STRUCTURE AND FUNCTIONING OF CENTRAL HIMALAYAN CHIRPINE FOREST ECOSYSTEM

J. S. SINGH and S. P. SINGH*
Department of Botany, Banaras Hindu University, Varanasi 221 005, India.
* *Department of Botany, Kumaun University, Nainital 263 002, India.*

ABSTRACT

The evergreen chirpine (*Pinus roxburghii*, Sarg) forest, extensively distributed between 1000 and 2000 m elevations, also occurred in the Himalaya during mid-Miocene. Chirpine has a tendency to form monospecific stands with sparse shrub layer. It is a ruderal-cum-stress tolerant species. The forest biomass is about 200 t ha^{-1} and the net primary productivity ranges between 18.5 and 24.5 t ha^{-1} yr^{-1}. Litter fall is greater than the average reported for warm temperate forests of the world. Litter decomposition is slow compared to broad-leaf species of the region. Chirpine shows an efficient mechanism of nutrient conservation and forms semi-stable communities under the influence of disturbance and recurring fire.

INTRODUCTION

Chirpine (*Pinus roxburghii*, Sarg) forest occurs extensively in the low-to-mid montane belt (1000–2000 m) of Central Himalaya[1]. Chirpine has withstood the onslaughts of man more successfully than the other species and because of the ability to grow on extremely degraded land, it is favoured for large scale plantations in the Central Himalaya where influence of man on the ecosystems has attained alarming dimensions[2]. Concern has been expressed on the expansion of chirpine into the climax oak forests which people prefer for many reasons[3].

In the present paper, we examine the structure and functioning of the Central Himalayan Chirpine forest ecosystem. The paper is based largely on investigations carried out by our group during the last decade.

ENVIRONMENTAL BACKGROUND

Chirpine is distributed in the outer Himalaya and the Siwaliks from Bhutan in the east and Afganistan in the west, covering about 9175 km^2 land in the Indian Himalaya[4]. Chirpine usually forms extensive pure forest and may occasionally descend up to 500 m and ascend to 2200 m elevation in the Central Himalaya. It also mixes with other species viz *Shorea robusta*, *Cedrella toona* and *Anogeissus latifolia* at low altitudes and with *Pinus wallichiana*, *Cedrus deodara* and *Quercus leucotrichophora* at higher altitudes.

In the outer ranges and the Siwaliks, Chirpine occurs on tertiary sandstone with occasional band of clay or beds of conglomerate while in the valleys considerable stretches of chirpine forest are found on quartzite. Other common geological formations include mica schist, gneiss and shales, and locally, limestone. The soil is residual, sandy loam with a greater proportion of coarser particles, higher C:N ratio and lower soil water compared to the soil of other forests[5]. Snowfall is infrequent in most parts. The annual rainfall ranges between 100 and 180 cm, the majority of which occurs during the monsoon (figure 1).

PALEOECOLOGICAL ASPECTS

During the mid-Miocene when there existed an 'incipient zonation' of vegetation in the Himalaya then only 2200–2400 m high, the temperate forests consisted of a number of placoarctic genera including *Pinus*[6]. In the sub-tropical and temperate belts of Kashmir a continuous flux of species occurred between broad-leaf forests and chirpine forest from 3.5 to 2.47 million years before the present.

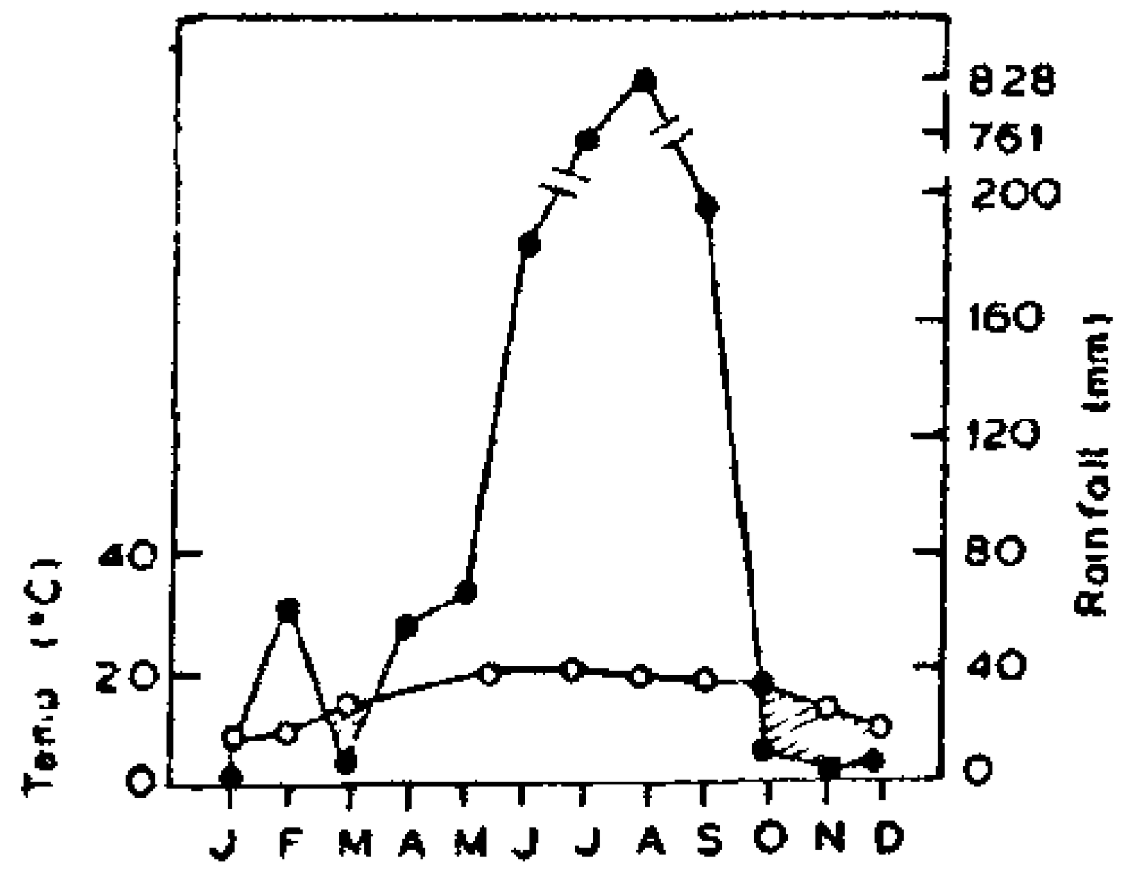

Figure 1. Ombrothermic diagram for a typical pine forest site near Nainital.

More recently, between about 8000 and 4500 years ago, a warm phase which resulted in massive snow melt, coincided with the invasion of chirpine forest by oaks (*Quercus* spp), resulting in the preponderance of oak forest in the Central Himalaya[6]. Subsequently in some regions, such as Kashmir valley and Himachal Pradesh oaks either disappeared or were pushed to sheltered areas within the conifer regions[7]. It is interesting that the oaks predominated and invaded the chirpine forests during the warm-phase of the climate because at present the oak forests are located at higher elevations (hence cooler environment) than the chirpine forests.

Table 1 *Importance value index for trees and density (individuals 100 m^{-2}) for shrubs, saplings and seedlings in a chirpine forest of Kumaun Himalaya (Values are averages of four stands on each aspect)*

Species	Aspect Northeast	East	Southwest
		Trees	
Pinus roxburghii Sarg	290.83	276.33	290.43
Engelhardtia spicata Leschen ex Bl	9.18	11.28	0
Quercus leucotrichophora A. Camus	0	12 40	0
Sapium insigne Benth	0	0	9.50
		Shrubs	
Lantana camara Linn	4.00	0.33	2.03
Rubus ellipticus Smith	1.00	0	0.68
Pyracantha crenulata (D. Don) Roem	0	3.68	0
Berberis asiatica Roxb ex Dc	0	0.33	0
		Saplings	
Pinus roxburghii	0.90	0.33	4.33
Pyrus pashia Buch-Ham ex D. Don	0.15	1.00	0
Engelhardtia spicata	0.90	0.50	1.43
Cocculus laurifolius DC	0	0.25	0
Adina cordifolia (Roxb) H.K.f. ex Brandis	0	0.07	0.07
Sapium insigne	0	0	0.15
		Seedlings	
Pinus roxburghii	139.00	0	23.68
Cocculus laurifolius	0	0.33	0

PHYTOSOCIOLOGY

In all chirpine forests studied[3,8,9], the Important Value Index (IVI) of chirpine is ≥ 250 (table 1). The shrub layer is poorly represented. In general, the total tree basal area of chirpine forests is lower (26–40 $m^2\ ha^{-1}$) than those of oak forests (53–84 $m^2\ ha^{-1}$) and some mixed forests that also include chirpine (50–82 $m^2\ ha^{-1}$).

Both the species richness and the Shannon–Wiener Index[10] (diversity) in chirpine forest are very low for the tree layer, although the adjacent mixed forests may be quite species-rich and diverse (table 2, figure 2). As we shall discuss later, ability of chirpine to prevent the re-invasion of broad-leaf species is a major cause for this situation. In contrast to the woody component, the herb layer of the chirpine forest is the most diverse among the forests of the region. This is due to a greater exposure of ground to light. Because of recurrent burning grasses predominate the herb layer.

The biological spectrum is characterized by a predominance of therophytes (table 3). This may be attributed to recurring fires, relative xericness of the habitat, broken canopy enabling annual herbs to grow during the rainy season, and heavy grazing[11]. In adjacent oak forests, which are characteristically moist and close-canopied, phanerophytes, instead of therophytes prevail.

Table 2 *Woody species richness and diversity (Shannon-Wiener Index) in chirpine forests and the forests in which chirpine mixes with broad-leaf species*

Forest	Site	Stands sampled	Species richness per stand	Diversity
		Trees		
Chirpine	A	8	1–3	0–0.13 (0 06)
Chirpine	B	12	1–2	0–1.302 (0.787)[a]
Chirpine	C	1	5	0.7
Chirpine-mixed broad-leaf forest	A	8	10–22	1.19–3.25 (2.15)
Sal-Chirpine		8	8–15	0.76–2.47 (1.88)
		Shrubs		
Chirpine	A	8	5–7	2.06–2.36
Chirpine	B[b]	12	1–2	0–0.943
Chirpine	C	1		
Chirpine-mixed broad-leaf forest	A	8	3–11	1.58–2.80
Sal-chirpine		8	4–7	1.2–2.19

[a]includes tree saplings; [b]includes tree seedlings; Values in parentheses indicate averages.

REGENERATION

Chirpine is a frequent reproducer not only in its own forests but also in other forests where it has intruded following disturbance and creation of open canopy[8]. Other species occurring in chirpine forest usually fail to regenerate (figure 3). In mature forests with relatively

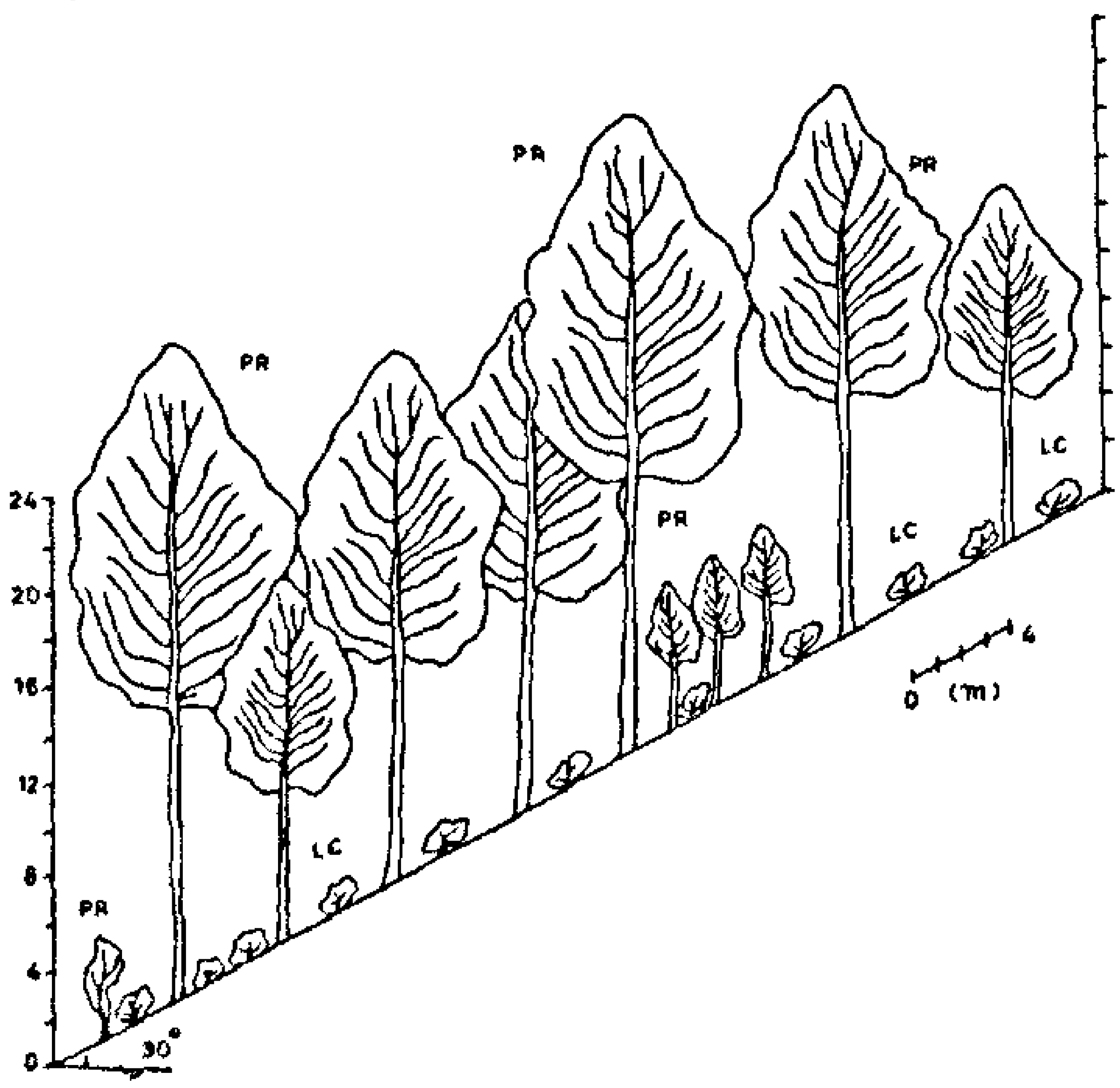

Figure 2. Profile diagram for a chirpine forest. The Y-axis represents height (m), and the scale on the X-axis represents canopy width and dbh (m). LC = *Lantana camara*; PR = *Pinus roxburghii*.

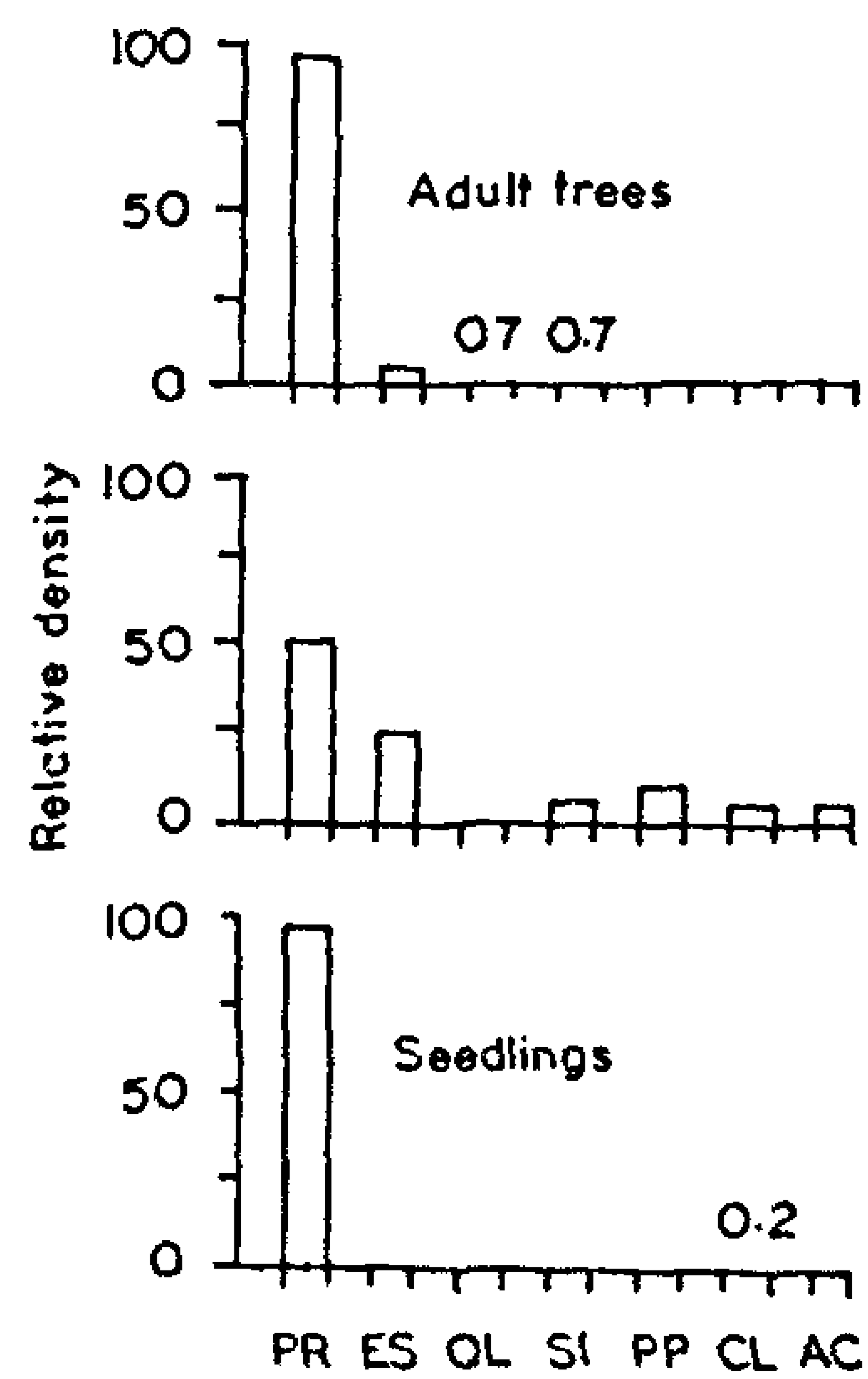

Figure 3. Relative density of different species in tree, sapling and seedling layers in chirpine forest. AC = *Adina cordifolia*; CL = *Cocculus laurifolius*; ES = *Engelhardtia spicata*; PP = *Pyrus pashia*; PR = *Pinus roxburghii*; QL = *Quercus leucotrichophora*; SI = *Sapium insigne*.

Table 3 *Biological spectra of chirpine forest in comparison with a banj oak forest and of total area of the Gaula Catchment, Kumaun Himalaya. Values are percentages of total species*

Vegetation type	Ph	Ch	H	G	Th
Pinus roxburghii forest	16.9	6.2	24.6	1.5	50.8
Quercus leucotrichophora forest	55.0	2.3	27.9	0	14.0
Total area	33.5	4.4	25.9	2.5	33.5

Ph = Phanerophytes; Ch = Chamaephytes; H = Hemicryptophytes, G = Geophytes; Th = Therophytes.

close canopy, chirpine may also fail to regenerate[12].

Our experiments indicate that chirpine belongs to the early successional, stress-tolerant category in the framework of primary adaptational strategy of plants suggested by Grime[13]. It has a wider response breadth on moisture gradient than any important tree species of the region, its seeds showing germination even at − 15 bar water stress[14]. It is perhaps the most fire-resistant species of the Himalaya. Ability to endure stress enables this early successional species to colonize and persist on most inhospitable sites like, exposed quartzite rocks[4]. Density-diameter distribution of trees over large area indicated a marked influence on the forest structure, of the preponderance of even-aged stands of chirpine[15]. Thus the overall regional population structure resembles that of early successional forests (figure 4). The exploitative management practices, selective removal of broad-leaf species and other biotic activities have encouraged chirpine at the expense of broad-leaf species, particularly oaks[15].

BIOMASS AND PRODUCTIVITY

Chaturvedi and Singh[16] examined the biomass and productivity of an age series (16–128 years) of chirpine. Compared to average total biomass for 50-year-old trees of *Pinus sylvestris*[17] and *Betula* sp[18] (183–250 kg tree^{-1}), the biomass of chirpine of equivalent age (488 kg tree^{-1}) is considerably greater and comparable to that reported for 28 to 48-year-old trees of *Cryptomeria japonica* (about 102–421 kg tree^{-1})[19].

Compared to oaks and sal, the root: shoot ratio for chirpine (average 0.23) is lower but falls within the range of 0.16–0.28 reported for temperate trees[20–23]. However, the bole in chirpine trees, on average accounts for a conspicuously greater proportion of above ground biomass as compared to Central Himalayan oaks (72% vs 50–56%). The total photosynthetic: non-photosynthetic biomass ratio declined from 0.082 in 25-year-old trees to 0.016 in 103-year-old trees, indicating that about five times more relative accumulation of biomass occurs in non-photosynthetic parts

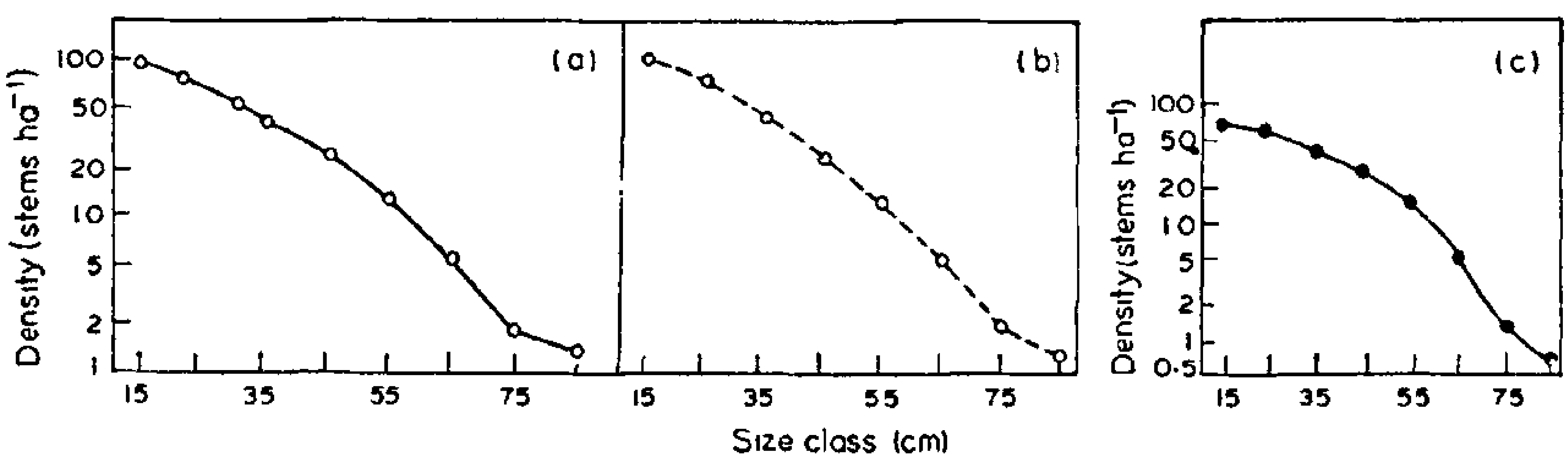

Figure 4. Density-diameter distribution curves; (a) For entire region, (b) for reconstituted samples according to the actual proportion of major species, (c) for all species in chirpine forest.

during the later years of growth. The relationship of mean production of bole and shoot to total leaf area and to roots indicated that there was a spurt in net production efficiency of the leaf surface and in nutrient supply efficiency of the root system during 36–39 years of tree age.

Being a successional community, the pure chirpine forest attains far lower biomass (about 200 t ha^{-1}) than the late-successional communities of the region (over 700 t ha^{-1})[24].

The net primary productivity of chirpine forest ranges between 18.5 and 24.5 t ha^{-1} yr^{-1}. These values are comparable with those of other forests of the region that occur below 2500 m and with the natural conifer forests of the temperate regions[25].

LITTER FALL AND DECOMPOSITION

The total annual litter fall ranges[26,27] between 2.2 and 3.9 t C ha^{-1} yr^{-1}, with majority of values being higher than 2.75 t C ha^{-1} yr^{-1}, the mean for the warm temperate forests[28], and compare with 3.9 t C ha^{-1} yr^{-1} for a *P. taeda* forest in south-eastern United States[27,29]. The tree leaf litter accounts for 82% of the total litter fall which is the upper limit of the range of 54–82% reported for the other Central Himalayan forests[27] and is towards the upper limit of the range of 40–85% reported for temperate forests.

Decomposition of chirpine litter is notably slower than that of other forest species of the region[5,30]. The chirpine leaf litter also supports a markedly smaller decomposer population and a fungal community which is distinct from those of other leaf litter species (table 4).

High lignin content (23% vs 9% in broad-leaf species like sal), high C:N ratio and lignin: N ratio (35 vs 15 in broad-leaf species like oak), and low litter moisture content of chirpine leaf litter retard its decomposition and lead to nutrient immobilization.

Table 4 *Comparison of chirpine litter decomposition with that of broad-leaf species of the Central Himalaya*

Litter	Chirpine	Several broad-leaf species
Rate of litter decomposition (% d^{-1})		
Leaf	0.126	0.150–0.253
Wood	0.060	0.067–0.122
Decomposer's population on leaf litter[a]		
Fungi (10^4 gm^{-1})	21.02	25.93–32.42
Bacteria (10^6 gm^{-1})	31.18	35.23–51.95
Actinomycetes (10^6 gm^{-1})	3.21	4.81–7.78
Micro-arthropod (individuals m^{-2})	1171	3259–7413
Community coefficient for fungi[b]	21.4	28–33.3

[a]average of 12 months; [b]average of coefficient values between the fungal community developed on a given leaf-litter species and on other species of the region.

WATER AND NUTRIENT CYCLES

The Himalayan catchments are sub-surface flow systems, and therefore, are particularly prone to landslips and land-slides[31]. A study comparing the oak and chirpine forest ecosystems receiving similar average gross monsoon rainfall (1264 and 1239 mm, respectively) indicated that through fall (as per cent of gross rainfall) was slightly lower (71%) in chirpine than in oak forest (78%), stem flow was also slightly lower (0.5% vs 0.7% in oak forest), and the canopy retention was higher in the chirpine forest (28.5% vs 21.5% in oak forest)[32]. Several workers[26,27,33–35] have contributed to our understanding of nutrient cycling in the chirpine forest (table 5). The Central Himalayan forest ecosystems represent an intermediate situation between the temperate and tropical forests of the world with regard to relative distribution of nutrients in soil and vegetal pool[35]. The per cent contribution of vegetation pool to the total amount of ecosystem nutrients in the chirpine forest is smaller than that for the Central Himalayan oak forests. In this respect, among the Central Himalayan forest ecosystems, the chirpine forest is closest to temperate forest ecosystems.

Substantial quantities of nutrients are reabsorbed (e.g. 51% N and 52% P) from old

Table 5 *Certain aspects of N and P budget and cycling in chirpine forest of the Central Himalaya. Site I represents average of four stands. Site II consists of one stand. Values in parentheses represent the percentages of the total nutrient in the ecosystems*

	Site I		Site II	
Compartmental pool (t ha^{-1})	N	P	N	P
Vegetation	1.106 (21.3)	0.145 (38.8)	1.161 (19.2)	0.132 (41.1)
Litter	0.131 (2.5)	0.011 (2.9)	0.110 (1.7)	0.011 (3.4)
Soil	3.964 (76.2)	0.218 (58.3)	4.794 (79.1)	0.178 (55.8)
Total in ecosystem	5.201	0.374	0.060	0.321
Accumulation in net production (t ha^{-1} yr^{-1})	0.143	0.020	0.164	0.015
Reabsorption before senescence (t ha^{-1} yr^{-1})	0.053	0.005	0.050	0.006
Net uptake from soil (t ha^{-1} yr^{-1})	0.091	0.010	0 113	0.012
Return in litter fall (leaf + wood)	0.054	0.005	0.057	0.006
Removal from canopy in through fall	0.004	0.0006	0.004	0.0005
Removal from canopy in stem flow	0.00006	0.00003	0.00006	0.00003
Root mortality	0.0009	0.0002	0.0008	0.0008
Total return (t ha^{-1} yr^{-1})	0.060	0.006	0.062	0.007
Retention in vegetation compartments (t ha^{-1} yr^{-1})				
Ratios:	0.031	0.004	0.051	0.005
Reabsorption: accumulation	0.37	0.33	0.31	0.11
Return: Vegetation pool	0.05	0 04	0.06	0.06
Litter: Litter fall	2.40	2.10	1.94	1.78

leaves of chirpine before abscission. This leads to 30–40% of N and P accumulations in net production (compared to 10% N and 8.5% P for oak forests) being derived from nutrients reused from previous years. Increased internal recycling of nutrients is an adaptation to nutrient-poor sites[36–38]. Though the litterfall is a major route of nutrient input to soil contribution of the precipitation is substantial, accounting for 17% N, 25% P, 39% K and 26% Ca in total annual input to soil[27]. The dry matter: N ratio in leaf fall of chirpine was 105, which is markedly greater than that for the broad-leaf species (e.g. 60 in oak). Thus the efficiency of litter production per unit of N is far greater in chirpine than in other species of the region. Vitousek[39] suggested that N efficiency of litter production varies as an inverse function of N available. The higher C:N ratio of chirpine litter not only reduces the rate of litter decomposition and increases the fuel-load on the forest floor, but also leads to immobilization of available N from the soil solution. This is a mechanism by which chirpine sequesters the available N and prevents re-invasion by high N-demanding broad-leaf species, including oaks[34]

SEASONAL PERIODICITY OF ECOSYSTEM ACTIVITIES

Largely because of the common influence of the monsoon, the seasonal periodicities of various activities in the chirpine forest are not different from those of other forest ecosystems of the region[5,40,41]. The evergreen trees show concentrated summer leaf drop immediately after the initiation of new foliage growth. Competitive stress for nutrients caused by the new foliage seems to induce the fall of old foliage. This strategy enables trees to develop a photosynthetically vigorous canopy dominated by new leaf population, in order to take full advantage of the monsoon period. Premonsoon rejuvenation of canopy allows the leaf to accumulate secondary chemicals which render it less palatable at the time of spurt of insect populations which coincides with the advent of monsoon.

The dry summer is also the period for peak flowering, however, in shrubs a secondary peak occurs during the rainy season (figure 5). From the standpoint of peak photosynthetic activity temporal variations are well marked between growth forms and also between groups of species of a given growth form (e.g. distinct herb populations in different seasons). Such a time separation characterizes niche-specialization of species and helps in community stabilization. Peak rate of litter decomposition occurs during the mid-rainy season and coincides with the peak in microarthropod population. The microbial population peaks later, in October, indicating that the microbes were more important when the substrate was more resistent.

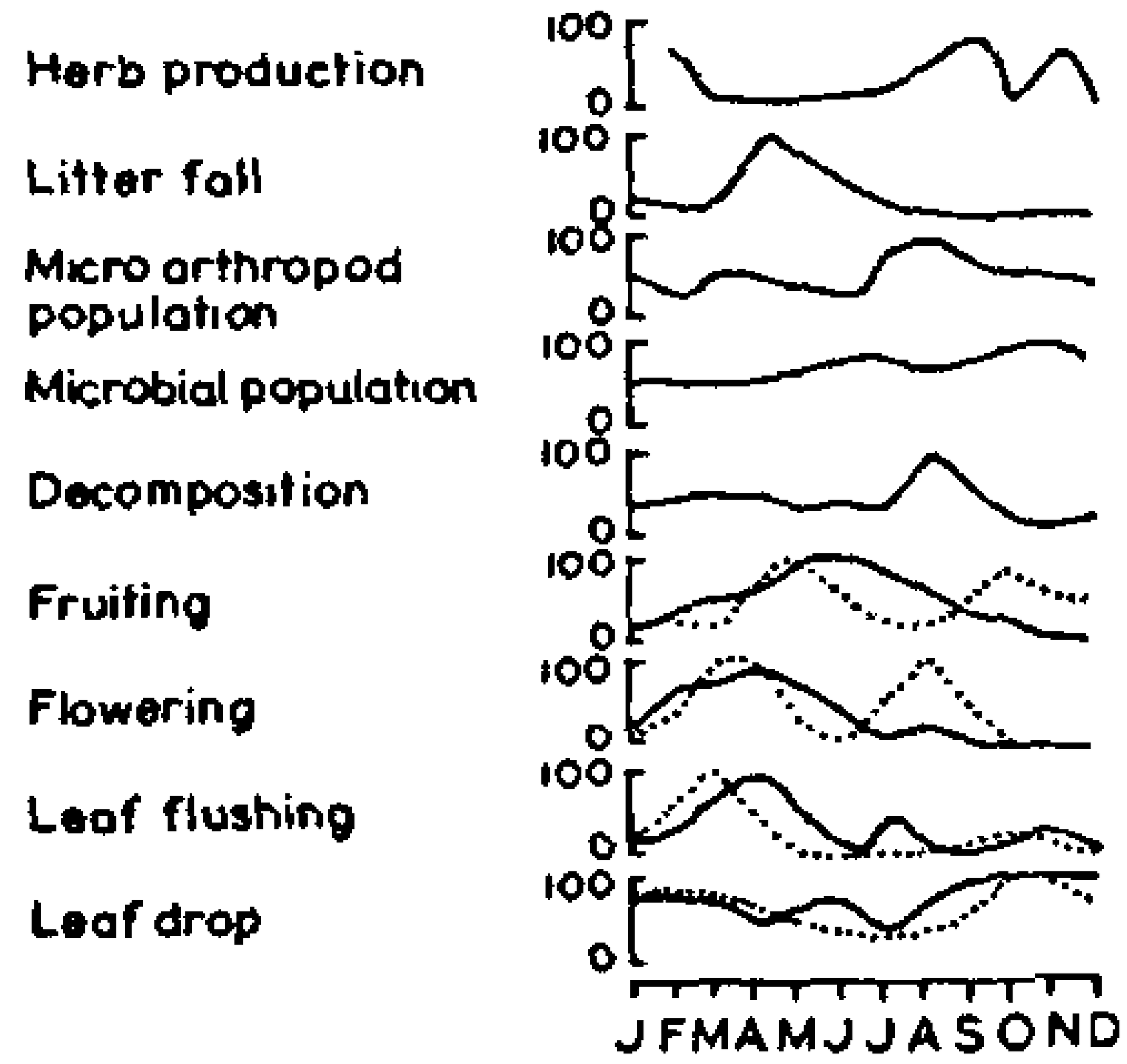

Figure 5. Periodicity of certain activities for chirpine forest within an annual cycle. Peak value in each case is taken as 100. Dotted curves are for shrubs and solid curves for trees. The actual peak values are herb production (g m^{-2}) 70; litter fall (g m^{-2})311; microarthropods (no. m^{-2}) 22922; microbial population (fungi 104 g^{-1}) 31.6; decomposition (wt. loss $month^{-1}$) 12.6; fruiting (no. of species) 4 for tree and 6 for herbs; flowering (no. of species) 3 for tree and 5 for shrubs; leaf flushing (no. of species) 4 for tree and 10 for shrubs; leaf drop (no. of species) 3 for trees and 9 for shrubs.

SUCCESSIONAL STATUS AND IMPLICATIONS OF CHIRPINE EXPANSION

Dudgeon and Kenoyer[42] opined that chirpine communities are unstable except for those in some special and dry habitats like quartzite formation, scarp slopes and schists, where they may form a xerophytic edaphic climax within a broad-leaf sclerophyll formation. Champion and Seth[1], on the other hand argue that between 1200 and 1800 m on southern aspects and on lower slopes on northern aspects, chirpine should be accorded climatic climax status. We consider chirpine an early successional community expanding widely, owing to natural and man made disturbances (landslides, erosion, burning, selective lopping and cutting of broad-leaf forests, etc), in natural region of banj oak (*Quercus leucotrichophora*). Due to its ruderal nature, chirpine is among the major colonizers of bare sites. However, apart from the ruderal characters, chirpine also exhibits several features attributed to stress-tolerant plants[14]. Combination of these two sets of strategies enabled chirpine to form semi-stable and extensive communities in the Central Himalaya where conditions are becoming increasingly disturbed and stressful. Other evidences indicating ruderal-cum-stress-tolerant status of chirpine are: (i) Continued fire protection checks the regeneration of chirpine owing to litter accumulation[43]. (ii) Ability to grow successfully on sites deficient in nutrients and water and occurrence of an efficient intra-plant nutrient cycling mechanism. (iii) Massive production of vagile seeds and possession of seed germination requirements which are compatible with early successional habitats. (iv) High leaf weight ratio and low root: shoot ratio in seedlings. These characters are generally attributed to ruderal plants. (v) Phenotypic responses to stress treatment, such as negligible changes in dry matter allocation to different plant parts, as attributed to stress-tolerant plants[14]. Since the perpetuity of large stretches of chirpine forest involves frequent burning and exploitation of biomass, this ecosystem oscillates continuously between reorganization and aggradation phases. During the former, total ecosystem biomass and nutrient pool are depleted, though the live biomass increases. Chirpine may still persist but accumulated effect of such depletions may ultimately limit the production and degrade the site. A situation of a smaller biomass and more open canopy would be less effective in withstanding the destabilizing physical forces, such as wind and soil erosion. Erosion can drive the ecosystem back to an extremely primitive stage from where recovery may be very slow. The expansion of chirpine forest also amounts to further increase in the proportion of even-aged forests and to the decrease of old growth, multistratal and diverse forests, required for various ecological and conservational purposes.

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NEWS

R. D. BIRLA AWARD FOR RESEARCH IN MEDICAL SCIENCES

The R. D. Birla award for research in Medical Sciences has been awarded to Prof. B. K. Bhachhawat, Head of the Department of Biochemistry, Delhi University, Delhi for his original work in the field of glycoconjugate. The award consists of a memento, a citation and an amount of rupees one lakh.

INDIRA GANDHI PRIZE FOR POPULARIZATION OF SCIENCE FOR 1986

Besides the regular awards, Indian National Science Academy announced a new award 'Indira Gandhi Prize for Popularization of Science'. The 1986 award was given to Mr. Surendra Jha, Editor of Science Age magazine from Bombay. The award was also given to Dr Mahidhara Nalini Mohan Rao, a radio physicist who is a well-known poet and writer on scientific topics in Telugu.

DHANWANTRI PRIZE OF THE INDIAN NATIONAL SCIENCE ACADEMY FOR 1986

Prof. P. N. Tandon, Head of the Neurosurgery Department, All India Institute of Medical Sciences, New Delhi has been awarded the Dhanwantri Prize (1986) for his outstanding contributions in the field of neurosciences, especially neurosurgery. The Prize is given once in five years to an eminent scientist for the outstanding work done in the country in any branch of medical sciences, including researches in drugs and methodology of ayurveda.