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Quantitative profile structure of certain forests in the Kumaun Himalaya

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Abstract. The structure of forests occurring within the north-western catchment of the river Gola in Kumaun Himalaya is quantitatively described. All the forestt indicated a total of four strata ; two upper strata represented by trees, the third stratum represented mainly by shrubs, and the fourth of herbs. The tree heighs of the A_2 (top most) stratum decreased with an increase in altitude. On the other hand, the proportion of trees devoted to the canopy in the A_1 and A_2 strata increased with an increase in altitude. In all forests, the crowns of the A_1 and A_2 strata were more deep than wide. In general, the shrub layer in three oak forests was comparatively dense and the crowns of the shrubs overlapped with each other. The canopy index, a relative measure of canopy coverage, of tree and shrub layers was maximum for *Quercus floribunda* forest and minimum for *Pinus roxburghii* forest. Further, the cooler aspects develcped a greater canopy index for these layers as compared to the warmer aspects. Oak forests exhibited a poor development of their herb layers. The trees in the *Quercus lanuginosa* forest weere more stable, while in *Pinus roxburghii* forest they were specially susceptible to wind effect. In general the warmer aspects had more stable trees, while the cooler aspects showed a lower tree stability. The different forest types, presently studied, could be graded, as follows, in a decreasing order of potential for soil protection : *Quercus floribunda* > *Quercus leucotrichophora* > *Quercus lanuginosa* > mixed > *Pinus roxburghii*.

Keywords. Himalayan forests ; profile structure ; canopy index.

1. Introduction

The Himalaya offers an array of forest types below the timber line, and is the cradle of major rivers of India, harbouring (thus) a net work of catchment areas. Growing human interference with the vegetation cover of the catchment of rivers has generally led to substantial reduction of forest cover which in turn has led to serious ecological disasters, such as, soil erosion, loss of soil fertility and catastrophic floods. As the catchment efficiency depends on the type, quantity and stratification of vegetation, a quantitative evaluation of its vegetation is a pre-requisite. However, such data are few (Ralhan *et al* 1982; Saxena and Singh

1982; Saxena *et al* 1982; Tewari and Singh 1981). Earlier studies, mainly qualitative, have been reviewed by Puri (1960) and Champion and Seth (1968). The present study describes the structure of the forests occurring within the north-western catchment of the river Gola in Kumaun Himalaya.

Due to the presence of a large variety of growth forms, forests are generally highly stratified (Smith 1974). Tropical forests usually have a total of five strata above the soil surface, while the temperate forests have only two or three strata (Richards 1952). Upto some extent, light and moisture determine the various strata which in turn modify the environment from the canopy to the forest floor. The amount of light received in various strata of a community varies, depending upon the density of different strata, type of vegetation, opening of forest crown, etc. (Knight 1965). The canopy closure also plays a major role n the regeneration of forests by conditioning the light intensity reaching the forest floor. According to Richards (1952) and Holdridge (1968), an excellent visual representation of the structure of a forest community can be communicated by constructing a profile diagram. Several workers, including Beard (1941, 1955), Burges and Johnston (1953), Dansereau (1957), Keay (1957), Webb (1959), Fosberg (1961) and Legris (1961) have recognized the usefulness of profile diagrams and their structural-functional information. Ashton and Brunig (1975) and Whitmore (1975) recently reviewed the structural variation in the humid tropical forests and in the forests of south-east Asia, respectively.

2. Study area and methods

2.1. *Location*

A total of 14 sites, located in the north-western catchment of river Gola in Kumaun Himalaya (29° 19′ to 29° 27′ N lat. and 79° 32′ to 79° 42′ E long.) were selected for the present study. The sites are at different altitude, aspects ands lope angles (table 1).

Table 1. Aspect, altitude and slope angle of the selected locations.

Forest type	Aspect	Altitude (m)	Slope angle (°)	Locality
Pinus roxburghii	NE, E, SW	1280–1320	30 65	Champhi, Sattal
Mixed	E, NW, S	1320–1365	25-50	Sattal
Q. leucotrichophora	NE, E, SW	1950-2025	40–50	Maheshkhan
Q. lanuginosa	S	2010	55–65	Maheshkhan
Q. floribunda	N, NE, E, S	2100–2227	35–55	Maheshkhan

Under the forest settlement of 1911 to 1915, some of the new reserves were grouped into 'settlement blocks'. The right and concessions to the villagers were given whenever possible for building-timber, wood for agricultural implements, grazing for a limited number of cattle, lopping, collection of fuel, grasses, etc. In 1921, the new reserve forests were divided into class I and class II forests and the rules regarding rights were modified. Class I forests retained their status as reserve forests but their management was under the civil authorities, while the class II forests were kept under the direct management of the Forest Department. According to the rules, in class I forests all *bonafied* residents of this region were allowed to graze cattle without any limit, fell and lop trees, cut grasses, etc., but the felling or lopping of timber trees were restricted. In the class II forests also, all *bonafied* residents of this region could graze cattle, lop *Quercus* and miscellaneous species, cut grasse and collect fallen fuel woods. The exceptions were the regeneration areas, fuel and fodder reserves and plantation areas in which some or all of these concessions were restricted. Timber trees were also reserved and not allowed to be cut or lopped. In 1964, the management of class I forests, except in those in which forest Panchayats had been formed, was transferred back to the Forest Department. The present sites are located in the forests of 'new reserve' category notified after 1915 and represent the original class II forests. Thus the rules regarding utilization were liberal and were not related to the carrying capacity of the area. The broad leaved trees, especially *Quercus* spp., were frequently lopped. To stop this, in 1974, the Government banned the felling by public, of all the trees of *Quercus leucotrichophora* and *Rhododendron arboreum* except for the dead, diseased and overmature trees.

2.2. *Climate, soil and geology*

The sites are characterized by a climate which shows three distinct seasons, *viz.*, rainy (June to September), winter (October to February) and summer (March to May). The average annual rainfall at Naini Tal is 2820 mm, 88% of which occurs between June to September. The mean maximum temperature ranges from 10·0 to 30·0° C and the mean minimum from 0·2 to 19·8° C.

The soil has been derived from parent materials comprising mainly of quartzite, quartz porphyry and schists (Raina and Dungrakoti 1975). The soil is dominated by sand particles. Proportion of sand is lower in oak forests compared to the mixed and *Pinus roxburghii* forests. The clay percentage differs little in different soils but in contrast to the pattern shown by sand, silt percentage is higher in the oak forests compared to other forests. The soil under all forests is slightly acidic. Details of climate and soil are given in Saxena and Singh (1980).

2.3. *Methods*

Sampling was done on four topographic situations (*viz.*, hill base, lower and upper slopes and hill top) for each aspect (site). Each sample consisted of 12 randomly placed 10 × 10 m quadrats. The size and number of quadrats were determined, respectively by species area curve (Oosting 1958) and the running mean method (Kershaw 1973). Detailed phytosociology of the woody species in these forests is described elsewhere (Saxena and Singh 1982).

In each quadrat, diameter at breast height (dbh at 1·37 m from the ground) of all trees > 10 cm dbh was measured and recorded individually by species. Each quadrat was subdivided into four 5 × 5 m plots for analysing shrubs, saplings and seedlings. All individuals of 3·3 to 10·0 cm dbh were tallied either as sapling or shrub, as appropriate. The herb layer was studied through tiller analysis (Singh 1967, 1969) by using 50 × 50 cm harvest plots. The sampling was done when the herbaceous vegetation was at its peak, *i.e.*, during last week of September to the first week of October. It is not intended to compare the density values for herbs with those of the trees, however.

The other measurements included total tree height, height to first branch and canopy width for each species. A rough sketch of the trees was made in the field. Height of the tree and canopy depth were measured by a hypsometer (Forbes 1961).

Profile diagrams were prepared for each topographic situations on each aspect following Knight (1963). In order to include a maximum number of species in the diagrams, an area equivalent to 20 × 10 m was found suitable. The number of trees, saplings and shrubs to be included in the diagram was calculated on the basis of their density (Curtis and McIntosh 1950). Trees of each species were selected for inclusion from among all trees of that species actually measured in the stand by using a random table (Campbell 1974).

The canopy indexes for tree and shrub layers were calculated by dividing the sum of the lengths of the strip covered by canopies by the total length of the profile strip. The resulting value was then multiplied by 100. These calculated values give only a relative measure of canopy coverage.

The quotient of slenderness (SG) for the top canopy trees, in each stand, was calculated by the formula given by Brunig and Heuveldop (1976) :

$$\mathrm{SG} = h/d,$$

where, h = average height of the tree (m) ; d = average diameter of tree at breast height (m).

Spatial distribution, abundance and stratification of vegetation are summarized in vegetational formulae (Christian and Perry 1953). Letters and figures were assigned to the trees, shrubs and herbs, to their component layers, and to the density of each. Thus, A_1 was used for low trees and A_2 for tall trees. The letters, B and C were used for shrubs and herbs, respectively. Heights were recorded for each stratum as mean values. Thus, A_2^{20} represents the trees with an average height of 20 m. Density was similarly treated by prefixing x, y or z for dense, average, or sparse and xx or zz for very dense and very sparse, respectively. Thus, a stand with two tree layers, one shrub and one herb layer at varying densities is expressed as :

$$A_2^{20}\, z,\ A_1^{10}\, y,\ B^{1\cdot 2}\, xx,\ C^{0\cdot 5}.\, x$$

This would indicate that the vegetation has two tree layers, one with average height of 20 m, the other with average height of 10 m, one shrub layer with mean height of 1·2 m and one herb layer with an average of 0·5 m. Further, the tall trees are sparse, low trees have an average density, the shrub layer is very denset and the herb layer is dense. The ranges for x, y, z, xx and zz are given in table

Table 2. Ranges of plant density for density symbols used in vegetational formulae.

(Individuals 200 m^{-2})

Density Symbols	A_2 and A_1 strata (trees + saplings)	B stratum (Shrubs)	C stratum (herbs + seedlings)
xx	81–100	801–1000	279033–347800
x	61–80	601–800	210265–279032
y	41–60	401–600	141497–210264
z	21–40	201–400	72729–141496
zz	1–20	1–200	3960–72728

2. The range of the stratal height was set as : stratum A_2 = 15 to 30 m ; stratum A_1 = 2 to 15 m and stratum $B = 0 \cdot 5$ to 2 m.

The herbaceous stratum (C) is not shown in the diagrams although the information is included in the vegetational formulae based on the earlier description by Saxena and Singh (1980).

Results

The profile diagrams for various forests are given in figures 1–5 and the vegetational formulae in table 3.

3.1. *Pinus roxburghii forest*

On all aspects, the average height of the A_2 stratum was higher on the hill top compared to other topographic situations (table 3). The A_2 stratum, on all topographic situations and aspects was represented by trees of *P. roxburghii* as illustrated by the profile diagram of this forest in figure 1. At the SW hill base and NE lower slope, the A_1 stratum was represented only by *P. roxburghii*. On the other hand the A_1 stratum at the hill base of east aspect consisted of *Pyrus pashia* and *Cocculus laurifolius*, while the same at the upper slope of this aspect had *Quercus leucotrichophora* and *Engelhardtia spicata*.

The crowns of *P. roxburghii* in the A_2 and A_1 strata were more deep than wide, and were conical in shape. The canopy of the A_2 stratum was comparatively denser and almost continuous at the NE hill base, lower slope and hill top, at the SW hill base and at the E lower slope. On other topographic situations and aspects, the canopy in this stratum was markedly broken. The canopy of the A_1 stratum on all topographic situations and aspects, was remarkably discontinuous. The trees in the A_2 and A_1 strata were very sparse (table 3).

The total combined canopy index of the A_1 and A_2 strata was highest at the NE lower slope and lowest on the E upper slope and hill top (table 4).

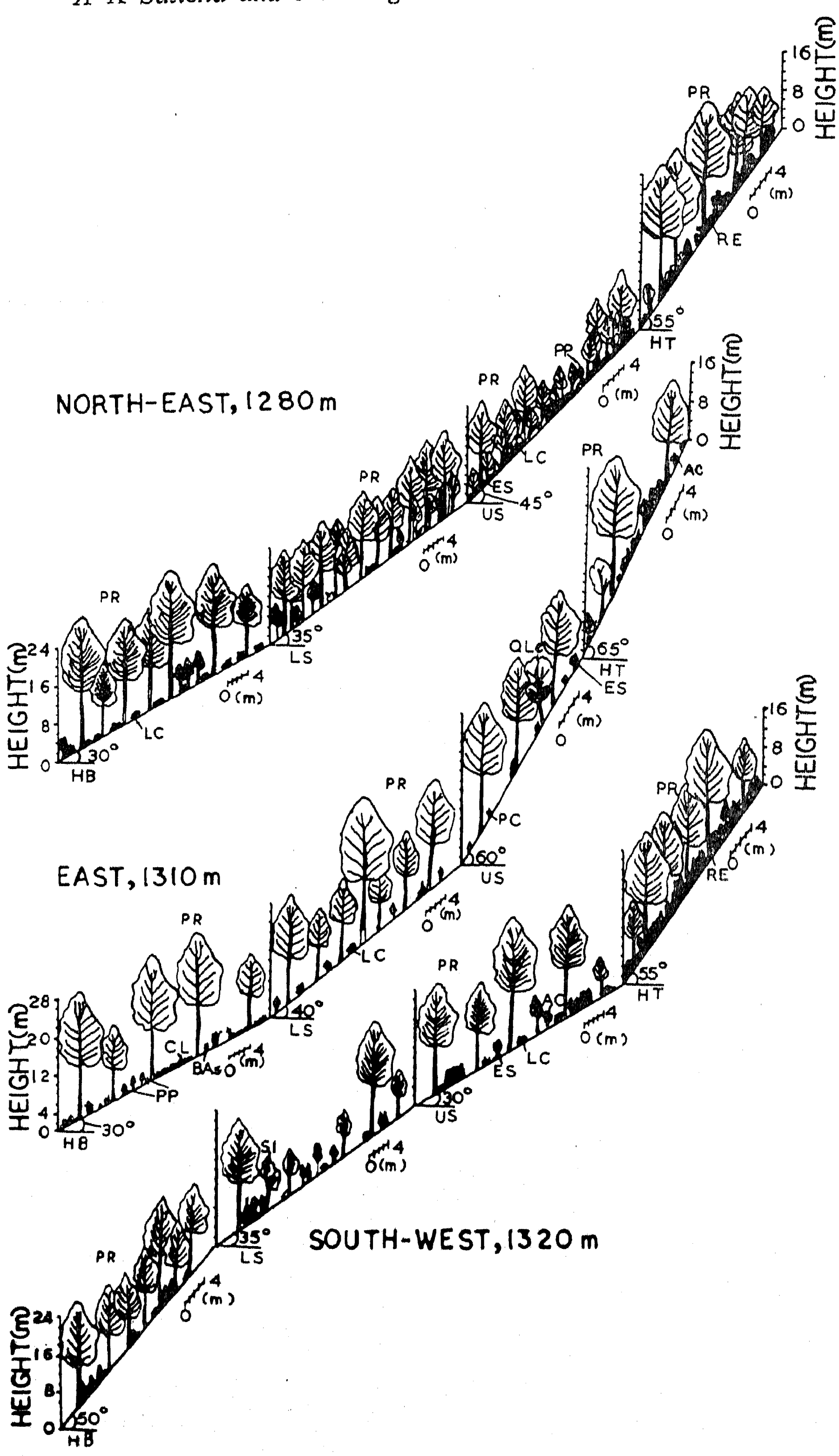

Figure 1. Profile diagram for *Pinus roxburghii* forest on north-east, east and south-west aspects. The scale on the *y*-axis is for the height and the scale on *x*-axis represents width of canopy and dbh. Each profile diagram is made up of four sections as follows: HB = hill base, LS = lower slope, US = upper slope, HT = hill top. Each section represents an area of 200 m². PR = *Pinus roxburghii* Sarg., ES = *Engelhardtia spicata* Leschen ex Bl. Var. *Colebrookiana* (Lindl. ex Wall.) Ktze, SI = *Sapium insigne* Benth., PP = *Pyrus pashia* Buch-Ham ex D.Don., QLe = *Quercus leucotrichophora* A. Camus, AC = *Adina cordifolia* (Roxb.) HK.f. ex Brandis, CL = *Cocculus laurifolius* DC., LC = *Lantana camara* Linn., RE = *Rubus ellipticus* Smith., PC = *Pyracantha crenulata* (D.Don) Roem., BAS = *Berberis asiatica* Roxb. ex DC.

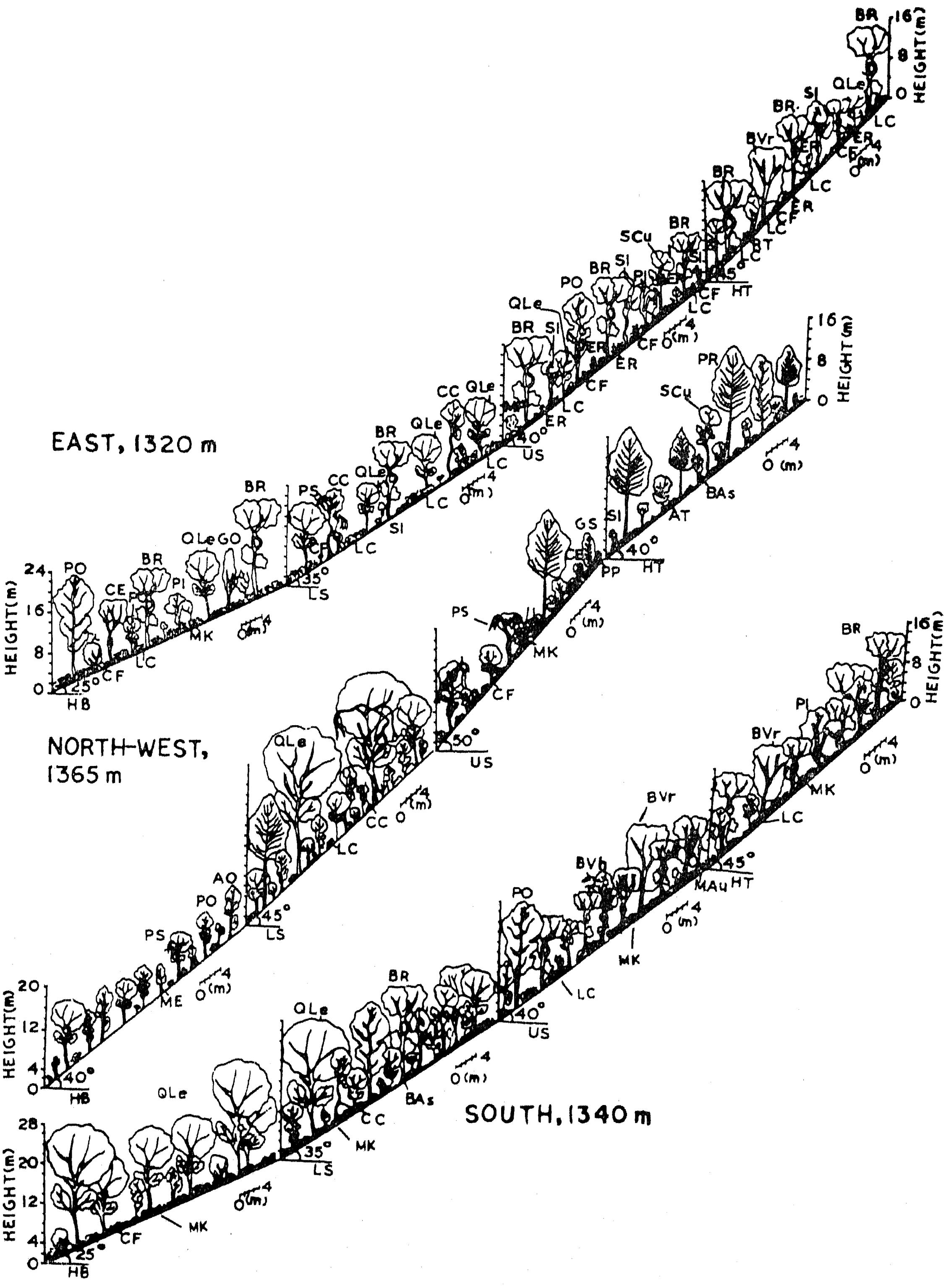

Figure 2. Profile diagram for mixed forest on east, north-west and south aspects. For rest of the explanation see figure 1. The additional species are : BR = *Bauhinia retusa* Buch-Ham. ex DC., PO = *Persea odoratissima* (Nees) Kosterm., PI = *Pistacia integerrima* Stewart, CE = *Celtis eriocarpa* Decaisne, GO = *Grewia oppositifolia*. Buch-Ham. ex Roxb., RT = *Rhamnus triqueter* Wall., CC = *Cedrela ciliata* Roem, PS = *Parthenocissus semicordata* Wall., ER = *Euphorbia royleana* Boiss, SCu = *Syzygium cumini* (L.) Skeels., MP = *Murraya paniculata* (L.) Jack., BVr = *Bauhinia variegata* Linn., BVh = *Bauhinia vahlii* Wight & Arn., AO = *Acer oblongum* Wall. ex DC., MAu = *Millettia auriculata* Baker ex Brand., MB = *Myrica esculenta* Var. *sapida* Buch-Ham., GS = *Grewia subinaequalis* DC., CF = *Cassia floribunda* car., MK = *Murraya koenigii* (L.) spreng., AT = *Aechmanthera tomentosa* Nees.

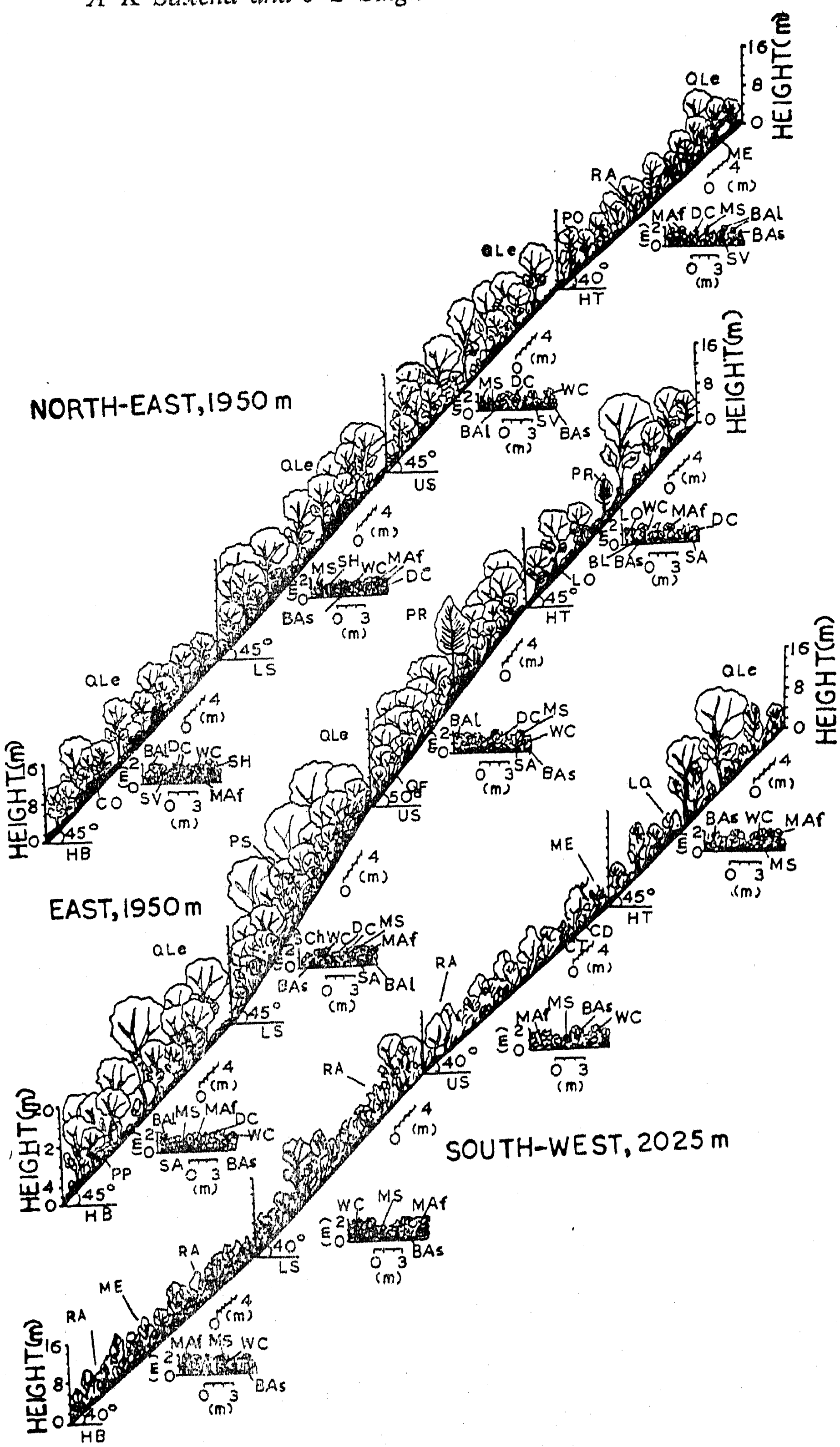

Figure 3. Profile diagram for *Quercus leucotrichophora* forest on north-east, east and south-west aspects. For rest of the explanation see figure 1. The inset diagram represents mainly the shrub layer magnified from the main diagram for an area equivalent to 15·7 m². The additional species are : RA = *Rhododendron arboreum* Sm., CO = *Cornus oblonga* Wall., LO = *Lyonia ovalifolia* (Wall.) Drude, QF = *Quercus floribunda* Rehder, SCH = *Symplocos chinensis* (Lour) Druce, LQ = *Lonicera quinquelocularis* Hardw., CT = *Cupressus torulosa* D.Don., CD = *Cedrus deodara* (Roxb. ex Lambert) D.Don., MAf = *Myrsine africana* Linn., MS = *Myrsine semiserrata* Wall., SH = *Sarcococca hookeriana* Baill., BAl = *Boenninghausenia albiflora* (Hook.) Reichenb., SV = *Smilax vaginata* Decaisne., SA = *Smilax aspera* Linn., WC = *Wikstroemia canescens* Meissn., DC = *Daphne cannabina* Sensu Hook. f., BL = *Berberis lycium* Royle.

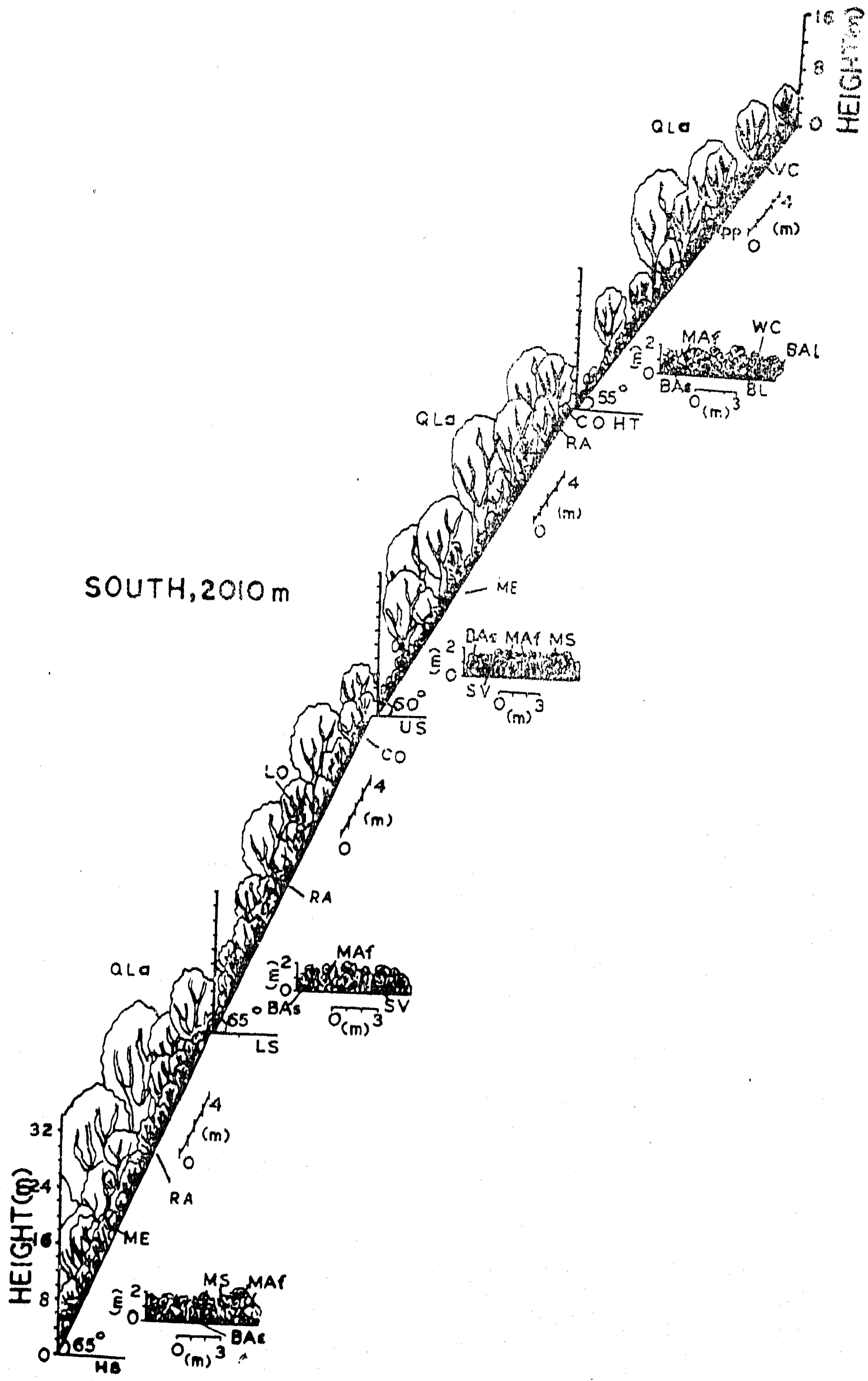

Figure 4. Profile diagram for *Quercus lanuginosa* forest on south aspect. For rest of the explanation see figures 1 and 3. The additional species are : QLa = *Quercus lanuginosa* D.Don., VC = *Viburnum cotinifolium* D.Don.

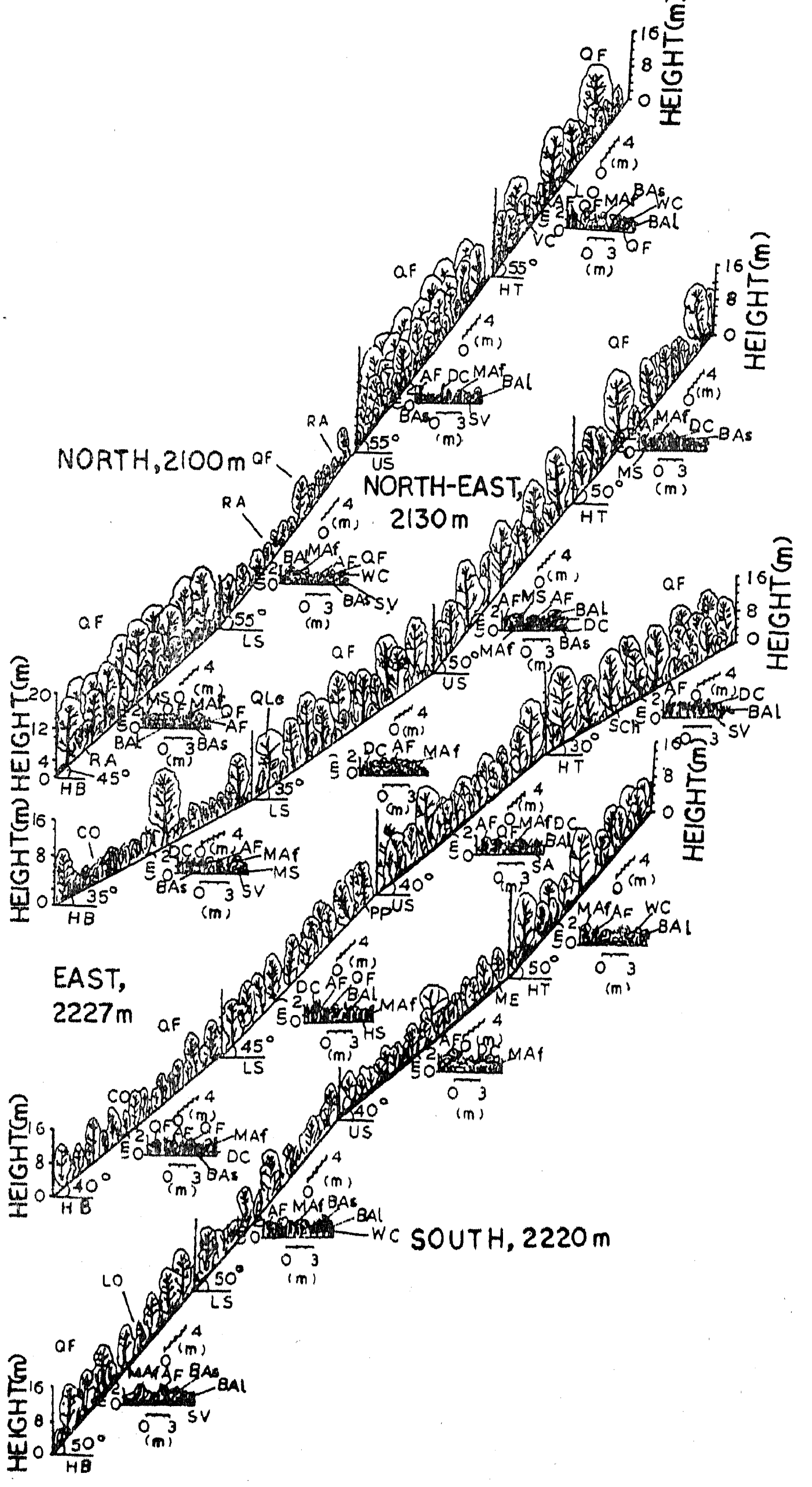

Figure 5. Profile diagram for *Quercus floribunda* forest on north, north-east, east and south aspects. For rest of the explanation see figures 1 and 3. The additional species is : AF = *Arundinaria falcata* Nees.

Table 3. Vegetational formulae for the stands examined. For explanation see text.

Forest type	Aspect	Position	Vegetation formula
1	2	3	4
Pinus roxburghii	North-east	Hill base	$A_2^{21\cdot9}zz$, $A_1^{5\cdot9}zz$, $B^{1\cdot2}zz$, Cy
		Lower slope	$A_2^{17\cdot4}zz$, $A_1^{7\cdot9}zz$, $B^{1\cdot2}zz$, Cy
		Upper slope	$A_2^{16\cdot5}zz$, $A_1^{7\cdot6}zz$, $B^{1\cdot0}zz$, Cy
		Hill top	$A_2^{25\cdot0}zz$, $A_1^{4\cdot5}zz$, $B^{1\cdot5}zz$, Czz
	East	Hill base	$A_2^{22\cdot4}zz$, $A_1^{2\cdot8}zz$, $B^{1\cdot1}zz$, Cx
		Lower slope	$A_2^{21\cdot2}zz$, $A_1^{5\cdot0}zz$, $B^{1\cdot5}zz$, Cy
		Upper slope	$A_2^{25\cdot9}zz$, $A_1^{8\cdot8}zz$, $B^{1\cdot5}zz$, Cy
		Hill top	$A_2^{26\cdot6}zz$, $A_1^{5\cdot5}zz$, $B^{1\cdot5}zz$, Cz
	South-west	Hill base	$A_2^{19\cdot6}zz$, $A_1^{4\cdot9}zz$, $B^{1\cdot5}zz$, Cy
		Lower slope	$A_2^{23\cdot7}zz$, $A_1^{5\cdot8}zz$, $B^{1\cdot4}zz$, Cxx
		Upper slope	$A_2^{23\cdot2}zz$, $A_1^{3\cdot8}zz$, $B^{1\cdot2}zz$, Cx
		Hill top	$A_2^{24\cdot9}zz$, $A_1^{4\cdot5}zz$, $B^{1\cdot5}zz$, Cxx
Mixed	East	Hill base	$A_2^{19\cdot1}zz$, $A_1^{9\cdot3}zz$, $B^{1\cdot6}zz$, Cxx
		Lower slope	$A_2^{15\cdot7}zz$, $A_1^{12\cdot5}zz$, $B^{5\cdot1}zz$, Cy
		Upper slope	$A_2^{17\cdot3}zz$, $A_1^{7\cdot6}zz$, $B^{1\cdot7}zz$, Cy
		Hill top	$A_2^{16\cdot5}zz$, $A_1^{7\cdot8}zz$, $B^{1\cdot2}zz$, Cy
	North-west	Hill base	A_2^{0}, $A_1^{8\cdot5}zz$, $B^{1\cdot1}zz$, Cz
		Lower slope	$A_2^{26\cdot7}zz$, $A_1^{8\cdot5}zz$, $B^{1\cdot2}zz$, Czz
		Upper slope	$A_2^{23\cdot2}zz$, $A_1^{7\cdot0}zz$, $B^{0\cdot9}zz$, Cz
		Hill top	$A_2^{20\cdot9}zz$, $A_1^{7\cdot9}zz$, $B^{1\cdot0}zz$, Cz
	South	Hill base	$A_2^{19\cdot8}zz$, $A_1^{7\cdot0}zz$, $B^{1\cdot5}zz$, Cy
		Lower slope	$A_2^{19\cdot0}zz$, $A_1^{8\cdot7}zz$, $B^{1\cdot6}zz$, Cz
		Upper slope	$A_2^{18\cdot5}zz$, $A_1^{10\cdot8}zz$, $B^{1\cdot6}zz$, Cz
		Hill top	$A_2^{16\cdot8}zz$, $A_1^{11\cdot7}zz$, $B^{1\cdot4}zz$, Cz
Quercus leucotrichophora	North-east	Hill base	$A_2^{15\cdot6}zz$, $A_1^{6\cdot6}zz$, $B^{1\cdot0}x$, Cz
		Lower slope	$A_2^{16\cdot8}zz$, $A_1^{5\cdot0}z$, $B^{0\cdot9}z$, Czz
		Upper slope	$A_2^{16\cdot5}zz$, $A_1^{5\cdot8}zz$, $B^{0\cdot9}x$, Czz
		Hill top	$A_2^{15\cdot3}zz$, $A_1^{6\cdot9}z$, $B^{1\cdot2}z$, Czz
	East	Hill base	$A_2^{18\cdot2}zz$, $A_1^{5\cdot1}zz$, $B^{1\cdot2}y$, Czz
		Lower slope	$A_2^{19\cdot1}zz$, $A_1^{7\cdot1}z$, $B^{1\cdot1}x$, Czz
		Upper slope	$A_2^{17\cdot2}zz$, $A_1^{8\cdot1}z$, $B^{0\cdot8}y$, Czz
		Hill top	$A_2^{22\cdot2}zz$, $A_1^{3\cdot9}z$, $B^{0\cdot9}x$, Czz
	South-west	Hill base	A_2^{0}, $A_1^{6\cdot1}z$, $B^{1\cdot3}zz$, Czz
		Lower slope	A_2^{0}, $A_1^{6\cdot2}z$, $B^{1\cdot0}zz$, Czz
		Upper slope	A_2^{0}, $A_1^{5\cdot8}z$, $B^{1\cdot0}zz$, Czz
		Hill top	$A_2^{19\cdot9}zz$, $A_1^{4\cdot7}z$, $B^{0\cdot9}zz$, Czz
Quercus lanuginosa	South	Hill base	$A_2^{19\cdot6}zz$, $A_1^{8\cdot9}xx$, $B^{1\cdot3}z$, Cz
		Lower slope	$A_2^{17\cdot5}zz$, $A_1^{4\cdot8}y$, $B^{1\cdot8}z$, Czz

1	2	3	4			
		Upper slope	$A_2^{17\cdot7}zz$,	$A_1^{3\cdot6}z$,	$B^{1\cdot2}zz$,	Czz
		Hill top	$A_2^{17\cdot4}zz$,	$A_1^{4\cdot1}y$,	$B^{1\cdot2}zz$,	Cz
Quercus floribunda	North	Hill base	$A_2^{17\cdot9}zz$,	$A_1^{5\cdot5}y$,	$B^{1\cdot5}x$,	Czz
		Lower slope	A_2^{0},	$A_1^{4\cdot0}y$,	$B^{1\cdot3}xx$,	Czz
		Upper slope	$A_2^{18\cdot8}zz$,	$A_1^{7\cdot7}y$,	$B^{1\cdot6}z$,	Czz
		Hill top	$A_2^{17\cdot4}zz$,	$A_1^{5\cdot5}y$,	$B^{1\cdot2}z$,	Czz
	North-east	Hill base	$A_2^{18\cdot2}zz$,	$A_1^{3\cdot6}xx$,	$B^{1\cdot6}xx$,	Czz
		Lower slope	$A_2^{15\cdot5}zz$,	$A_1^{6\cdot1}z$,	$B^{1\cdot0}y$,	Czz
		Upper slope	$A_2^{16\cdot5}zz$,	$A_1^{4\cdot4}x$,	$B^{1\cdot4}x$,	Czz
		Hill top	$A_2^{17\cdot7}zz$,	$A_1^{4\cdot5}xx$,	$B^{1\cdot3}y$,	Czz
	East	Hill base	A_2^{0},	$A_1^{4\cdot5}x$,	$B^{1\cdot0}y$,	Czz
		Lower slope	A_2^{0},	$A_1^{6\cdot3}x$,	$B^{0\cdot9}y$,	Czz
		Upper slope	$A_2^{15\cdot8}zz$,	$A_1^{6\cdot4}xx$,	$B^{1\cdot3}x$,	Czz
		Hill top	$A_2^{16\cdot4}zz$,	$A_1^{6\cdot1}y$,	$B^{1\cdot1}xx$,	Czz
	South	Hill base	A_2^{0},	$A_1^{4\cdot4}xx$,	$B^{1\cdot4}z$,	Czz
		Lower slope	A_2^{0},	$A_1^{4\cdot7}xx$,	$B^{1\cdot1}y$,	Czz
		Upper slope	A_2^{0},	$A_1^{5\cdot2}x$,	$B^{0\cdot9}y$,	Czz
		Hill top	$A_2^{16\cdot0}zz$,	$A_1^{4\cdot3}xx$,	$B^{0\cdot8}xx$,	Czz

The *B* stratum, being very sparse was not well defined on any topographic situation and aspect (table 3). *Lantana camara* was the only occupant of this stratum on most of the topographic situations and aspects. This stratum had the highest canopy index at the E hill base and the lowest on the SW hill top (table 4).

The herb layer in most stands indicated an average density and was composed of *Chrysopogon serrulatus-Desmodium polycarpum* community (table 3).

The trees in the A_2 stratum, on the NE hill top were highly resistant to swaying and bending by wind (SG = 52·2) (table 4). On the other hand, tree stability was lowest at the SW lower slope (SG = 71·6).

3.2. *Mixed forest*

The profile structures of the mixed forest stand are shown in figure 2. On S and E aspects, the hill base position indicated the highest average height of trees in A_2 stratum (table 3). On NW aspect, the maximum average height of the A_2 stratum was recorded on the lower slope, while at the hill base this stratum was altogether absent. Except for the S hill base where *Q. leucotrichophora* was the sole occupant of the A_2 stratum and the NW upper slope where *P. roxburghii* alone formed the A_2 stratum, this stratum was constituted by a mixture of species such as *Bauhinia retusa*, *Persea odoratissima*, *Celtis eriocarpa*, *Bauhinia variegata*, *Cedrela ciliata*, *Grewia subinaequalis*, etc. The canopy of this stratum was fairly irregular and discontinuous and trees were very sparse. The crowns

Table 4. Canopy depth, canopy index and quotient of slenderness for different forests in north-western part of Gola catchment.

Forest type	Aspect	Position	Average canopy depth (m) strata A_2	A_1	Canopy index (%) strata A_2+A_1	B	Total	Quotient of slenderness (SG) stratum A_2
1	2	3	4		5			6
Pinus roxburghii	North-east	Hill base	12·7	3·5	128·6	37·6	166·2	57·9
		Lower slope	10·5	4·4	190·6	14·9	205·5	61·9
		Upper slope	9·3	4·4	144·3	40·4	184·7	62·3
		Hill top	14·3	3·0	115·7	18·4	134·1	52·2
	East	Hill base	13·1	2·0	98·8	40·8	139·6	56·3
		Lower slope	12·0	3·1	110·6	10·6	121·2	60·9
		Upper slope	14·3	5·9	68·2	13·7	81·9	62·6
		Hill top	15·3	3·2	69·4	11·4	80·8	59·8
	South-west	Hill base	11·2	3·5	108·6	14·5	123·1	66·4
		Lower slope	13·5	3·6	81·6	18·4	100·0	71·6
		Upper slope	13·4	2·8	110·2	18·4	128·6	57·6
		Hill top	14·4	3·1	155·3	9·4	164·7	65·0
Mixed	East	Hill base	13·6	6·0	116·9	256·0	372·9	39·5
		Lower slope	9·8	6·2	91·8	151·4	243·2	50·3
		Upper slope	11·6	5·1	126·7	397·3	524·0	46·6
		Hill top	12·7	5·1	123·5	483·5	607·0	60·2
	North-west	Hill base	0	6·3	82·0	16·9	98·9	0
		Lower slope	17·3	5·0	169·0	27·5	196·5	48·3
		Upper slope	13·4	3·8	100·8	60·8	161·6	57·9
		Hill top	13·3	4·8	111·4	154·9	266·3	57·9
	South	Hill base	13·6	5·1	147·8	512·2	660·0	45·4
		Lower slope	12·2	5·8	169·8	450·2	620·0	40·6
		Upper slope	12·0	6·7	128·2	491·8	620·0	41·6
		Hill top	12·0	8·4	139·2	408·2	547·4	56·6
Quercus leucotrichophora	North-east	Hill base	10·6	4·6	156·5	974·1	1130·6	45·6
		Lower slope	11·2	3·7	206·3	394·1	600·8	47·9
		Upper slope	11·0	4·0	191·8	760·0	951·8	44·4
		Hill top	10·4	4·6	167·0	398·8	565·8	47·7
	East	Hill base	12·3	3·3	230·6	807·5	1038·1	41·3
		Lower slope	13·1	4·6	335·7	896·0	1231·7	47·6
		Upper slope	11·3	5·3	328·2	630·6	958·8	44·8
		Hill top	15·0	2·6	168·6	1020·4	1189·0	42·5
	South-west	Hill base	0	4·2	131·4	165·9	297·3	0
		Lower slope	0	4·2	161·2	151·4	312·6	0
		Upper slope	0	4·2	144·7	208·6	353·3	0
		Hill top	13·6	3·2	142·0	116·5	258·5	49·6

Table 4. (*Contd.*)

1	2	3	4			5		6
Quercus lanuginosa	South	Hill base	14·3	2·6	333·7	418·8	752·5	30·2
		Lower slope	12·7	3·4	218·8	368·6	587·4	30·5
		Upper slope	12·7	2·5	209·0	255·3	464·3	30·8
		Hill top	17·8	2·8	182·4	218·8	401·2	35·7
Quercus floribunda	North	Hill base	14·1	4·1	277·3	777·6	1054·9	52·8
		Lower slope	0	3·0	160·8	344·7	1505·5	0
		Upper slope	14·6	6·0	350·6	360·0	710·6	58·0
		Hill top	13·5	4·3	214·9	316·0	530·9	69·3
	North-east	Hill base	15·0	2·8	237·3	1165·5	1402·8	42·3
		Lower slope	13·0	4·6	176·0	673·7	849·7	56·0
		Upper slope	13·2	3·4	260·4	868·6	1129·0	56·1
		Hill top	14·0	3·4	255·7	539·6	795·3	56·2
	East	Hill base	0	3·9	205·5	608·6	814·1	0
		Lower slope	0	4·9	241·6	556·1	797·7	0
		Upper slope	13·0	4·9	320·8	833·3	1154·1	58·7
		Hill top	13·6	4·7	275·3	814·1	1089·4	59·4
	South	Hill base	0	3·6	280·0	402·7	682·7	0
		Lower slope	0	3·8	247·5	600·0	847·5	0
		Upper slope	0	4·1	224·7	896·5	1121·2	0
		Hill top	12·8	3·4	256·0	1574·0	1830·0	53·0

of trees were usually deeper than wide. On S and E aspects the maximum average canopy depth occurred at the hill base and on the NW aspect at the lower slope (table 4).

The trees in the A_1 stratum were also very sparse (table 3). However, the canopy was comparatively better developed at the NW hill base than on other topographic situations and aspects. Almost all trees in this stratum were young individuals of species which reach the A_2 stratum upon maturity. Like the A_2 stratum, the crowns tended to be more deep than wide on all topographic situations and aspects.

On S and NW aspects, the canopy index ($A_2 + A_1$ strata) was highest at the lower slope, while on E aspect it was highest on the upper slope (table 4).

With the exception of NW aspect, the *B* stratum was well developed with almost a continuous canopy. This stratum was dominated by *L. camara,* which despite a low density developed a spreading, close canopy, except for NW hill top where it was dominated by *Aechmanthera tomentosa.* The canopy index of the shrub layer was maximum at the S hill base and minimum at the NW hill base (table 4).

The herb layer on most of the positions of NW and S aspect was sparse, while on E aspect it indicated an average density (table 3). This layer was composed of *Dicliptera bupleuroides—Oplismenus burmanii* community.

The trees of the A_2 stratum were more slender on the S and E hill tops (sG = 56·6 and 60·2, respectively), and on the NW upper slope and hill top

(SG = 57·9) (table 4). These results indicate lower stability of trees at these positions, hence they are more susceptible to wind damage.

3.3. *Quercus leucotrichophora forest*

The canopy in the A_2 stratum was almost continuous at the E hill base, lower slope and upper slope and at the NE lower slope (figure 3). At the SW hill base and lower and upper slopes, the A_2 stratum was absent. Where present, it was composed of only *Q. leucotrichophora* with the exception of the E upper slope, where one tree of *P. roxburghii* (per 200 m^2) occurred with *Q. leucotrichophora*. The crowns of the trees were more deep than wide in this stratum. The canopy depth was maximum on the E hill top and minimum on the NE hill top (table 4). Stratum A_1 was dominated by *Q. leucotrichophora* on all positions of E and NE aspect (figure 3). On the other hand this stratum on all the four situations of SW was dominated either by *Myrica esculenta*, *Rhododendron arboreum* or by *Lyonia ovalifolia*. The E hill top had one tree of *P. roxburghii* per 200 m^2. The canopy in this stratum was more or less continuous on almost all positions and aspects. Most of the gaps in the A_2 stratum were closed by trees in the stratum A_1, thus, strata A_2 and A_1 together formed a good cover on all positions and aspects. The crowns in this stratum were more deep than wide.

The trees on all positions and aspects in the A_2 stratum were very sparse, while on most of the positions and aspects in A_1 stratum they were sparse (table 3).

The shrub stratum (*B*) was well defined on all positions and aspects (figure 3). With the exception of NE and E upper slope, all other positions on different aspects were dominated by the shrub *Myrsine africana*. On the E and NE upper slope *Boenninghausenia albiflora* was the dominant shrub. The shrub layer on all positions of SW was very sparse, while on the NE lower slope and hill top the same was sparse (table 3). This layer on the E lower slope and hill top and on the NE hill base and upper slope was dense. The canopy index of this stratum was maximum on the E hill top (table 4).

On most topographic situations and aspects, the plants in the herb layer were very sparse (table 3). This layer was comprised of *Arundinella nepalensis*—*Carex nubigena* community.

Tree stability was lowest on the SW hill top (SG = 49.6) where only two trees of *Q. leucotrichophora* per 200 m^2 occurred (table 4).

3.4. *Quercus lanuginosa forest*

At the S hill base and upper slope, the canopy of the A_2 stratum was fairly dense and at places the crowns touched each other (figure 4). On the other hand at the lower slope and hill top positions, canopies were broken ; only two trees of *Q. lanuginosa* were present per 200 m^2 on each of these positions. This stratum consisted of only *Q. lanuginosa* trees on all positions. The crowns were deeper than wide. The average canopy depth was maximum at the hill base (table 4).

The canopy of the A_1 stratum was more dense as compared to that of the A_2 stratum on all positions (table 3). Though, this stratum was dominated by *Q. lanuginosa*, other species such as *R. arboreum*, *M. esculenta*, *L. ovalifolia*, *Cornus oblonga*, etc., were also present. Like A_2 stratum, the crowns of this stratum were also deeper than wide.

The canopy index of $A_2 + A_1$ strata was maximum at the hill base and minimum on the hill top (table 4).

The plants in the stratum *B* were very sparse on the upper slope and hill top positions, and sparse at the hill base and lower slope positions (table 3). The dominant shrub on all positions was *M. africana.* The shrub canopy index was maximum at the hill base and minimum on the hill top (table 4).

The herb layer on the hill base and hill top positions was sparse and on the lower and upper slopes very sparse (table 3). This layer was dominated by the *Apluda mutica—Themeda anathera* community.

The quotient of slenderness for the A_2 stratum trees was highest on the hill top and lowest at the hill base (table 4).

3.5. *Quercus floribunda forest*

The profile diagrams for the *Quercus floribunda* forest stands are illustrated in figure 5. The A_2 stratum was well defined only at the N hill base and upper slope. The trees of this stratum on all positions and aspects belonged to *Q. floribunda.*

The crowns of the A_2 stratum tended to be deeper than wide. The average canopy depth was the highest at the NE hill base and the lowest on the S hill top (table 4).

The stratum A_1 had a remarkably dense canopy, the individual crowns usually touched each other. A majority of trees in this stratum was represented by young individuals of *Q. floribunda.* Other species in this stratum were : *R. arboreum, L. ovalifolia, C. oblonga, Pyrus pashia, Q. leucotrichophora,* etc. The crowns were deeper than wide.

The trees in the A_2 stratum on all positions and aspects were very sparse, while in A_1 stratum the trees on most positions and aspects were either dense or very dense (table 3). The canopy index of the upper two strata ($A_2 + A_1$) was the highest on the N upper slope and the lowest at the N lower slope (table 4).

Below the two storeys of trees, the stratum *B* consisting chiefly of shrubs was well defined in this forest. The plants were very dense at the NE hill base, N lower slope and on the E and S hill top (table 3). On all S positions, at the E hill base and at the N lower slope, *M. africana* was the dominant shrub while *M. semiserrata* played the vicariant role on the N hill top. On rest of the positions and aspects *Arundinaria falcata* showed its dominance. The canopy index of this stratum was on the whole higher than that of the corresponding stratum in other forests of the study area (table 4).

The herb layer on all positions and aspects was very sparse (table 3) and was composed of *Muehlenbergia duthieana-Helictotrichon asperum* community.

The tree stability in A_2 stratum was the highest at the NE hill base (SG = 42·3) and the lowest on the N hill top (SG = 69·3) (table 4).

4. Discussion

The structure of the forests varied from stand to stand. Such inter-stand variations in tree stature, crown geometry and canopy architecture are common (Anderson 1961 ; Ashton 1964 ; Brunig 1970, 1976 ; Brunig and Heuveldop 1976).

In these forests there was a total of four strata ; two upper strata represented by trees, the third stratum represented mainly by shrubs, and the fourth by herbs. The maximum average tree height (across positions and aspects) in the A_2 stratum was recorded for *P. roxburghii* forest (22·4 m) and the minimum for *Q. floribunda* forest (17.1 m). *Q. leucotrichophora* and *Q. lanuginosa* forests had almost equal average tree height (about 18·0 m) in this stratum. Further, with increasing altitude the tree height of the A_2 stratum decreased ($Y = 27{\cdot}3008—0{\cdot}0047\,X$; $r = —0{\cdot}6799$, $P<0{\cdot}001$; where Y = tree height in m and X = altitude in m). Brown (1919) suggested that the decrease in plant height with increasing altitude is due to the combined effects of decreased temperature and decreased illumination (due to increased cloudiness). Richards (1952) pointed out that this dwarfing of the vegetation may be partly due to exposure to strong wind.

In all forests, the crowns of the A_2 stratum were deeper than wide. On an average, across positions and aspects, about 80% length of the trees in *Q. floribunda*, 72% in *Q. lanuginosa*, 68% in *Q. leucotrichophora*, 67% in mixed and about 57% in *P. roxburghii* forests was covered by the canopy. Contrary to the tree height, the proportion of the tree devoted to canopy in the A_2 stratum increased with an increase in the altitude ($Y = 36{\cdot}6628 + 0{\cdot}0185\,X$; $r = 0.8395$, $P < 0{\cdot}001$; where Y = percent length of the tree devoted to canopy and X = altitude in m). Thus the tree compensated for decrease in height by allocating more of its length to development of photosynthetic canopy.

The canopies in the A_1 stratum were comparatively denser than those in A_2 stratum in all forests except those of *P. roxburghii.* The plants on most positions and aspects in A_1 stratum were very sparse in *P. roxburghii* and mixed forests, sparse in *Q. leucotrichophora* forest, average in *Q. lanuginosa* forest and dense to very dense in *Q. floribunda* forest. Most of the individuals in this stratum belonged to the species which constituted the A_2 stratum. However, some other trees such as, *R. arboreum, L. ovalifolia, C. oblonga, S. insigne, M. esculenta, C. laurifolius. Rhamnus triqueter,* etc., were confined only to this stratum.

The average tree height (across positions and aspects) A_1 stratum was the highest in the mixed forest (8·9 m) and the lowest in *Q. lanuginosa* forest (4·1 m). In this stratum also, almost all trees in all forest types had their crowns deeper than wide. As the altitude increased, the percent of tree height covered by canopy also increased ($Y = 45{\cdot}2850 + 0{\cdot}0134\,X$; $r = 0{\cdot}806$, $P < 0{\cdot}001$; where Y = percent length of the tree devoted to canopy and X = altitude in m) ; maximum (78·8%) being in the *Q. floribunda* forest and minimum (62·2%) in the *P. roxburghii* forest. The proportion of the tree devoted to canopy depth was greater in the A_2 stratum compared to the A_1 stratum.

There was usually no clear vertical discontinuity between the canopies of A_2 and A_1 strata because of the occurrence of a variable number of layers in each stratum. The exceptions were the E hill base and hill top and SW upper slope of

P. roxburghii forest, where a clear vertical discontinuity between the A_2 and A_1 strata occurred.

The shrub density on most positions and aspects in *Q. floribunda* forest was average, while it was very sparse in *P. roxburghii* and mixed forests. In *Q. leucotrichophora* forest, SW aspect exhibited very sparse density, while on most positions of NE and E, the plants were dense. In general, the shrub layer (*B* stratum- in three oak forests was comparatively dense and the crowns of the shrubs over) lapped each other. In the *P. roxburghii* forest, this stratum was not well developed.

The canopy index, a crude and relative measure of canopy cover, of both tree and shrub layers was maximum for *Q. floribunda* forest and minimum for *P. roxburghii* forest. On categorizing the aspects into cooler (N, NE, E, and NW) and warmer (S and SW), the cooler aspects developed a greater canopy index for tree ($\bar{X} = 183 \cdot 7\%$) and shrub ($\bar{X} = 431 \cdot 5\%$) layers as compared to the warmer aspects (canopy index for tree layer, $\bar{X} = 170 \cdot 4\%$ and for shrub layer, $\bar{X} = 318 \cdot 9\%$).

About 50% of the stands each in *P. roxburghii* and mixed forests had, respectively, an average and sparse plant density in the herb layer, while in *Q. leucotrichophora* and *Q. floribunda* forests the herbaceous plants were very sparse. The plants in this layer were sparse to very sparse in *Q. lanuginosa* forest. Poor development of herbaceous plants under the oak forests may be because of a tendency of inverse relationship between the canopy cover (of tree + shrub layers) and the development of the herb layer (Richards 1952; Smith 1956 ; Zobel *et al* 1976 ; Killingbeck and Wali 1978). Naturally, relatively open overhead canopies would induce the development of the herb layer.

The data on the quotient of slenderness (SG) indicates the stability of trees ; the lower the SG value the higher is the stability (Brunig and Heuveldop 1976). In the present area the trees in *Q. lanuginosa* forest were more stable, while in the *P. roxburghii* forest trees were specially susceptible to wind effect. Since *P. roxburghii* is a rich source of resin, trees are tapped heavily in this region (Saxena 1977). As the tapping reduces the diameter, the resistence of the heavily tapped trees to wind is greatly reduced (Assmann 1970). Because of the characteristic low wind stability the tapping of this species for resin should be very cautious and perhaps should be avoided in those forests which are exposed to greater wind velocities or having poor stocking density.

A majority of trees in the present forests were more wind resistant as compared to those in the humid tropical forests (Brunig and Heuveldop 1976). It may be pointed out that a mountainous country, due to varied nature of slopes, is characterized by a higher degree of wind turbulence compared to a non-mountainous region, and therefore, lower values of quotient of slenderness in the present trees may be an adaptational feature.

In general the warmer aspects had more stable trees, *i.e.*, lower SG value ($\bar{X} = 50 \cdot 5$), while the cooler aspects showed lower tree stability, *i.e.*, high SG value ($\bar{X} = 55 \cdot 1$). In comparison to cooler aspects, the warmer aspects experience greater wind velocities (Smith 1974). The low SG values of trees, thus growing on warmer aspects may be an adaptational feature.

The canopies in the different strata also influence the soil condition of a site. Packer 1951) observed that overland flow and erosion decrease with increase in cover. A dense cover of vegetation is the most powerful weapon for reducing erosion. According to Lull (1964), the drops that drip from the leaves are generally larger than the rain drops and their terminal velocity is reached by the time they have fallen 7·5 m. Trimble and Weitzman (1954) concluded that a high tree canopy has a limited value in reducing the erosion potential of rainfall intensity, but a forest with a canopy that reaches close to the ground can effectively reduce the erosion potential. Thus a site with trees confined only to the A_2 stratum and having their canopies concentrated on the top will be relatively less protective for the soil. But when the trees in the A_2 stratum are supported by deep and dense canopies in A_1 or B strata, the vegetation becomes more protective for the soil. A forest with a multilayered canopy with a high canopy index and a well developed forest floor will, thus, have a greater protective value as compared to a forest which has fewer layers and a lower canopy index (Kittredge 1948).

In this region, the rainfall is concentrated in a short monsoon period (June to September). This is preceded by a long dry period (winter and summer seasons) during which the herbaceous cover dries up and shatters. Additionally during this dry period, grazing, herbage removal for animal feed and ground fires, particularly in pine forests further decimate the herb-litter cover, leaving often a semibare floor. At the culmination of this dry period, the monsoon breaks with a high rainfall intensity. Under such situations, if the tree canopy is thin or high or monolayered with little or no shrubby undergrowth, soil erosion and runoff are remarkably accelerated. Keeping the above in mind the present forest could be graded in a decreasing order of potential for soil protection : *Q. floribunda* > *Q. leucotrichophora* > *Q. lanuginosa* > mixed > *P. roxburghii.* In sensitive catchment areas maintained for soil and water conservation, *Q. floribunda* and *Q. leucotrichophora* forests should, therefore, be encouraged.

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(SG = 57·9) (table 4). These results indicate lower stability of trees at these positions, hence they are more susceptible to wind damage.

3.3. *Quercus leucotrichophora forest*

The canopy in the A_2 stratum was almost continuous at the E hill base, lower slope and upper slope and at the NE lower slope (figure 3). At the SW hill base and lower and upper slopes, the A_2 stratum was absent. Where present, it was composed of only *Q. leucotrichophora* with the exception of the E upper slope, where one tree of *P. roxburghii* (per 200 m^2) occurred with *Q. leucotrichophora*. The crowns of the trees were more deep than wide in this stratum. The canopy depth was maximum on the E hill top and minimum on the NE hill top (table 4). Stratum A_1 was dominated by *Q. leucotrichophora* on all positions of E and NE aspect (figure 3). On the other hand this stratum on all the four situations of SW was dominated either by *Myrica esculenta, Rhododendron arboreum* or by *Lyonia ovalifolia*. The E hill top had one tree of *P. roxburghii* per 200 m^2. The canopy in this stratum was more or less continuous on almost all positions and aspects. Most of the gaps in the A_2 stratum were closed by trees in the stratum A_1, thus, strata A_2 and A_1 together formed a good cover on all positions and aspects. The crowns in this stratum were more deep than wide.

The trees on all positions and aspects in the A_2 stratum were very sparse, while on most of the positions and aspects in A_1 stratum they were sparse (table 3).

The shrub stratum (*B*) was well defined on all positions and aspects (figure 3). With the exception of NE and E upper slope, all other positions on different aspects were dominated by the shrub *Myrsine africana*. On the E and NE upper slope *Boenninghausenia albiflora* was the dominant shrub. The shrub layer on all positions of SW was very sparse, while on the NE lower slope and hill top the same was sparse (table 3). This layer on the E lower slope and hill top and on the NE hill base and upper slope was dense. The canopy index of this stratum was maximum on the E hill top (table 4).

On most topographic situations and aspects, the plants in the herb layer were very sparse (table 3). This layer was comprised of *Arundinella nepalensis—Carex nubigena* community.

Tree stability was lowest on the SW hill top (SG = 49.6) where only two trees of *Q. leucotrichophora* per 200 m^2 occurred (table 4).

3.4. *Quercus lanuginosa forest*

At the S hill base and upper slope, the canopy of the A_2 stratum was fairly dense and at places the crowns touched each other (figure 4). On the other hand at the lower slope and hill top positions, canopies were broken ; only two trees of *Q. lanuginosa* were present per 200 m^2 on each of these positions. This stratum consisted of only *Q. lanuginosa* trees on all positions. The crowns were deeper than wide. The average canopy depth was maximum at the hill base (table 4).

The canopy of the A_1 stratum was more dense as compared to that of the A_2 stratum on all positions (table 3). Though, this stratum was dominated by *Q. lanuginosa*, other species such as *R. arboreum, M. esculenta, L. ovalifolia,* *Cornus oblonga*, etc., were also present. Like A_2 stratum, the crowns of this stratum were also deeper than wide.

The canopy index of $A_2 + A_1$ strata was maximum at the hill base and minimum on the hill top (table 4).

The plants in the stratum *B* were very sparse on the upper slope and hill top positions, and sparse at the hill base and lower slope positions (table 3). The dominant shrub on all positions was *M. africana*. The shrub canopy index was maximum at the hill base and minimum on the hill top (table 4).

The herb layer on the hill base and hill top positions was sparse and on the lower and upper slopes very sparse (table 3). This layer was dominated by the *Apluda mutica—Themeda anathera* community.

The quotient of slenderness for the A_2 stratum trees was highest on the hill top and lowest at the hill base (table 4).

3.5. *Quercus floribunda forest*

The profile diagrams for the *Quercus floribunda* forest stands are illustrated in figure 5. The A_2 stratum was well defined only at the N hill base and upper slope. The trees of this stratum on all positions and aspects belonged to *Q. floribunda*.

The crowns of the A_2 stratum tended to be deeper than wide. The average canopy depth was the highest at the NE hill base and the lowest on the S hill top (table 4).

The stratum A_1 had a remarkably dense canopy, the individual crowns usually touched each other. A majority of trees in this stratum was represented by young individuals of *Q. floribunda*. Other species in this stratum were : *R. arboreum*, *L. ovalifolia*, *C. oblonga*, *Pyrus pashia*, *Q. leucotrichophora*, etc. The crowns were deeper than wide.

The trees in the A_2 stratum on all positions and aspects were very sparse, while in A_1 stratum the trees on most positions and aspects were either dense or very dense (table 3). The canopy index of the upper two strata ($A_2 + A_1$) was the highest on the N upper slope and the lowest at the N lower slope (table 4).

Below the two storeys of trees, the stratum *B* consisting chiefly of shrubs was well defined in this forest. The plants were very dense at the NE hill base, N lower slope and on the E and S hill top (table 3). On all S positions, at the E hill base and at the N lower slope, *M. africana* was the dominant shrub while *M. semiserrata* played the vicariant role on the N hill top. On rest of the positions and aspects *Arundinaria falcata* showed its dominance. The canopy index of this stratum was on the whole higher than that of the corresponding stratum in other forests of the study area (table 4).

The herb layer on all positions and aspects was very sparse (table 3) and was composed of *Muehlenbergia duthieana-Helictotrichon asperum* community.

The tree stability in A_2 stratum was the highest at the NE hill base (SG = 42·3) and the lowest on the N hill top (SG = 69·3) (table 4).

4. Discussion

The structure of the forests varied from stand to stand. Such inter-stand variations in tree stature, crown geometry and canopy architecture are common (Anderson 1961 ; Ashton 1964 ; Brunig 1970, 1976 ; Brunig and Heuveldop 1976).

In these forests there was a total of four strata ; two upper strata represented by trees, the third stratum represented mainly by shrubs, and the fourth by herbs. The maximum average tree height (across positions and aspects) in the A_2 stratum was recorded for *P. roxburghii* forest (22·4 m) and the minimum for *Q. floribunda* forest (17.1 m). *Q. leucotrichophora* and *Q. lanuginosa* forests had almost equal average tree height (about 18·0 m) in this stratum. Further, with increasing altitude the tree height of the A_2 stratum decreased ($Y = 27{\cdot}3008—0{\cdot}0047\,X$; $r = —0{\cdot}6799$, $P<0{\cdot}001$; where Y = tree height in m and X = altitude in m). Brown (1919) suggested that the decrease in plant height with increasing altitude is due to the combined effects of decreased temperature and decreased illumination (due to increased cloudiness). Richards (1952) pointed out that this dwarfing of the vegetation may be partly due to exposure to strong wind.

In all forests, the crowns of the A_2 stratum were deeper than wide. On an average, across positions and aspects, about 80% length of the trees in *Q. floribunda*, 72% in *Q. lanuginosa*, 68% in *Q. leucotrichophora*, 67% in mixed and about 57% in *P. roxburghii* forests was covered by the canopy. Contrary to the tree height, the proportion of the tree devoted to canopy in the A_2 stratum increased with an increase in the altitude ($Y = 36{\cdot}6628 + 0{\cdot}0185\,X$; $r = 0.8395$, $P < 0{\cdot}001$; where Y = percent length of the tree devoted to canopy and X = altitude in m). Thus the tree compensated for decrease in height by allocating more of its length to development of photosynthetic canopy.

The canopies in the A_1 stratum were comparatively denser than those in A_2 stratum in all forests except those of *P. roxburghii.* The plants on most positions and aspects in A_1 stratum were very sparse in *P. roxburghii* and mixed forests, sparse in *Q. leucotrichophora* forest, average in *Q. lanuginosa* forest and dense to very dense in *Q. floribunda* forest. Most of the individuals in this stratum belonged to the species which constituted the A_2 stratum. However, some other trees such as, *R. arboreum, L. ovalifolia, C. oblonga, S. insigne, M. esculenta, C. laurifolius. Rhamnus triqueter*, etc., were confined only to this stratum.

The average tree height (across positions and aspects) A_1 stratum was the highest in the mixed forest (8·9 m) and the lowest in *Q. lanuginosa* forest (4·1 m). In this stratum also, almost all trees in all forest types had their crowns deeper than wide. As the altitude increased, the percent of tree height covered by canopy also increased ($Y = 45{\cdot}2850 + 0{\cdot}0134\,X$; $r = 0{\cdot}806$, $P < 0{\cdot}001$; where Y = percent length of the tree devoted to canopy and X = altitude in m) ; maximum (78·8%) being in the *Q. floribunda* forest and minimum (62·2%) in the *P. roxburghii* forest. The proportion of the tree devoted to canopy depth was greater in the A_2 stratum compared to the A_1 stratum.

There was usually no clear vertical discontinuity between the canopies of A_2 and A_1 strata because of the occurrence of a variable number of layers in each stratum. The exceptions were the E hill base and hill top and SW upper slope of

P. roxburghii forest, where a clear vertical discontinuity between the A_2 and A_1 strata occurred.

The shrub density on most positions and aspects in *Q. floribunda* forest was average, while it was very sparse in *P. roxburghii* and mixed forests. In *Q. leucotrichophora* forest, SW aspect exhibited very sparse density, while on most positions of NE and E, the plants were dense. In general, the shrub layer (*B* stratum- in three oak forests was comparatively dense and the crowns of the shrubs over) lapped each other. In the *P. roxburghii* forest, this stratum was not well developed.

The canopy index, a crude and relative measure of canopy cover, of both tree and shrub layers was maximum for *Q. floribunda* forest and minimum for *P. roxburghii* forest. On categorizing the aspects into cooler (N, NE, E, and NW) and warmer (S and SW), the cooler aspects developed a greater canopy index for tree ($\bar{X}$ = 183·7%) and shrub ($\bar{X}$ = 431·5%) layers as compared to the warmer aspects (canopy index for tree layer, $\bar{X}$ = 170·4% and for shrub layer, $\bar{X}$ = 318·9%).

About 50% of the stands each in *P. roxburghii* and mixed forests had, respectively, an average and sparse plant density in the herb layer, while in *Q. leucotrichophora* and *Q. floribunda* forests the herbaceous plants were very sparse. The plants in this layer were sparse to very sparse in *Q. lanuginosa* forest. Poor development of herbaceous plants under the oak forests may be because of a tendency of inverse relationship between the canopy cover (of tree + shrub layers) and the development of the herb layer (Richards 1952; Smith 1956 ; Zobel *et al* 1976 ; Killingbeck and Wali 1978). Naturally, relatively open overhead canopies would induce the development of the herb layer.

The data on the quotient of slenderness (SG) indicates the stability of trees ; the lower the SG value the higher is the stability (Brunig and Heuveldop 1976). In the present area the trees in *Q. lanuginosa* forest were more stable, while in the *P. roxburghii* forest trees were specially susceptible to wind effect. Since *P. roxburghii* is a rich source of resin, trees are tapped heavily in this region (Saxena 1977). As the tapping reduces the diameter, the resistence of the heavily tapped trees to wind is greatly reduced (Assmann 1970). Because of the characteristic low wind stability the tapping of this species for resin should be very cautious and perhaps should be avoided in those forests which are exposed to greater wind velocities or having poor stocking density.

A majority of trees in the present forests were more wind resistant as compared to those in the humid tropical forests (Brunig and Heuveldop 1976). It may be pointed out that a mountainous country, due to varied nature of slopes, is characterized by a higher degree of wind turbulence compared to a non-mountainous region, and therefore, lower values of quotient of slenderness in the present trees may be an adaptational feature.

In general the warmer aspects had more stable trees, *i.e.*, lower SG value ($\bar{X}$ = 50·5), while the cooler aspects showed lower tree stability, *i.e.*, high SG value ($\bar{X}$ = 55·1). In comparison to cooler aspects, the warmer aspects experience greater wind velocities (Smith 1974). The low SG values of trees, thus growing on warmer aspects may be an adaptational feature, The canopies in the different strata also influence the soil condition of a site. Packer 1951) observed that overland flow and erosion decrease with increase in cover. A dense cover of vegetation is the most powerful weapon for reducing erosion. According to Lull (1964), the drops that drip from the leaves are generally larger than the rain drops and their terminal velocity is reached by the time they have fallen 7·5 m. Trimble and Weitzman (1954) concluded that a high tree canopy has a limited value in reducing the erosion potential of rainfall intensity, but a forest with a canopy that reaches close to the ground can effectively reduce the erosion potential. Thus a site with trees confined only to the A_2 stratum and having their canopies concentrated on the top will be relatively less protective for the soil. But when the trees in the A_2 stratum are supported by deep and dense canopies in A_1 or B strata, the vegetation becomes more protective for the soil. A forest with a multilayered canopy with a high canopy index and a well developed forest floor will, thus, have a greater protective value as compared to a forest which has fewer layers and a lower canopy index (Kittredge 1948).

In this region, the rainfall is concentrated in a short monsoon period (June to September). This is preceded by a long dry period (winter and summer seasons) during which the herbaceous cover dries up and shatters. Additionally during this dry period, grazing, herbage removal for animal feed and ground fires, particularly in pine forests further decimate the herb-litter cover, leaving often a semibare floor. At the culmination of this dry period, the monsoon breaks with a high rainfall intensity. Under such situations, if the tree canopy is thin or high or monolayered with little or no shrubby undergrowth, soil erosion and runoff are remarkably accelerated. Keeping the above in mind the present forest could be graded in a decreasing order of potential for soil protection : *Q. floribunda* > *Q. leucotrichophora* > *Q. lanuginosa* > mixed > *P. roxburghii*. In sensitive catchment areas maintained for soil and water conservation, *Q. floribunda* and *Q. leucotrichophora* forests should, therefore, be encouraged.

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