests, *Pinus roxburghii* forest, *Quercus floribunda* forest, *Quercus leucotrichophora* forest, *Quercus lanuginosa* forest, *Quercus semecarpifolia* forest, Phytosociology, Diversity, Profile structure**

Introduction

According to Champion and Seth (1968), in western and central Himalaya the three common oaks, viz., *Quercus leucotrichophora* (1800-2300 m), *Q. floribunda* (2000-2500 m) and *Q. semecarpifolia* (2500-3300 m) provide a simple and convenient basis for subdivision of the altitudinal zones. *Pinus roxburghii* may also extend up to 2300 m on ridges. In this respect Naini Tal and its environs become interesting from ecological point of view because altitudinal variation over

**Present address;* Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado 80523, USA.

short distances results in the occurrence of forests representing all the above four species. Quantitative information on the forests in Kumaun Himalaya is lacking except for a few studies undertaken recently (Saxena et al. 1978, Pandey & Singh 1981a,b, Saxena & Singh 1980, 1982).

The present study provides quantitative information on analytic characters, tree diversity, profile structures and regeneration status of certain selected forests at and around Naini Tal.

Study area and Methods

Sites

On the basis of preliminary reconnaissance, six sites, located at and around Naini Tal (29°24′ N lat. and 79°28′ E long.), were selected for the analysis of forests. Table 1 gives the major forest species, aspect, altitude, locality and predominant lithology for different sites.

Climate

The mean maximum temperature at Naini Tal ranges between 10.3°C (January) and 27.7°C (May) and mean minimum between 3.6°C (January) and 16.9°C (June). The mean monthly rainfall varies from 6.8 (November) to 804.3 mm (July). Annual rainfall averages at 2821.6 mm, out of which about 88% occurs during the rainy season. Depending on these climatic variations, the year is divisible into three seasons, viz., rainy (June to September), winter (October to February) and summer (March to May). Further details of the climate are given in Pandey and Singh (1981 a).

Methods

The phytosociological analysis of each forest was conducted by using twelve 10×10 m quadrats, distributed at random. The size and the number of quadrats were determined, respectively by the

Table 1 *The location of study sites*

Site No.	Major species	Aspect	Altitude (m)	Locality	Predominant lithology
1.	*Pinus roxburghii*	South-east	1300	Champhi	Quartzite and gneiss
2.	*Quercus floribunda*	North-east	2050	Govt.-House	Pyritons slates interbeded with limestone
3.	*Quercus floribunda*	North	2120	Ayar-patta	Slates and dolomites
4.	*Quercus leucotrichophora*	South-west	2270	Snow-view	Mainly calcareous slates (Marl)
5.	*Quercus lanuginosa*	West	2194	Kilbury	Slates, pink limestones and diamictites
6.	*Quercus semecarpifolia*	South-east	2611	Naina-peak	Purple and green slates with yellow weathering limestone

species area curve (Misra 1968) and the running mean method (Kershaw 1973). In each quadrat, trees with $\geq$31.5 cm cbh (circumference at breast height, i.e. 1.37 m from the ground) were individually measured for cbh. Individuals of 10.5 to 31.4 cm cbh were recorded either as saplings or as shrubs, as the case may be, and individuals $<$10.5 cm cbh were considered as seedlings. Other measurements included total height, height to first branch and canopy width for each species. A rough sketch of the trees was also made in the field. Height of the tree and canopy depth were measured through hypsometer (Forbes 1961).

The vegetational data were quantitatively analysed for abundance, density and frequency according to the formulae given by Curtis and McIntosh (1950). The relative values of frequency, density and dominance were determined following Phillips (1959). These quantities were summed to represent IVI of individual species (Curtis 1959). The ratio of abundance to frequency for different species was determined for eliciting the distribution patterns. This ratio indicates regular (0.025), random (0.025 to 0.05) and contagious ($>$0.05) distributions (Curtis & Cottam 1956).

Community coefficients between different forests were calculated following Jaccard (1912) by using IVI data for the tree layer and density data for the shrub layer.

The tree species diversity for different forest types was determined by using Shannon-Wiener information function *(H)* (Shannon & Wiener 1963):

$$H = -\sum_{i=1}^{S} (Ni/N) \log_2 (Ni/N),$$

where Ni is the total number of individuals of species i, and N is the total number of individuals of all species in a stand. In another set of calculations, the values for basal cover were used instead of density for the above calculations.

Concentration of dominance *(cd)* was measured by Simpson's index (Simpson 1949):

$$cd = \sum_{i=1}^{S} (Ni/N)^2$$

where Ni and N are the same as for Shannon-Wiener information function. The calculations for the species diversity and concentration of dominance were made on individuals $\geq$31.5 cm cbh.

Profile diagrams were prepared for each site following Knight (1963). In order to include a majority of species in the profile diagrams, an area of 200m^2 was considered suitable. The number of trees, saplings and shrubs to be included in the diagram were calculated on the basis of their density. Plants of each species, for the inclusion in the diagram, were selected from among all trees of each species actually measured on the site by using a random table.

The relative canopy index for tree and shrub layers for each site was calculated by the following formula (Saxena 1979):

$$\text{Canopy index} = \frac{\text{Sum of the lengths of the strip covered by canopies}}{\text{Total length of the profile strip}} \times 100$$

The quotient of slenderness (*SG*), for each site for all tree strata, was calculated following Brunig and Heuveldop (1976):

$$SG = h/d,$$

where h=average height of the tree *(m)*; and d=average diameter of tree at breast height *(m)*. The values of SG for each site were averaged across all tree strata.

To represent the population structure of each tree species the following cbh classes were established:

Class	*Range in cbh (cm)*
A	0 to 10.4 (seedlings)
B	10.5 to 31.4 (saplings)
C	31.5 to 65.5
D	66 to 100
E	100.5 to 134.5
F	135 to 169
G	169.5 to 203.5
H	204 to 238
I	238.5 to 272.5

The total number of individuals belonging to the above individual girth classes were calculated for each species on each site. The number of individuals in each girth class, for each species, was divided by the total number of individuals in all girth classes of that species on a site. The resultant value was multiplied by 100 to yield percent density for each girth class for each species.

Results and Discussion

Analytic Characters (table 2)

Pinus roxburghii was the only tree species on site 1. Among sites 2 and 3 which had a preponderance of *Quercus floribunda*, the total basal cover (TBC) of this species as well as of forest was greater on the former site which was relatively more protected. On site 2, although *Q. leucotrichophora* had maximum mean basal cover (MBC) among all species, due to low values of relative density (RD) and relative frequency (RF), it assumed an IVI lower than *Q, floribunda*. Similarly, on site 3, *Ficus foveolata* exhibited maximum value for MBC, but because of its lower RD and RF, it had an IVI lower than *Q. floribunda*, *Ilex dipyrena* and *Q. leucotrichophora*.

In terms of IVI, TBC and density, *Q. leucotrichophora* followed by *Q. floribunda* dominated the 4th site. *Q. lanuginosa* was dominant species on 5th site. Although *Rhododendron arboreum* on this site had maximum MBC, on account of its lower relative density and frequency, this species had very low IVI. *Q. semecarpifolia* had the maximum TBC on site 6, while the minimum TBC was recorded for *I. dipyrena*. *Q. semecarpifolia*, which had lowest value for MBC, exhibited greatest IVI, because of its greater RD and RF.

Thus, the TBC was maximum for *Q. leucotrichophora* forest (site 4) and minimum for *P. roxburghii* forest (site 1), and the total density varied from 3.9 (*Q. floribunda* forest on site 3) to 16.7 plants $100m^{-2}$ (*Q. floribunda* forest on site 2). Although *Q. floribunda* forest on the two sites exhibited little difference in TBC, tree density was markedly different. The data on MBC per tree for these sites indicated that the forest on site 2 was younger in comparison to that on site 3. Although *Q. leucotrichophora* (site 4) and *Q. lanuginosa* (site 5) forests exhibited almost equal density, on account of higher values for MBC of the dominant species, the former forest had higher total basal cover.

The values for TBC and density in several temperate forests as reported by different authors vary from 1560 to 5930 cm^2 100 m^{-2}, and from 3.5 to 20.8 trees 100 m^{-2}, respectively, while in tropical forests (except for tropical rain forests) the same ranges from 1073 to 3062 cm^2 $100m^{-2}$, and from 5.5 to 11.7 trees 100 m^{-2} (Saxena 1979). The forest basal cover (FBC) on the present sites, thus, was in the range reported for the temperate forests, whereas density values overlapped those of the tropical and temperate forests.

Table 2 *Analysis of certain Kumaun Himalaya forests. Only trees – ≥31.5 cm cbh are considered in this table.*

Species	Frequency (%)	Density (trees 100 m^{-2} ± 1 SE)	Abundance (tree 100 m^{-2})	A/F	Mean basal area (cm^2 $tree^{-1}$)	Total basal cover (cm^2 100 m^{-2} ± 1 SE)	Relative frequency (%)	Relative density (%)	Relative dominance (%)	Importance Value Index (IVI)
Site 1										
Pinus roxburghii Sarg.	100.00	5.16±0.69	5.16	0.052	520.68	2686.74±761.82	100.00	100.00	100.00	300.00
Site 2										
Quercus floribunda Lindl.	100.00	14.75±2.31	14.75	0.147	181.42	2675.96±854.15	52.17	88.16	75.87	216.20
Quercus leucotrichophora A. Camus	33.33	0.75±0.39	2.25	0.067	672.38	504.29±378.50	17.39	4.48	14.29	36.16
Cupressus torulosa Don.	16.66	0.58±0.39	3.50	0.060	426.17	247.18±171.84	8.69	3.46	7.0	19.15
Litsea umbrosa Nees	25.00	0.41±0.27	1.60	0.060	181.85	74.56±50.33	13.04	2.45	2.11	17.60
Cedrus deodara Hook. f.	8.33	0.16±0.16	1.90	0.240	104.43	16.71±16.71	4.34	0.95	0.47	5.76
Euomynus tingens Wall.	8.33	0.08±0.08	0.96	0.120	101.50	8.12±8.12	4.34	0.47	0.23	5.04
Total		16.73				3526.82				299.91
Site 3										
Quercus floribunda	58.33	1.41±0.50	2.42	0.042	960.68	1354.57±574.96	31.81	41.46	50.10	123.37
Ilex dipyrena Wall.	58.33	1.66±0.40	2.80	0.035	251.21	417.02±182.04	31.81	34.14	15.42	81.37
Quercus leucotrichophora	41.66	0.58±0.22	1.40	0.034	936.93	543.42±287.70	22.72	17.07	20.10	59.89
Ficus foveolata Wall.	8.33	0.08±0.08	0.96	0.120	2174.50	173.96±173.96	4.54	2.43	6.43	13.40
Fraxinus micrantha Lengel Sheim	8.33	0.08±0.08	0.96	0.120	1914.37	153.15±153.50	4.54	2.43	5.66	12.63
Rhododendron arboreum Smith	8.33	0.08±0.08	0.96	0.120	763.62	61.09±61.09	4.54	2.43	2.25	9.22
Total		3.89				2703.21				299.88

(continued on page 126)

(Table 2 *contd.*)

Species	Frequency (%)	Density (trees 100 m^{-2} ± 1 SE)	Abundance (tree 100 m^{-2})	A/F	Mean basal area (cm^2 $tree^{-1}$)	Total basal cover (cm^2 100 m^{-2} ± 1 SE)	Relative frequency (%)	Relative density (%)	Relative dominance (%)	Importance Value Index (IVI)
					Site 4					
Quercus leucotrichophora	100.00	4.16±0.65	4.16	0.042	786.46	3271.68±1021.58	48.00	50.00	54.11	152.11
Quercus floribunda	91.66	3.58±0.69	3.90	0.004	674.10	2413.30±759.97	43.99	43.00	39.91	129.90
Rhododendron arboreum	16.66	0.58±0.43	3.50	0.210	622.05	360.79±281.64	7.99	7.00	5.96	20.95
Total		8.32				6045.77				299.96
					Site 5					
Quercus lanuginosa D. Don.	100.00	7.50±0.72	7.50	0.075	464.81	3486.14±1048.92	66.67	92.93	93.72	253.32
Quercus floribunda	33.33	0.41±0.19	1.25	0.037	357.82	146.71±63.65	22.22	5.08	3.94	31.24
Rhododendron arboreum	8.33	0.08±0.08	0.96	0.120	870.50	69.64±69.64	5.55	0.99	1.87	8.41
Cedrus deodara	8.33	0.08±0.08	0.96	0.120	215.50	17.24±17.24	5.55	0.99	0.46	7.00
Total		8.07				3719.73				299.97
					Site 6					
Quercus semecarpifolia Sm.	91.66	4.25±0.84	4.60	0.051	1209.78	5141.58±449.45	78.57	92.72	91.60	262.89
Fraxinus micrantha	16.66	0.25±0.17	1.50	0.090	1254.72	313.68±245.82	14.28	5.45	5.59	25.32
Ilex dipyrena	8.33	0.08±0.08	0.96	0.120	1914.37	153.15±153.15	7.14	1.81	2.73	11.68
Total		4.58				5608.41				299.89

The tree layer composition differed markedly among the forests as shown by community coefficient values (table 3). The tree layers of *P. roxburghii* and *Q. semecarpifolia* forests were remarkably different from other forests. This is understandable because *Q. semecarpifolia* is a high altitude oak and *P. roxburghii* occurred on the lowest elevation in this study, thus the forests represented by these two species were very different from the others which occupied an overlapping altitudinal range. The tree layers, in general, were more similar among *Q. floribunda* (on two sites) and *Q. leucotrichophora* forests. *Q. floribunda* forest showed only 54% similarity in the tree layer, among its two sites; this was because of greater relative preponderance of *I. dipyrena* (IVI=81) and *Q. leucotrichophora* (IVI=60) on site 3. Thus, the forest on site 3 was of a more mixed nature than the forest on site 2.

The total shrub population varied considerably among the forests (figure 1). *Q. floribunda* forest supported the largest shrub population while *P. roxburghii* and *Q. semecarpifolia* forest were the poorest in this regard.

In *Q. floribunda* forest on site 2, the shrub layer was dominated by *Arundinaria falcata*, while on site 3 *Boenninghausenia albiflora* was dominant (figure 1). In *Q. leucotrichophora* and *Q. lanuginosa* forests, the shrub layer was dominated, respectively, by *Indigofera gerardiana* and *Artimisia vulgaris*. *Daphne cannabina* in *Q. semecarpifolia* forest and *Inula cappa* in *P. roxburghii* forest emerged as dominant shrubs.

A perusal of community coefficient values for the shrub layer (table 4) indicates a remarkable degree of dissimilarity among the different forests (values ranged from 0 to 32%). Perhaps the shrubs are more sensitive to subtle environmental differences than the trees.

The total density of saplings and seedlings was maximum in *Q. floribunda* forest (on site 2) and minimum in *Q. semecarpifolia* forest (figure 1). Further, *Q. lanuginosa*, *Q. semecarpifolia* and *P. roxburghii* dominated the sapling population in their respective forests, whereas *Q. leucotrichophora* and *Q. floribunda* (on site 3) forest indicated the dominance of, respectively, *Q. floribunda* and *Machilus duthiei* saplings (figure 1). *Q. floribunda* dominated the seedling population in all except *P. roxburghii* and *Q. semecarpifolia* forests.

These forests were characterised by a preponderance of contagious distribution and the rarity of regular distribution. The general preponderance of contagious

Table 3 *Community coefficients calculated on the basis of IVI of tree species for different forests*

Forest types	*Pinus roxburghii*	*Quercus floribunda* (site 2)	*Quercus floribunda* (site 3)	*Quercus leucotrichophora*	*Quercus lanuginosa*	*Quercus semecarpifolia*
Pinus roxburghii	100	0	0	0	0	0
Quercus floribunda (site 2)		100	53.64	54.81	12.85	0
Q. floribunda (site 3)			100	64.18	13.22	8.11
Q. leucotrichophora				100	13.22	0
Q. lanuginosa					100	0
Q. semecarpifolia						100

Table 4 *Community coefficients calculated on the basis of density of shrub species under different forests*

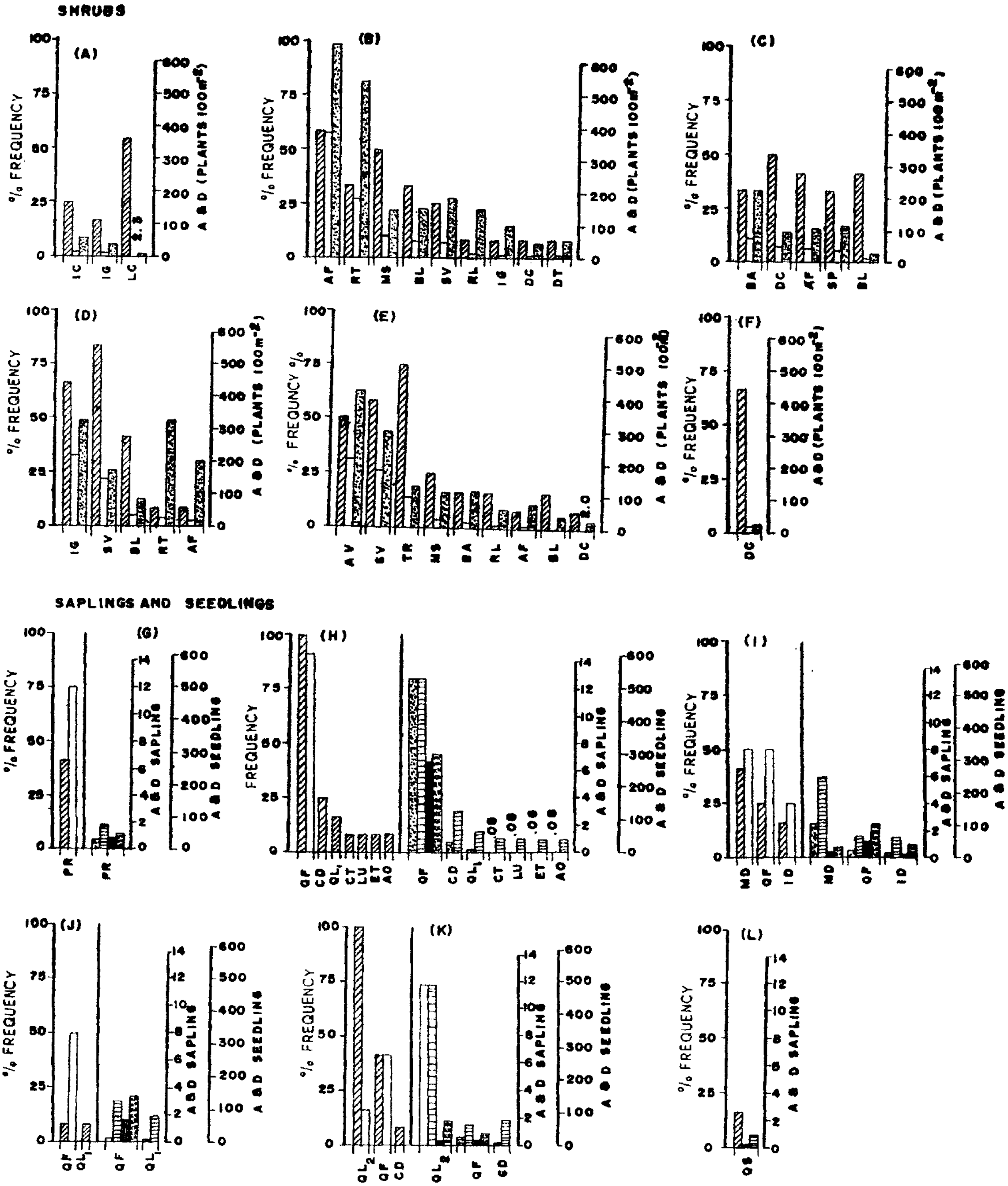
Forest types	*Pinus roxburghii*	*Quercus floribunda* (site 2)	*Quercus floribunda* (site 3)	*Quercus leucotrichophora*	*Quercus lanuginosa*	*Quercus semecarpifolia*
Pinus roxburghii	100	1.6	5.36	2.72	0	0
Quercus floribunda (site 2)		100	12.29	22.14	14.94	1.02
Q. floribunda (site 3)			100	8.96	8.84	14.44
Q. leucotrichophora				100	31.82	0
Q. lanuginosa					100	0.71
Q. semecarpifolia						100

Table 5 *Number of species, diversity index (H) and concentration of dominance (cd) in different forests*

Forest types	No. of species	Diversity index (H)		Concentration of dominance (cd)	
		On density basis	On basal cover basis	On density basis	On basal cover basis
Pinus roxburghii	1	0	0	1.0	1.0
Quercus floribunda (site 2)	6	0.7053	1.2197	0.7773	0.5874
Q. floribunda (site 3)	6	1.8294	2.0234	0.3138	0.3190
Q. leucotrichophora	3	1.9280	1,2811	0.4385	0.4462
Q. lanuginosa	4	0.5002	0.4587	0.8489	0.8659
Q. semecarpifolia	3	0.3930	0.4827	0.8490	0.8310

Figure 1 Frequency, abundance and density of shrubs, saplings and seedlings. Obliquely hatched bars=frequency of shrubs (A to F) and saplings (G to L); open bars=density of shrubs (A to F) and frequency of seedlings (G to K); dotted bars=abundance of shrubs (A to F) and density of saplings (G to L); horizontally hatched bars=abundance of saplings (G to L); vertically hatched bars=density of seedlings (G to K); and bars dotted with cross marks= abundance of seedlings (G to K). Wherever the values were too low to permit visible plotting, they are indicated in numerals. Frequency values are in percentage, and abundance and density in plants 100 m^{-2}.

A=Abundance, *D.*=density. *IC*=*Inula cappa DC.*, *IG*=*Indigofera gerardiana* Wall., *LC*=*Lantana camara* L., *AF*=*Arundinaria fulcata* Nees, *RT*=*Randia tetrasperma* Roxb., *MS*=*Myrsine semiserrata* Wall., *BL*=*Berberis lycium* Royle, *SV*=*Smilax vaginata* Decne, *RL*=*Rubus lasiocarpus* Smith, *DC*=*Daphne cannabina* Wall., *DT*=*Desmodium titilaefolium Don.*, *BA*=*Boenninghausenia albiflora* Reichenb., *SP*=*Sarcoccoca pruniformis* Lindl., *AV*=*Artimisia vulgaris* Linn., *TR*=*Teucrium royleanum* Wall., *PR*=*Pinus roxburghii*, *QF*=*Quercus floribunda*, *CD*=*Cedrus deodara*, QL_1=*Quercus leucotrichophora*, *CT*=*Cupressus torulosa*, *LU*=*Litsea umbrosa*, *ET*=*Euomynus tingens*, *AO*=*Acer oblongum* Wall., *MD*=*Machilus duthiei* King, *ID*=*Ilex dipyrena*, QL_2=*Quercus lanuginosa*, *QS*=*Quercus semecarpifolia*


SHRUBS
(A)
(B)
(C)
(D)
(E)
(F)
% FREQUENCY
A B D (PLANTS 100m^{-2})
IC IG LC
AF RT MS BL SV RL IG DC DT
BA DC AF SP BL
IG SV BL RT AF
AV SV TR MS BA RL AF BL DC
DC
SAPLINGS AND SEEDLINGS
(G)
(H)
(I)
(J)
(K)
(L)
A B D SAPLING
A B D SEEDLING
PR
QF CD QL CT LU ET AO
MD QF ID
QF QL
QL QF CD
QS

distribution in natural vegetation has been reported by several workers, including Greig-Smith (1957), Kershaw (1973) and Singh and Yadava (1974). According to Odum (1971), clumped (contagious) distribution is the commonest pattern in nature, random distribution is found only in very uniform environments, and the regular distribution occurs where severe competition between the individuals exists. Contagious distribution depends on the (i) local habitat differences, (ii) daily and seasonal weather changes, and (iii) reproductive processes.

Tree Species Diversity

Although the number of species was maximum in *Q. floribunda* forest, the diversity on density basis was greater in *Q. leucotrichophora* forest where only three species were present (table 5). On the basis of basal cover, however, the diversity was maximum in *Q. floribunda* forest on site 3 (table 5). It may be recalled that the diversity index as calculated here is not only dependent on number of species but is rather strongly influenced by the equitability of distribution of the quantity used in calculations, among the species present. *P. roxburghii* forest indicated zero diversity as the forest was monospecific.

Monk (1967) and Risser and Rice (1971) obtained 2-3 as the highest values for diversity index for temperate forests. In an eastern deciduous forest of North America, Braun (1950) reported tree species diversity between 1.69 and 3.40. On the other hand, tropical forests indicate higher diversity as calculated by Knight (1975) for young (H=5.06) and old (H=5.40) stands. Thus the diversity index for different forests in the present study fall in the range of values reported for temperate forests and are markedly lower than those reported for tropical forests.

The concentration of dominance was highest in *P. roxburghii* forest and lowest in *Q. floribunda* forest on site 3. The higher value for *P. roxburghii* forest is in conformity with its being a monospecific forest, while the lower value for *Q. floribunda* forest indicates that in this forest, the dominance is shared by many species.

Whittaker (1965) and Risser and Rice (1971) have reported values for concentration of dominance for certain temperate vegetation; these range between 0.10 to 0.99. For a tropical forest Knight (1975) reported an average value of 0.06. Thus, the values of concentration of dominance also fall in the range of values reported for temperate forests.

The lower diversity and consequently greater concentration of dominance in temperate vegetation could be due to lower rate of evolution and diversification of communities (Fischer 1960, Simpson 1964) and severity in the environment (Connel & Orias 1964).

Dominance-diversity curves for the tree layer (on the basis of IVI) have been drawn for the present forests to interpret the community organisation in terms of resource share and niche space (figure 2a). The curves for all the forests fit the geometric series which conforms to the niche pre-emption hypothesis (Whittaker 1975). The geometric form is often exhibited by vascular plant communities having low diversity (Whittaker 1972). *P. roxburghii* forest indicated single species dominance which was also pronounced in *Q. semecarpifolia* forest. Among the oak forests, *Q. floribunda* forest indicated relatively greater equitable share of resources among the various species. The dominance-diversity curves for the shrubs (figure 2b) indicated a behaviour almost similar to that of the trees.

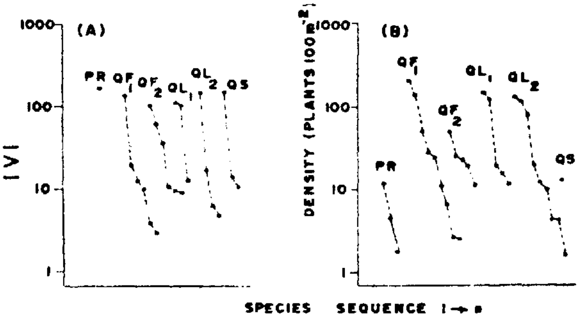


Figure 2 Dominance-diversity curves. (A) for tree layer, (B) for shrub layer.

PR=*Pinus roxburghii* forest, *QF*$_1$=*Quercus floribunda* forest on site 2, *QF*$_2$=*Quercus floribunda* forest on site 3, *QL*$_1$=*Quercus leucotrichophora* forest, *QL*$_2$=*Quercus lanuginosa* forest, and *QS*=*Quercus semecarpifolia* forest

Profile Structure

The profile diagrams for the present forests are included in figure 3. With the exception of *Q. semecarpifolia* forest, a total of four tree strata was recognisable although there was much interstratal overlapping. In *Q. semecarpifolia* forest, there were only two tree strata. In addition to the tree strata, there was a shrub stratum sheltering, in turn, a layer of herbs. The herb layer, however, is not shown in figure 3.

In A and B Strata, the maximum average tree height occurred in *Q. floribunda* forest (site 2) and minimum in *Q. lanuginosa* forest (table 6). On the other hand, in C and D strata *P. roxburghii* forest exhibited highest average tree height and *Q. floribunda* forest the lowest. The average height of the shrub stratum was maximum in *Q. leucotrichophora* and *Q. semecarpifolia* forests, and minimum *in P. roxburghii* forest (table 6).

The crowns of all tree strata in all forests were deeper than wide. The proportion of the tree devoted to the canopy in A stratum was highest for *Q. leucotrichophora* forest (80.1%), in B stratum for *Q. floribunda* forest on site 3 (84.3%) and in C and D strata for the same forest on site 2 (82.3 and 97.5%, respectively). In all tree strata, the percent of tree height covered by canopy was minimum in *P. roxburghii* forest. In general, the tree canopy in *P. roxburghii*, *Q. floribunda* (site 3) and *Q. lanuginosa* forests were relatively broken and irregular. However, in the latter two forests the shrub layer provided an excellent ground cover. The shrub layer canopy under *Q. leucotrichophora*, *Q. floribunda* and *Q. lanuginosa* forests was fairly dense. In *P. roxburghii* and *Q. semecarpifolia* forests the shrub canopies were irregular and discontinuous.

The total canopy index of the tree layer was highest for *Q. floribunda* forest on site 2 and lowest in the same forest on site 3. *Q. semecarpifolia* forest exhibited lowest shrub canopy index and *Q. lanuginosa* forest the highest.

According to Kittredge (1948), Trimble and Weitzman (1954) and Lull (1964), a forest having a multilayered canopy with greater canopy index and depth, and well developed forest floor will be more protective for soil and water in comparison to a forest which has fewer layers and lower canopy index. The site will be less protective if all the trees are confined only to the tallest stratum with their canopies concentrated at the top. However, if the top-layer trees are supported by deep and dense canopies in lower strata, the site will be more protective. By keeping this in mind, the relative protective value of different forest types could be graded in the order:

Q. floribunda (site 2) > *Q. leucotrichophora* > *Q. floribunda* (site 3) >

Table 6 *Average tree height, canopy depth, canopy index and quotient of slenderness for different forests*

Forest type	Locality	Average tree height (m)					Average canopy depth (m)				Canopy index (%)						Quotient of slenderness (SG) (Average for tree strata)
		A*	B	C	D	Shrubs	A	B	C	D	A	B	C	D	Total (A,B,C,D)	Shrubs	
Pinus roxburghii	Champhi	19.0	15.8	12.5	8.4	1.6	10.9	9.1	6.8	4.8	15.9	11.7	38.4	18.4	84.4	267.6	58.80
Quercus floribunda (site 2)	Govt. House	28.6	18.2	7.9	4.0	1.9	19.0	14.2	6.5	3.9	28.4	26.6	107.0	141.2	303.2	1021.5	26.00
Quercus floribunda (site 3)	Ayar-Patta	18.4	11.5	7.0	4.6	1.7	14.6	9.7	4.9	3.7	7.2	8.8	15.0	32.7	63.7	590.8	40.83
Quercus leucotrichophora	Snow-View	16.6	13.0	9.4	5.4	2.0	13.3	9.5	6.8	4.3	6.2	21.7	39.4	60.8	128.1	1198.4	47.43
Quercus lanuginosa	Kilbury	11.0	10.0	8.3	5.6	1.8	8.2	8.2	5.9	4.7	10.2	7.8	9.4	45.9	73.3	1537.6	29.18
Quercus semecarpifolia	Naina-Peak	17.7	13.0	0	0	2.0	12.3	9.6	0	0	7.3	80.5	0	0	87.8	45.3	9.50

* A, B, C, D refer to different strata.

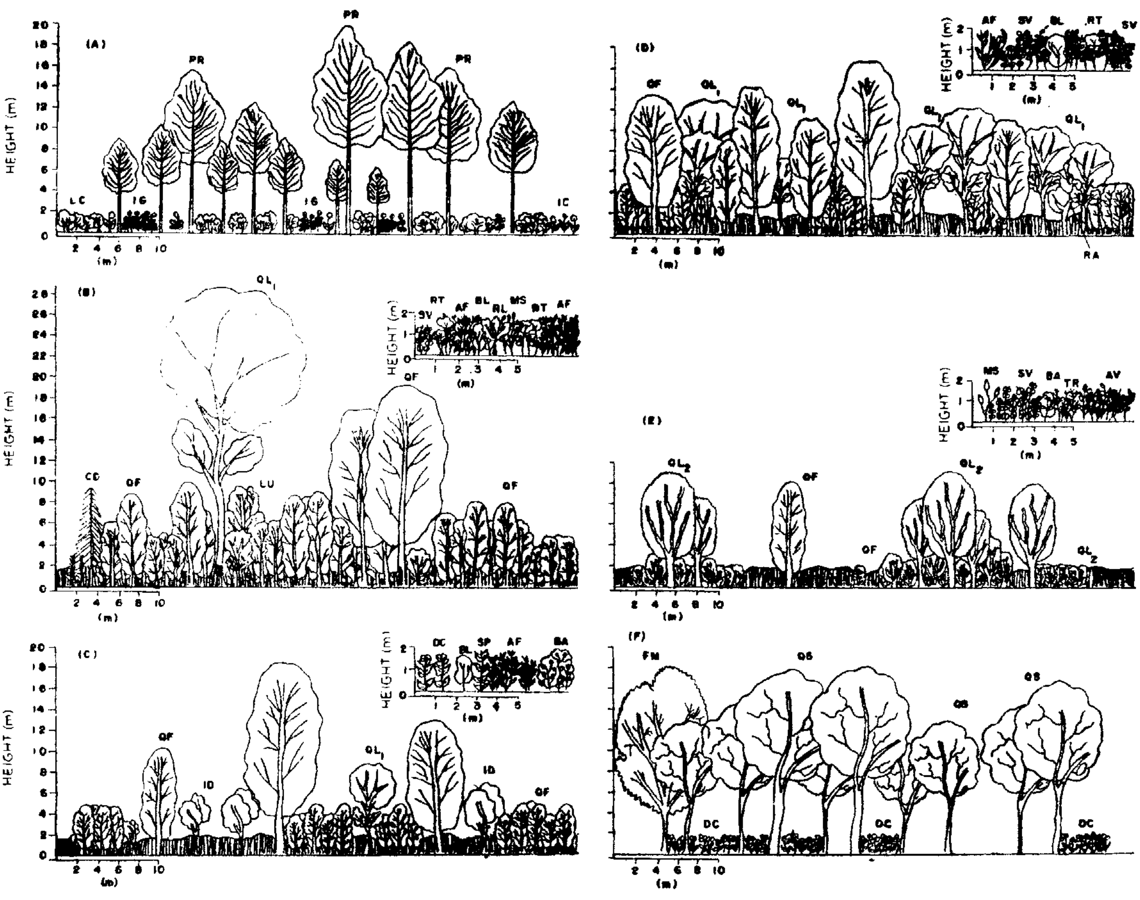


Figure 3 Profile diagrams *(A) Pinus roxburghii* forest, *(B) Quercus floribunda* forest on site 2, *(C) Quercus floribunda* forest on site 3, *(D) Quercus leucotrichophora* forest, *(E) Quercus lanuginosa* forest and *(F) Quercus semecarpifolia* forest. The scale on the y-axis is for the height and the scale on x-axis represents width of canopy. Each diagram represents an area of 200 m^2. The inset diagrams in Fig. 3 B to 3 E represent mainly the shrub magnified from the respective main diagrams for an area equivalent to 15.7 m^2

For explanation of the abbreviated names of the species see figure 1. The additional species are: *RA=Rhododendron arboreum, FM=Fraxinus micrantha*

Q. lanuginosa > *Q. semecarpifolia* > *P. roxburghii*. Additionally, with regard to water conservation, Gupta (1980), on the basis of potential evapotranspiration data for juvenile stages of forest species (Dabral 1970) which indicated that the amount of water consumed per gram of dry matter production is maximum for pines out of all the species studied, has argued that the large scale pine plantations may have adversely affected the streamflow in the Himalayas. Evidently, broad-leaf canopies will be much more appropriate for maintaining the watersheds in a healthy condition.

The quotient of slenderness is related with wind stability of trees; the wind stability is higher if the value of SG is smaller (Brunig & Heuveldop 1976). On the basis of wind resistance of trees (table 6), the present forests could be graded as follows:

Q. semecarpifolia > *Q. floribunda* (site 2) > *Q. lanuginosa* > *Q. floribunda* (site 3) > *Q. leucotrichophora* > *P. roxburghii*. During a massive wind storm in April, 1981 thousands of *P. roxburghii* trees were knocked down in this area within one night confirming their low wind stability. Most of these trees broke at the point where they had been tapped for resin; Saxena (1977) has earlier reported on the severity of cuts made for resin tapping. In view of the above it would be appropriate to investigate further the proper stocking density

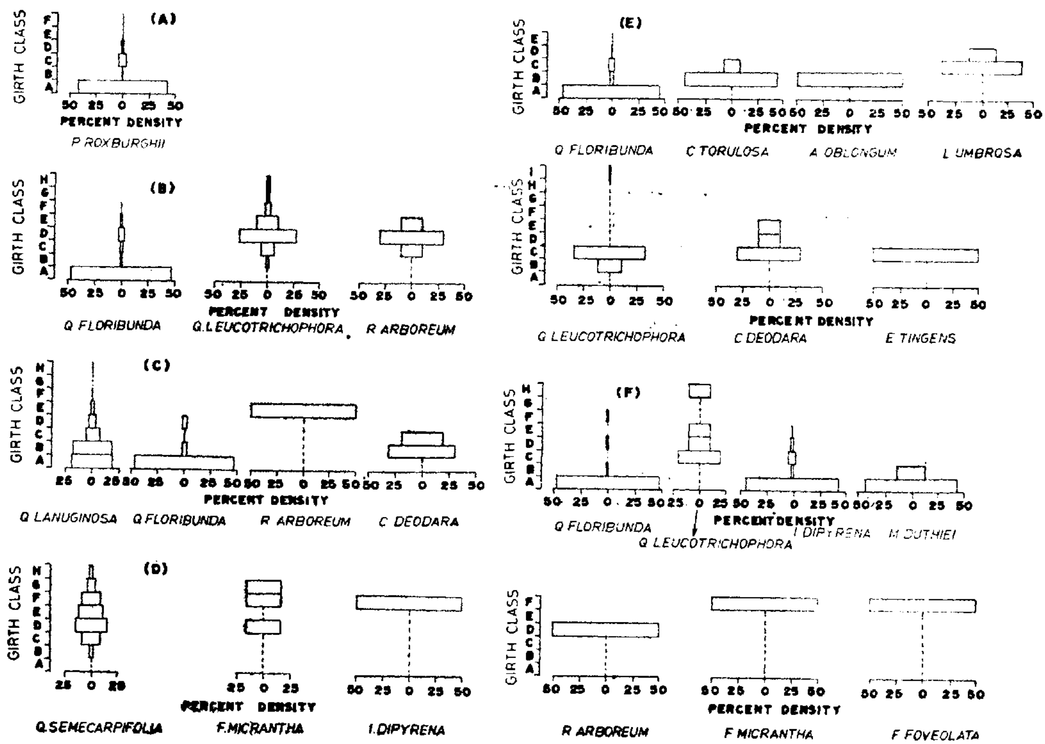


Figure 4 Population structures of species in *(A) Pinus roxburghii* forest, *(B) Quercus leucotrichophora* forest, *(C)=Quercus lanuginosa* forest, *(D) Quercus semecarpifolia* forest, *(E) Quercus floribunda* forest on site 2, and *(F) Quercus floribunda* forest on site 3

for *P. roxburghii* to maximise wind resistance and more appropriate resin tapping technology.

Population Structure

The population structures of various tree species occurring in different forest types are given in figure 4. From these, the following common patterns could be recognized. One pattern of population structure is represented by *Q. floribunda* in *Q. floribunda* and *Q. leucotrichophora* forests, with a greater proportion of individuals in seedling stage compared to larger girth classes indicating frequent reproduction (Knight 1975). Another pattern is exemplified by *Q. leucotrichophora* and *Q. semecarpifolia* in their respective forest types having most of the individuals in intermediate girth classes and a decreasing population both towards higher and lower girth classes with absence of seedlings. Benton and Werner (1976) stated that if such a trend continues, the population is on the way to extinction. The population structure of certain species (e.g. *M. duthiei* in *Q. floribunda* forest on site 3) is characterised by the presence of seedlings and saplings only. This structure indicates that species could be recent invader and may become a canopy species later on. Population structures of *Litsea umbrosa* and *Cupressus torulosa* in *Q. floribunda* forest on site 2 illustrate that these species reproduced in the past but have stopped doing so in recent years. *P. roxburghii* forest is comprised of a monospecific stand in which *P. roxburghii* is represented both by seedlings and saplings.

Thus, *Q. floribunda* represents an expanding population, *Q. leucotrichophora* and *Q. semecarpifolia* had stabilized populations in the past but may disappear from these sites in near future, *L. umbrosa* and *C. torulosa* were recruited in the ecosystem in the past but have stopped regenerating, and *M. duthiei* on site 2 may increase in future.

The data on population structure can be interpreted to show the future trend in species composition. Thus, the composition of *P. roxburghii* forest will remain the same, on the other hand, in *Q. leucotrichophora* forest, *Q. leucotrichophora* and *Rhododendron arboreum* may disappear from the forest, while *Q. floribunda* may emerge as a dominant species. In *Q. floribunda* forest, *I. dipyrena* and *M. duthiei* on site 3 may become codominants with *Q. floribunda* while on site 2 *Q. floribunda* will expand further. Similarly, *Q. floribunda* in *Q. lanuginosa* forest may become codominant with *Q. lanuginosa*. In *Q. semecarpifolia* forest, the complete absence of seedlings of any species poses the danger of complete replacement of this forest by a scrub or a grassland vegetation. Although this study is based on a limited area, the absence of adequate regeneration of *Q. semecarpifolia* and *Q. leucotrichophora*, particularly that of the latter, as discussed above, poses interesting questions, i.e., why *Q. leucotrichophora* which developed climax forests in the past is reducing its regeneration giving way to *Q. floribunda?* Have there been subtle changes in the ennviroment recently causing this shift? Studies of N. Upreti and S. P. Singh in this laboratory (personal communication) indicate that the mature seed of *Q. floribunda* largely fall to the ground during August-October and the ensuing seedlings get sufficient residual moisture as well as protection (due to good growth of understorey plants), while those of *Q. leucotrichophora* fall mostly during December-March when soil moisture is very little and temperature is too low for germination. Additionally, the seeds of *Q. leucotrichophora* get more heavily infested by *Calandra glandium* Marshall resulting into a marked reduction in viability. What were the factors which compensated in the past for the apparent discordance in the timings of seedfall-germination and availability of optimal soil moisture and temperature conditions in the case of *Q. leucotrichophora?* Or, is it that the vegetation follows a long-term pattern of cyclical changes wherein the dominants are replaced and re-replaced by one another? Answers to these questions would hopefully emerge from future long-term researches covering a much larger area.

In conclusion, *Q. leucotrichophora* forest had maximum basal cover. *Q. floribunda* forest exhibited the largest shrub population, while *P. roxburghii* and *Q. semecarpifolia* had the least developed shrub layer. The values of diversity index and concentration of dominance fall in the range of values reported for temperate forests. Oak forests appear much more appropriate for maintaining the watersheds in a healthy condition. The trees in the *P. roxburghii* forest appear specially susceptible to wind effect. Population structures of different species indicate that *Q. leucotrichophora* and *Q. semecarpifolia* had stabilized populations in the past but may disappear from these sites in near future.

Acknowledgements

The funding support from the Department of Science and Technology (HCS/DST/187/76) is gratefully acknowledged.

References

Benton A H and Werner Jr, W E 1976 *Field Biology and Ecology* (New York.) McGraw-Hill, Inc., 564 pp

Braun E L 1950 *The Ecology of the Forests of Eastern North America, Their Development, Composition, and Distribution.* Deciduous Forests of Eastern North America, McGraw-Hill (New York : Blakiston)

Brunig E F and Heuveldop J 1976 *Structure and Function in Natural* and *Man Made Forests in the Humid Tropics.* IUFRO World Congress. Proceeding– Referate-Exposes. Norway pp 500–511

Champion HG and Seth SK 1968 *A Revised survey of the Forests Types of India.* Government of India Publications, New Delhi. 404 pp

Connel J H and Orias E 1964 The ecological regulation of species diversity; *Amer. Natur.* **48** 399–414

Curtis J T 1959 *The Vegetation of Wisconsin. An ordination of plant communities.* Univ. (Wisconsin Press, Madison, Wisconsin) 657 pp

——and Cottam, G 1956 *Plant Ecology Work Book.* Laboratory field reference manual Burgess Publishing (Minnisota: Co) 193 pp

——and McIntosh R P 1950 The interrelations of certain analytic and synthetic phytosociological characters; *Ecology* **31** 434–455

Dabral B G 1970 Preliminary observations on potential requirements in *Pinus roxburghii, Eucalyptus citriodora, Populus cassale* 488 and *Dalbergia latifolia; Indian For.* **96** 775–780

Fischer A G 1960 Latitudinal variation in organic diversity; *Evolution* **14** 64–81.

Forbes R D 1961 *Forestry hand book.* (New York: The Ronald Press Co.)

Greig-Smith P 1957 *Quantitative plant ecology.* (London) Butterworths

Gupta R K 1980 Consequences of deforestation and overgrazing on the hydrological regime of some experimental basins in India; *Proc. Helsinki Symp.* June 1980: IAHS-AISH Publ. No. 130 81–87 pp

Jaccard P 1912 The distribution of the flora in the alpine zone; *New Phytol.* **11** 37–50

Kershaw K A 1973 *Quantitative and Dynamic Plant Ecology.* (London: Edward Arnold Ltd.) 308 pp

Kittredge J 1948 *Forest Influences.* (New York : McGraw-Hill Book Co., Inc.)

Knight D H 1963 A distance method for constructing forest profile diagrams and obtaining structural data; *Trop. Ecol.* **4** 89–94

——1975 A phytosociological analysis of species-rich tropical forest on Barro Colorado Island, Panama; *Ecol. Monogr.* **45** 259–289

Lull H W 1964 Ecological and silvicultural aspects, section 6; in *Hand book of Applied Hydrology*. ed. V T Chaw pp. 6–1 to 6–30. (New York: McGraw-Hill Book Company, Inc.)

Misra R 1968 *Ecology Workbook.* (New Delhi) Oxford and IBH Publishing Co., 244 pp

Monk C D 1967 Tree species diversity in eastern deciduous forest with particular reference to north central florida; *Am. Net.* **101** 173–187

Odum E P 1971 *Fundamentals of Ecology.* W. B. Saunders Co. Philadelphia

Pandey U and Singh J S 1981a A quantitative study of the forest floor, litter fall and nutrient return in an oak-conifer forest in Himalaya. I. Composition and dynamics of forest floor; *Acta Oecologica* **2** 49–61

——and —— 1981b A quantitative study of the forest floor, litter fall and nutrient return in an oak-conifer forest in Himalaya. II. Pattern of litter fall and nutrient return; *Acta Oecologica.* **2** 83–99

Phillips E A 1959 *Methods of Vegetation Study* A Holt-dryden book. Henry Holt and Co. Inc. 107 pp

Risser P G and Rice E L 1971 Diversity in tree species in Oklahoma upland forests; *Ecology* **52** 876–880

Saxena A K 1977 On resin tapping of a *Pinus roxburghii* forest in Naini Tal *Uttarakhand Bharati* **2** 59–69

——1979 *Ecology* of *Vegetation Complex* of *North-Western Catchment* of *River Gola.* Ph.D. Thesis, Kumaun University, Naini Tal 484 pp

—— Pandey, U and Singh J S 1978 On the ecology of oak forests in Naini Tal hills, Kumaun Himalaya; in *Glimpses of Ecology*; eds. J S Singh and B Gopal. Prof. R. Misra commemoration volume. (Jaipur: International Scientific publications), pp. 167–180

—— and Singh J S 1980 Analysis of forest-grazingland vegetation in parts of Kumaun Himalaya; *Indian J. Range Mgmt.* **1** 13–32

—— and —— 1982 A phytosociological analysis of forest communities of a part of Kumaun Himalaya. *Vegetation* (In press)

Shannon C E and Wiener W 1963 *The Mathematical Theory of Communiation.* (Urbana Univ. Illinois Press)

Simpson E H 1949 Measurement of diversity; *Nature* **163** 688

Simpson G G 1964 Species diversity of North American recent mammals; *Syst. Zool.* **13** 57–73

Singh J S and Yadava P S 1974 Seasonal variation in composition, plant biomass, and net primary productivity of a tropical grassland at Kurukshetra India; *Ecol. Monogr.* **44** 351–375

Trimble G R and Weitzman S 1954 Effect of hardwood forest canopy on rainfall intensities; *Trans. Am. Geophys. Union* **35** 226–234

Whittaker R H 1972 Evolution and measurement of species diversity; *Taxon* **21** 213–251

—— 1975 *Communities and Ecosystems.* 2nd ed. (New York: MacMillan Publishing Co., Inc.) 385 pp

—— and Niering W A 1965 Vegetation of the Santa Catalina Mountains. II. A gradient analysis of the south slope; *Ecology* **45** 429–452