Proc. Indian natn. Sci. Acad. **B63** No. 3 pp. 151-173 (1997)

Forests of Himalaya with Particular Reference to Man and Forest Interactions in Central Himalaya*

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Migration of the Indian Plate northwards after the isolation from Madagascar about 80 million years ago, its collision with the Asian Plate and consequent underthrusting of the Indian Plate led to the rise of the Himalaya. Owing to its varied topography and climate, Himalaya supports a variety of forests up to the timberline. This forest wealth provides several important ecosystem services. However, in most parts, and particularly below the altitude of 2,200 m. often the forests are degraded and interspersed with deforested open 'blanks' and village settlements. Presently less than 5% of the geographical area of the Central Himalaya has forest with crown densities over 60%. The agroecosystems are centres of massive energy consumption and their viability depends on the supply of energy from the forest. Each kcal of agronomic yield (including milk) requires the expenditure of about 7 kcal from the adjacent forest in terms of fodder, fuel and leaf manure. Even with the massive subsidy from the forests, the agronomic production in Central Himalaya is sufficient for only 50% of the needs of the population. The harvest and forest clearing release 10.2×10^{12} g carbon annually. The net annual release of carbon to the atmosphere from the Central Himalaya amounts to 4.6×10^{12} g making the forest a source of CO_2 for the atmosphere instead of a sink. Although all types of the Central Himalayan forests have been under severe biotic stress during the last one century, man's onslaught on oak forest ecosystems has been particularly severe. The human interference has caused changes in species composition. The density-diameter distribution curve for all species in the entire region shows an overall convex appearance (largely second derivative negtive). Such a structure reflects predominantly an early successional forest. Pine has been invading the oak forest. Characteristics of pine (high nutrient withdrawal efficiency, high C:N ratio, nutrient immobilization in decomposing litter) enable it to invade and hold the site against future reinvasion of oak. Thus the diverse and multistratal forest is being converted into species-poor and little or unstratified forest. The Central Himalayan catchments are subsurface flow systems and are prone to landslides. The nonforested sites produce seasonal overland flow greater than the forested sites, and the soil loss is dependent on the volume of overland flow produced. The pine zone suffers from more landslides. Canopy of the multistratal forest (e.g. oak) is more protective to soil against rain-drop impact than single layered canopy (e.g. pine).

Key Words : Agroecosystem, Farming systems, Forest depletion, Forest structure, Forest types, Himalaya, Landslide

Introduction

Extending for about 2500 km from east to west, the Himalayan Arc covers more than 10 degrees of latitudinal expanse ($27\text{-}38^0$N), and is the cradle of major rivers of the Indian subcontinent. Altitude and climatic conditions vary greatly, resulting into highly diverse ecological

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* Paper presented at the Seminar on 'Plant Wealth of India', held at Gangtok, Sikkim on 4 May, 1994.

conditions and vegetation types. The temporal and spatial variations in physical conditions have resulted in markedly diverse phytogeographic stocks, characterized by a high degree of endemism (Singh & Singh 1987). For example, the eastern Himalaya including the northeast India expected to harbour about 8000 species of flowering plants is considered a cradle of flowering plants, and the western Himalaya having about 5000 species of flowering plants is the home of 800 endemic species (Rao 1994). The species combined and recombined in time to constitute varied forest communities, which range from species-rich broad leaf forests to alpine scrubs, beyond which large expanses of grasslands ensheath the mountain surfaces. These forests constitute immense plant wealth not only in terms of biodiversity but also in providing necessary ecosystem services, such as protecting wildlife and soil, sustaining man, stabilizing climate, optimizing water yield, and purifying air and water. The image one has of the dense, unbroken mantle of forests and of inaccessible valleys and ridges, is, however, shattered upon entering the Himalaya - in most parts, and particularly below the altitude of 2,200m, often the forests are degraded and interspersed with deforested open 'blanks' and village settlements.

Roughly the mountain ranges west of 77° E long, which include Kashmir, Punjab and Himachal Pradesh, fall within the western Himalaya, between 77-84° E including mountains of Uttar Pradesh and western Nepal, in the central Himalaya, and the ranges east to 84° E long including the mountains of north-eastern India and Assam, in the eastern Himalaya. Apart from giving a general background, in this presentation I will particularly focus on the state of forest in the central Himalaya, as impacted by man. This will also underline the important ecological services that the forest wealth has been providing to the mankind.

Evolution of the Forest Vegetation

Around 80 million years before the present (BP), the Indian Plate was isolated from Madagascar and between 80-40 million yrs BP it migrated 4000-5000 km northwards toward Asia (figure 1). This movement was remarkably rapid between 65-50 million yrs BP (15-20 cm yr^{-1}) and between 50-40 million yrs BP the Indian Plate collided with Asia (southern Tibet) when the movement rate decreased abruptly to a relatively constant 5 cm yr^{-1}, the rate at which India continues to penetrate into the rest of Asia. In the process of collision and underthrusting of the Indian Plate, some of the crust of Indian lithosphere was shaved off. These shavings constitute the Himalaya (Molnar 1986).

During the lower Miocene, tropical forests occurred on the southern slopes of the Himalaya. Palms of uncertain taxonomic identities were also present on the hill slopes. Subsequently during the upper Pliocene, a palm savanna, consisting of *Palmoxylon wadiai* and *P. jamuense*, with grasses, particularly *Poacites* developed on surfaces such as conglomerates of boulders in the Siwalkis.

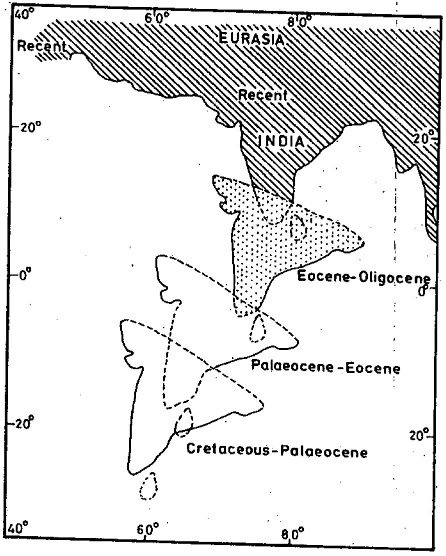


Figure 1 Movement of the Indian Plate and its collision with the Asian Plate (based on Olivet et al. 1987)

An 'incipient altitudinal zonation' of vegetation was established during the mid-Miocene on the Himalaya, then only 2200-2400 m high (Vishnu-Mittre 1984). Wet tropical forests on the lower slopes, wet temperate forests on the higher slopes, and wet sub-tropical types between the two, constituted the vegetational pattern.

The Miocene orogeny and possibly, planetary dynamics caused conspicuous climatic changes involving the pluvial cycles during the Pliocene, i.e.,the repetition of cold and dry, and warm and wet phases. Consequently, the vegetation was modified. Some forest types, such as tropical wet evergreen *Dipterocarpus-Anisoptera* forest, disappeared from the Western Himalaya, species from the extra-Himalayan regions arrived in large numbers. The proportions of different biomes, such as forests and steppe showed wide fluctuations. The steppe expanded during the cooling phase and forest during the warming phase. During the Pliocene, *Cedrus deodara,* a Mediterranean species, immigrated into the Himalaya. The period witnessed the arrival and expansion of *Pinus wallichiana,* following the decline of area under *Cedrus-Quercus* forest in the Kashmir valley. However, subsequently, *Pinus wallichiana* was replaced, as the earlier forest (*Cedrus-*

Quercus) with an additional member, *Picea* bounced back.

The final uplift of the Himalaya led to the development of subalpine and alpine zones. As in the present, over large areas, *Quercus semecarpifolia* and *Betula utilis* were the chief forest-forming species of the then subalpine and alpine belts. During the last glaciation (about 0.7 million B.P.), the steppe covered most of the areas above 3000m, but only for relatively short period. With the commencement of the subsequent warm-phase, *Q. semecarpifolia* and *Betula utilis* in relatively moist areas and *Juniperus* on dry hill slopes intruded upon the steppe. More recently, from about 8000-4500 BP, a warm phase which resulted in massive snow-melting was accompanied by the invasion of oaks (*Quercus* spp., of which *Q. leucotrichophora* was possibly the most important) into the chir pine (*Pinus roxburghii*) forests in the Central and parts of western Himalaya.

The uplift of these mountains caused three important ecological changes: (i) increase in the breadth of climatic gradient from a relatively uniform warm and humid stage (succeeded by cool-warm alternating oscillations) to that which now encompasses warm to extremely cold conditions with permanent snow cover at higher altitudes; (ii) continual but spasmodic and explosive surface modifications owing to the tectonic stress; and (iii) creation of mountain barriers which influenced the distribution pattern of rainfall. The widening of the climatic gradient provided opportunities to several species to express their fullest range of elevational adaptability. Distributional ranges of other species were segregated along the altitudinal gradient. For example, during the later Pliocene there existed in the Kashmir valley at about 1700m a mixed vegetation comprising species which now are widely separated in their elevational ranges (e.g., *Quercus glauca*, now occurring below 1800m, and *Betula utilis*, around 3000m, and *Litsea elongata*, occurring around 2000m, and *Quercus semecarpifolia*, above 2500m), grew together. This may indicate that either the climatic requirements of these species were different in the geological past from those they exhibit now, as suggested by Vishnu-Mittre (1984), or those earlier taxa were paleo-ecotypes of the modern species, if identification of these species were unquestionable. It is also possible that the population centres of these species were dispersed with time as a result of competitive interactions superimposed on the evolutionary changes induced by the changing gamut of environmental factors.

Thus, the tropical wet evergreen forests now restricted to the eastern part of the Himalaya, occurred throughout east-west arch of the Himalaya in the geological past. The Miocene flora was largely replaced subsequently by the modern flora, which possibly constituted much of the present flora. Quite a few modern Himalayan species are suggested to have emerged from the precursors in the Miocene tropical flora. Thereafter, the changes that followed were limited to changes in the area of a species and their relative importance in various communities.

Drastic modification of mountain surfaces due to removal and deposition of debris during the various phases of rise of mountains destructed the original vegetation in varying expanses and prepared ground for ecological succession until another spell of massive destruction occurred. Thus, there occurred repeated destruction and replacement of late successional communities by early successional ones, giving rise to a mosaic of communities of varying successional levels on the face of the mountains (Singh & Singh 1987)

Today along the elevational gradient from 300 to 3600m, 11 forest formation-types ranging from submontane broadleaf ombrophilous forest to very high-montane scrub can be recognised (Singh & Singh 1987). These together with the vegetation-types recognised by Champion and Seth (1968) are given in table 1.

Table 1 *Formation-types in the Himalaya recognized by Singh and Singh (1987). The vegetation-types recognized by Champion and Seth (1968) are given for comparison*

Formation-type	Equivalent groups, subgroups and categories of Champion and Seth (1968)
Sub-montane broadleaf ombrophilous forest	Northern tropical wet evergreen forest (IB) and mesic part of northern tropical semi-evergreen forest (2B), lower part of northern sub-tropical broadleaved wet hill forest (8B)
Sub-montane seasonal broadleaf forest	Drier part of 2B and moist parts of the mixed deciduous forest (3C/C_3)
Sub-montane broadleaf summer-deciduous forest	Northern dry mixed deciduous forest (5B/C_2), and dry Siwalik sal forest (5B/C_{1a}), moist mixed deciduous forest (3C/C_3)
Low-montane needle-leaf forest with concentrated summer leafdrop	Sub-tropical pine forest (10C/C_1)
Low-montane sclerophyllous evergreen broadleaf forest	Sub-tropical dry evergreen forest (10C/C_1)
Mid-montane broadleaf ombrophilous forest	East Himalayan wet temperate forest (11B/C), higher part of northern sub-tropical broadleaf wet hill forest (8B)
Low-to mid-montane hemi-sclerophyllous broadleaf forest with concentrated summer leafdrop	Lower western Himalayan temperate forest (12/C_1) and upper west (12/C_2) excluding coniferous categories and deciduous category
Mid-montane needle-leaf evergreen forest	Coniferous categories of lower western (12/C_1) and upper west (12/C_2) and east Himalayan moist temperate forest (12/C_3)
Mid-montane winter-deciduous forest	Moist temperate forest category of lower western Himalayan temperate forest (12/C_{1c})
High montane mixed stunted forest	Subalpine forest (14)
Very high-montane scrub	Alpine scrub (15)

Forest Cover in Central Himalaya

For the Central Himalaya, direct ordination of species importance values on elevation gradient shows a typical altitudinal pattern of vegetation composition (figure 2). Considerable overlaps in the distribution of species populations indicate a gradual change in the vegetation along the elevation gradient. Evergreen species with leaf longevity of one year or just above one year (*e* type) generally dominate the forests throughout the elevation gradient. Only towards the upper limit of the altitudinal gradient, deciduous species (e.g. *Betula utilis*), and evergreen species with leaf longevity of several years (*ee* type) (e.g. *Abies pindrow*) share dominance with the *e* type evergreens (Singh & Singh 1992). Both, species richness and alpha diversity (i.e. within stand) decline away from the intermediate elevations, where environment is presumably most favourable (Singh et al. 1994). This pattern also occurs regionally in eastern North America (Monk 1967), although not in all temperate forests (Zobel et al. 1976). Beta-diversity, a measure of species compositional change along environmental gradients, was maximum between 2000-3000m elevation (Singh et al. 1994), indicating huge variation in habitat and a mixing of subalpine and temperate flora.

In general, the biomass and net primary production of the intact central Himalayan forests tended to be on the higher end of previously reported ranges for physionomically similar forests (Singh & Singh 1992, Singh et al. 1994). The

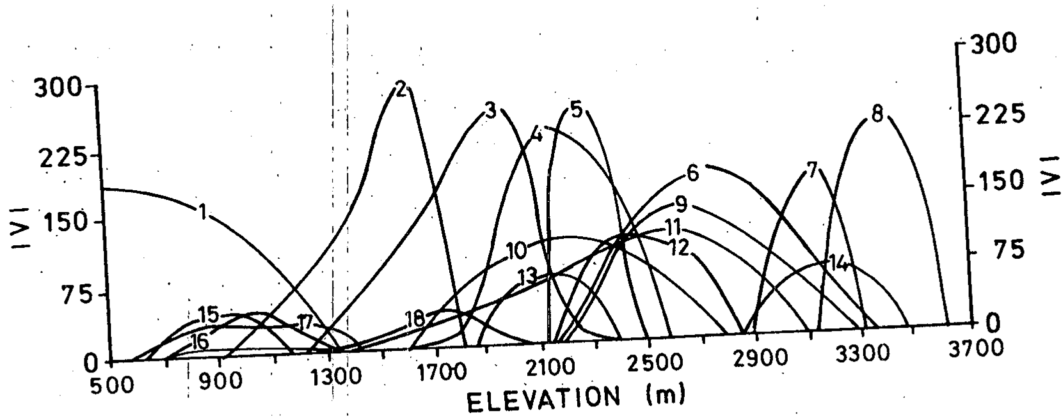


Figure 2 The IVI (Importance Value Index) of major tree species along an elevation gradient of the Central Himalaya. The higher extreme of the elevational gradient represents the timberline. 1. *Shorea robusta*, 2. *Pinus roxburghii*, 3. *Quercus leucotrichophora*, 4. *Quercus floribunda*, 5. *Quercus lanuginosa*, 6. *Abies pindrow*, 7. *Betula utilis*, 8. *Rhododendron campanulatum*, 9. *Quercus semecarpifolia*, 10. *Alnus nepalensis*, 11. *Rhododendron arboreum*, 12. *Acer mono*, 13. *Aesculus indica*, 14. *Rhododendron barbatum*, 15. *Mallotus philippensis*, 16. *Toona ciliata*, 17. *Syzygium cumini*, 18. *Persea odoratissima* (after Singh & Singh 1992)

intact forests have been a major sink for atmospheric carbon dioxide.

Commercial forest exploitation and overuse related with agricultural activities are the major causes of the depletion of forest cover. Presently less than 5% of the geographical area has forest with crown densities over 60% (table 2). Another ecosystem type, the alpine grassland is still reasonably intact, although it is heavily affected by grazing from domestic animals migrating from the agricultural zone. This accounts for additional 15% area. Only these two types form the protective system in terms of Odum (Odum 1983). The remaining 90% area shows heavy but varying levels of degradation. This vast fraction is mainly divisible into (i) partly protective systems, consisting of new growth forest of early successional species; (ii) natural non-biological systems of permanent snow cover and bare rocks at elevations about 4000-5000m; (iii) degraded systems, mostly totally deforested and excessively vulnerable to erosion and destabilizing forces of nature; and (iv) productive cropland systems.

Forest Exploitations

Although all types of the Central Himalayan forests have been under severe biotic stress during the last one century, man's onslaught on oak forest ecosystems has been particularly severe. Oaks, being good source of fuelwood, fodder, agricultural tools, and the climate of the oak zone being favourable for man, attracted human settlements most. Thus the zone of human settlements and oak zone broadly overlapped and further, the organized forestry showed a conspicuous bias against the oak forest ecosystems. Singh and Singh (1986) have given a chronological summary of exploitation of

Table 2 *Landuse for the Central Himalayan landscape (based on Singh et al. 1984a, and Singh & Singh 1991)*

System category	Per cent of geographical area
Protective	9.3
Forests with crown density above 60%	4.4
High altitude meadows	4.9
Partly protective	24.3
Forests with crown density 40-60%	15.1
Forests with crown density 20-40%	9.2
Degraded (mostly blanks converted from forests)	22.3
Natural nonbiological	26.4
(Permanent snow and bare rocks)	
Productive (mostly cropfields)	15.7
Urban-industrial (including roads)	2.0

oak forests. Most of the human population of this region originally immigrated from plains of Uttar Pradesh, Maharashtra and Gujarat (Atkinson 1882), where for quite a long period forests had not been a significant part of the landscape. The earliest settlers destroyed forests locally, possibly in quantities far greater than their basic requirements, as forests were alien to their culture. During the pre-British period (before 1816), the population was low and oak and other forests were in plenty to support the forest-based agriculture and to meet the demands of construction, and cottage industries, such as iron smelting, charcoal-making and mining at subsistence level. In order to enhance the revenue, immediately after their arrival in 1816, the British decided in 1823 to expand agricultural activity which had temporarily broken down under the military pressure of Gurkhas and Rohillas. Old fields where secondary succession had advanced were again cropped and new cropfields were carved out on forested slopes. By the late 1860s in Kumaun the cultivated land had more than doubled (Tucker 1983). The 1840s and 1850s constituted the first era of large-scale uncontrolled deforestation to meet the timber demands of the expanding cities on the Indo-Gangetic Plains. The commercial exploitation of forests thus continued along with the expansion of agriculture. Continued population growth has led to more farming, and as a result the area under cultivation increased at a rate of 1.5% yr^{-1} and the cattle population at a rate of 0.18% yr^{-1} (Shah 1982).

It is not possible to estimate the rate at which village forests (all the forest types which villages could use) became inadequate to meet the demand of subsistence economy of the villagers. It appears that they became inadequate by the beginning of the 20th century, when most of the forests in the hills had been categorized as reserved. This led to a keen and perpetual struggle between the people and the Forest Department, and politicised movements against the restrictions on the use of forest resources were launched by the people in different parts of the Central Himalaya. The latest being the "Chipko Andolan." In the forest available to villagers no silvicultural practices were used before Independence, and after Independence only a few attempts, albeit unsuccessful, were made to revive them.

Farming Systems

The population of the Indian Central Himalaya was 3.81×10^6 in 1971 and it increased to 4.81×10^6 in 1981 (Anonymous 1981). Thus the increase was at a compound rate of about 2.28% yr^{-1} (Shah 1981). About 82% of the population is rural with 90% of them being engaged in agriculture. The density of population averages 89 persons/km^2 and is highest (120-150 persons/km^2) between 600-1800m elevations. About 42% people are in the age group of less than 15 years and 52% in the age group of 15-59 years.

There are three basic farming systems; all are livestock based and represent specific human answers to problems of

Plate I Figures 1-4 **1,** A multistratal intact Oak (*Quercus leucotrichophora*) forest in the Central Himalaya; **2,** A single-storey chirpine (*Pinus roxburghii*) forest without a shrub layer, in the Central Himalaya; **3,** Pine (*Pinus roxburghii*) encroaching an oak (*Quercus leucotrichophora*) forest in the Central Himalaya; **4,** An alpine grassland dominated by *Danthonia Cachemyriana* at about 3900m elevation in the Central Himalaya climate, topography and resource base. These are, livestock farming, mix livestock-crop farming and mix crop-livestock farming; representing respectively, three different ways of life, nomadism, semi-nomadism and settled agriculture. The nomads, exemplified by 'Gujjars,' have no permanent land base, their huts are scattered in high vallleys where they stay in summer to graze their cattle in the lush, high altitude meadows and migrate with their herds to lower elevations in winter (Bose 1972). The semi-nomadic way of life is exemplified by 'Gaddis', whose permanent villages are located in the valley bottoms where they engage in agriculture. During summer, while their women and children remain behind in the villages, men roam with their sheep and goats in the higher meadows and return to the villages with the onset of winter (Bose 1972). A somewhat similar interseasonal, transelevational migration is also practiced by the 'Bhotias' (Bhandari 1981). The crops grown by these semi-nomadic high altitude farmers are mostly pseudo-cereals (*Amaranthus* spp., *Fagopyrum esculentum, F. tataricum*), hull-less barley (*Hordeum himalense*), and potato (*Solanum tuberosum*) and local varieties of wheat (*Triticum aestivum*).

The settled agriculture is most common between 1000-2500m elevations. The farming is still cattle-based. A majority of cultivation is rainfed. Cropping intensity varies from three crops/year in irrigated fields to three crops per two successive years in rainfed fields. Among cereals, finger millet (*Eleusine coracana*), maize (*Zea mays*), paddy (*Oryza sativa* var. *indica*) and wheat are most common, and among vegetables, potato is the most prevalent crop. In this region there may be 17.6 people ha^{-1} of cultivated land compared to 2.3-5.8 in the rest of the State of Uttar Pradesh (Moddie 1981). Consequently, this altitudinal range (1000-2500m), also called the middle mountains, has experienced most severe ecological degradation. In this article I will specifically deal with the middle mountain situation of the Indian Central Himalaya, and illustrate how have forests been subsidizing crop production.

Impact of Agriculture

The agroecosystems in Central Himalaya are centres of massive energy consumption and their viability depends on the supply of energy from the forest. Figure 3 represents the energy flow among the most important components of the average Central Himalayan agroecosystem. A complete inventory was made of all inputs and outputs. The inputs included (a) labour in terms of animal-days and man-days, (b) fertilizers in terms of quantities of manure and chemicals, and (c) seed. The outputs included (i) yield of edible crop products; (ii) yield of crop by-products; and (iii) milk.

In this model the agroecosystem is composed of three major components: humans, cattle and cropland (Pandey & Singh 1984). Cattle are used to process energy from the forest (through fodder), to supply manure for the cropfield, draft animal power to cultivation, and milk for

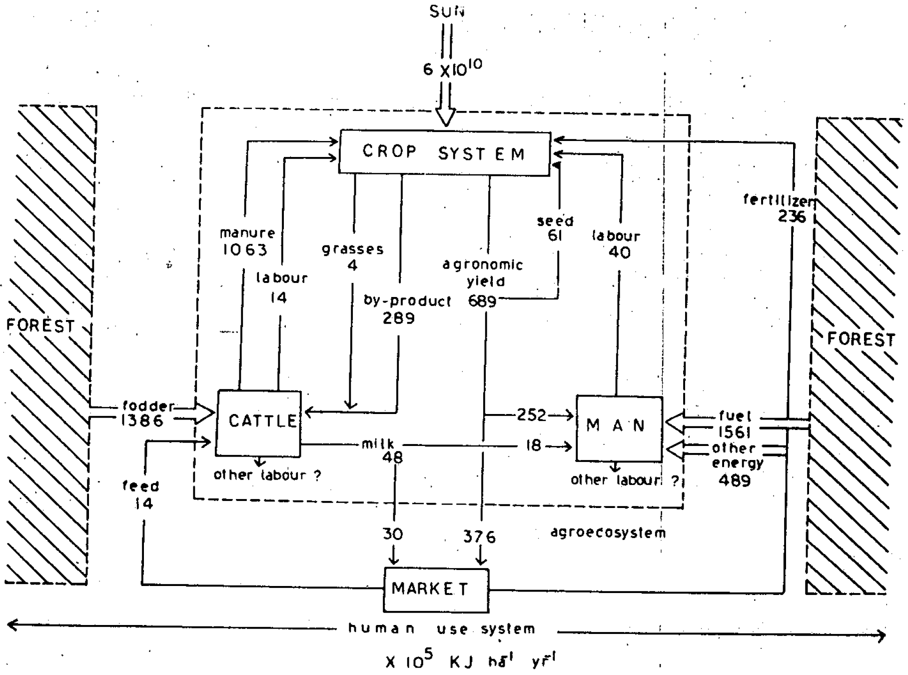


Figure 3 Average energy flow through the human use system for Central Himalayan villages. All values are X10^5 KJ/yr/ha of cultivated land. Solar radiation is in 6x10^{10} KJ/yr/ha. "Other energy" represents imported food from the market (based on Pandey & Singh 1984) and Singh et al. 1984a).

human consumption. Forests also provide fuel. Additional energy is imported from the market as animal feed, chemical fertilisers and supplementary human food. Export to the market includes milk and vegetables. The forest, the agroecosystem and the market thus constitute the human use system. Each kcal of agronomic yield (including milk) requires the expenditure of about 7 kcal from the adjacent forest in terms of fodder, fuel and leaf manure. Even with this massive subsidy from the forests, the agronomic production in Central Himalaya is sufficient for only 50% of the needs of the population (Singh et al. 1984a). The remaining half comes from the adjacent Gangetic plains; in addition the cropland soils are considerably degraded, as evidenced by the soil organic carbon being only one-fourth to one-eighth that of the forest soil from which they were derived.

According to various estimates, about 15 ha of forest in the existing condition is required to support one ha of cultivation on a sustained basis, whereas the present cropland: forest area ratio is about 1:2 (Singh et al. 1984a, Pandey & Singh 1984). Thus the carrying capacity of the forest has already been far exceeded. This has resulted in overgrazing of the forest floor, destroying the seedlings and young plants of trees and thus inhibiting forest regeneration. According to Shah (1982), if the current rate of deforestation were to continue the total remaining forest resources of the Central Himalaya would disappear by the middle of next century.

The broad-leaved trees are repeatedly lopped for leaves and firewood, leading to their gradual disappearance. The oak (particularly *Quercus leucotrichophora* and *Q. floribunda*) supplies lead fodder for cattle, wood for fuel and timber for farm implements. Its soil is rich in humus and N, and is often used as supplemental manure. Farmland has frequently extended into oak forest, and with increasing demands for fodder and firewood, its trees are repeatedly lopped, seed output is reduced, pressures from seed predators such as the flying squirrel (*Ptaurista petusista* var. *albiventer*) and langur (*Presbytis entellus*), and pests (*Calandra glandium*), increased on an already diminished seed crop, and the scanty young regeneration is grazed by livestock and rabbits (*Lepus nigricollis*) (Singh et al. 1984a, Saxena & Singh 1984). As a result this forest is fast disappearing.

With the destruction of the forest, habitat for wildlife is shrinking, and such species as the flying squirrel, chir pheasant (*Catrus wallichi*), blue-winged minla (*Minla cyanouroptera*), barking deer (*Montiacus muntiack* var. *vaginalis*), wild pig (*Sus scrofa* var. *cristattus*), goat antelope (*Nemorphaedus goral* var. *goral*), red hill fox (*Vulpes bengalensis*), black deer (*Solenarctos thibetanus thibetanus*) and leopard (*Panthera perdus* var. *fusca*) have become rare in the area and some of them are endangered (Singh et al. 1984a).

Low agricultural productivity forces people to migrate elsewhere in search of livelihood. The men leave the villages to work in the urban areas, while the women stay behind to fulfil the traditional male roles as well as their own. Consequently, the male: female ratio in the villages is 1:1.4 for the working age group of 15-50 years; and during the peak agricultural season the women have to work as long as 11 hrs a day; 7 hrs for cultivation and animal husbandary, 3 hr for household activities and 1 hr for child rearing (Khanka 1983). With the decreasing forest cover, the ratio of energy expended in direct agricultural activity to energy expended in fodder and fuel collection is increasing every year as women have to go farther and farther afield to gather wood and forage. Because of small land holdings, farmers cannot grow forage crops in their field. Before long increasing amounts of dung will be burned as fuel and for lack of manure the productivity of the land will decline further. The final consequences are a highly degraded physical environment and a population unable to earn a living.

Consequences of Forest Cover Depletion

The consequences of the forest cover depletion are many; three of them are considered here.

Source for Atmospheric CO_2

Determination of whether forests are a net source or sink for CO_2 requires knowledge of the forested area and

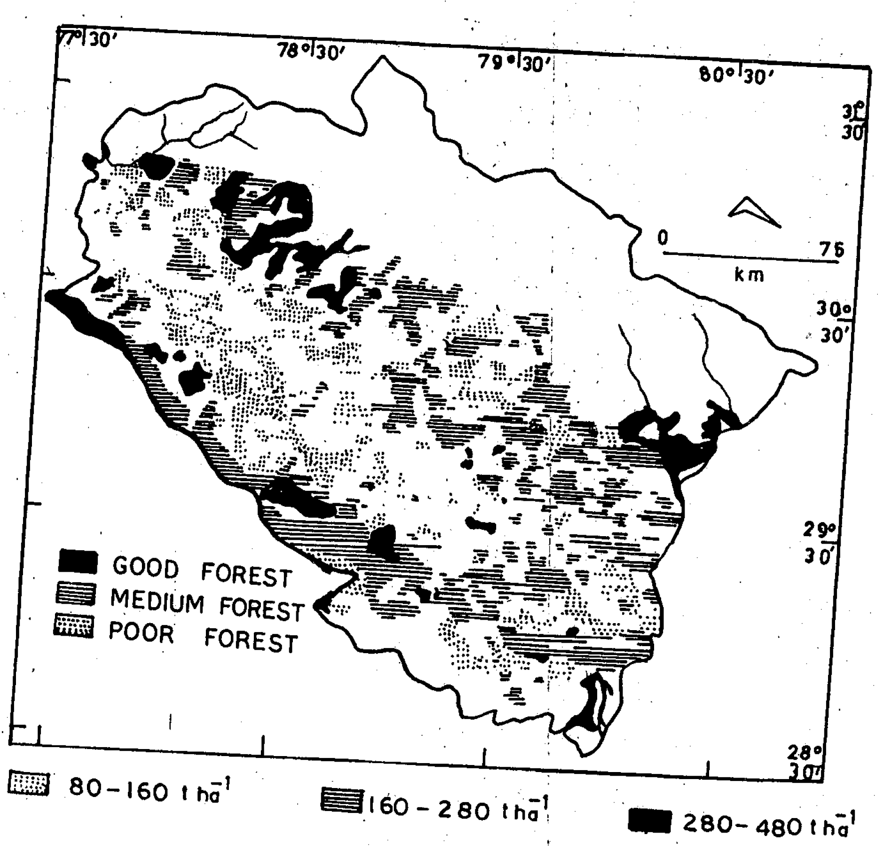


Figure 4 Forest biomass map for Central Himalaya

biomass, and the rates of net primary production and exploitation. Data on biomass, net production, litterfall, and litter decomposition, of some 17 forest sites have been collected and synthesized (Singh et al. 1985). Landsat images and aerial photographs have been used to assess the forested area and biomass. Utilizing these data and the recorded forest exploitation rates, it was possible to assess the storage and release of carbon from the Central Himalayan forests.

Utilizing the false colour composite Landsat 1 images on bands 4, 5 and 7, for the year 1972, the area was classified into non-forested and forested land (table 2). The forested land was further divided into three categories, good, medium, and poor forests corresponding to ≥ 60%, 30-60%, and 10-30% crown-cover. Standing biomass measured on reference sites was related to crown-cover interpreted from aerial photographs through logarithmic equations for each forest type. Subsequently, aboveground biomass ranges were substituted for crown class-values on the interpreted map (figure 4).

Estimates of litter mass, biomass of herb and shrub layers, and soil carbon (to a depth of 30 cm), from representative sites, were directly extrapolated for the three categories of forest. Annual tree net production averaged 6% of the total tree biomass, and the annual net production of shrub and herb layers was 75% of the total shrub plus herb biomass. Litterfall plus root mortality averaged 53% of the total net production. This amount sustains the soil processes and satisfies the soil respiratory needs. Thus, the net accumulation of biomass over the annual cycle was 47% of the net production. These factors were used to calculate the ranges in net production and net accumulation of carbon (table 3).

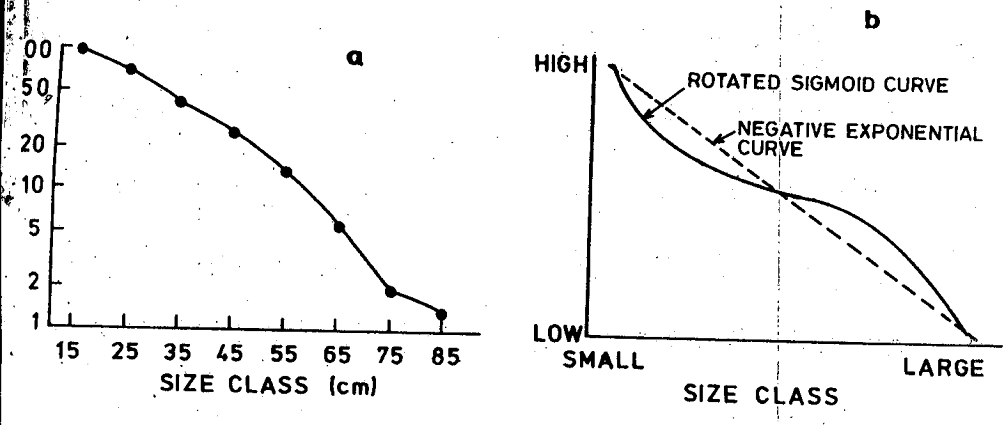
Forest covers about 14.6×10^3 km^2 of the Central Himalaya and stores 241.8×10^{12}g C (table 3). Carbon fixation in net production is 11.8×10^{12}g/yr and the net accumulation is 5.6×10^{12} g/yr. The main net source of vegetative carbon to the atmosphere is clearing of forests. The harvest and forest clearing for agriculture release is 10.2×10^{12} g carbon annually. Thus, the net annual release of carbon to the atmosphere from the Central Himalaya amounts to 4.6×10^{12} g. It is clear that, because of over-exploitation, the Himalayan forests have become a net source of CO_2 to the atmosphere (Singh et al. 1985).

Change in Forest Composition

Saxena et al. (1984) analysed the forest structure of the Kumaun Himalaya

Table 3 *Carbon dynamics for total forest of Indian Central Himalaya for 1972-73 (based on Singh et al. 1985)*

	Range	Area-weighted average
Standing crop ($\times 10^{12}$ gC)		
Above ground tree	87.4x201.8	144.6
Below ground tree	20.5-47.4	33.9
Total tree	107.9-249.2	178.6
Shrub+herb	0.9-2.1	1.5
Total vegetation	108.8-251.3	180.1
Litter	1.7-4.0	2.8
Soil	35.6-82.2	58.9
Total (overall)	146.1-337.5	241.8
Net production ($\times 10^{12}$ gC/yr)		
Tree	6.5-14.9	10.7
Shrub+herb	0.7-1.6	1.1
Total	7.2-16.5	11.8
Net accumulation ($\times 10^{12}$ g C/yr)		
Vegetation	3.4-7.7	5.6
C release due to forest clearing ($\times 10^{12}$ gC/yr)		
Above ground	4.8-11.1	7.9
Below ground	0.4-0.9	0.7
Agricultural expansion	1.0-2.2	1.6
Total	6.2-14.2	10.2
Net release	2.8-6.5	4.6



e 5 **(a)** Density-diameter distribution curve for all species of the entire region of the Kumaun Himalaya d on Saxena et al. 1984); **(b)** *d-d* curves expected for uneven-aged and old stand equilibrium forests d on West et al. 1981)

ugh semi-logarithmic density-eter distribution (*d-d* curve) (figure Uneven-aged forests dominated by ers yield an over-all straight line ative exponential curve) *d-d* ionship, and predominantly uous forests at old stand equilibrium ay a rotated sigmoid curve, having teau in the *d-d* distribution near the diameter range (West et al. 1981, e 5b). A *d-d* curve with an overall ex appearance (largely second ative negative), as found for all es in the entire Central Himalayan n (figure 5a), is a result of exploitation ices, which maximize the even-aged acter and the proportion of mediate-aged stands. Biotic rbance (especially grazing and ient lopping) is such that eration is adequate only in young cted stands, and it is poor in older s. Obviously, the relatively shade-tolerant oak species are failing to regenerate, while the shade-intolerant species (such as pine) are profusely regenerating in young forest stands where canopy shade is not intense. The overall total regional forest structure thus gives an impression of a "pioneer" or early successional forest. Extinctions are thus possible among the slow growing shade-tolerant tree species and among organisms with life cycles tied to these trees. The fast growing trees have less dense wood than slow growing shade-tolerant trees, and therefore with the increase in populations of fast growing species which also have high turnover rate, the primary forests may increasingly become a net carbon source (Phillips & Gentry 1994). This has implications for future global change.

The exploitative management practices and the biotic stress exerted by the hill population (grazing, lopping, felling for fuel) in relation to oak species have encouraged the pine in various ways. Much of the area now occupied by pine was originally under the potential natural vegetation of oaks. Conversion of oak forests to pine is still proceeding, perhaps on a still large scale. In 1978, in the Naini Tal forest division alone, at least seven forest compartments originally included in the fuel (oak) working circle were transferred to the pine working circle (Dwivedi & Mathur 1978). Compartmetal histories exhibit several other examples of increasing preponderance of pine (table 4). When pine invades the site, it holds it against a possible reinvasion of oak through such adaptational strategies as well developed internal nutrient cycling, nutrient immobilization in decomposing litter, and fire-promoting characteristic (Singh et al.1984b).

The high, dry matter: nitrogen ratio of litter and high, C : N ratio of the soil in pine forest reduce the rate of litter decomposition and increase the fuel load on the forest floor. In addition, the

Table 4 *Increase in the population density of* ***Pinus roxburghii*** *in 20 predominantly pine forest compartments selected at random. Density values are in stems >10cm diameter per hectare (based on Saxena et al. 1984)*

Compartment number and block	Density in the base year	Density in 1978
1, Gagar*	16.0	234.4
3, Gagar*	0.6	113.1
4, Gagar*	10.0	86.6
6, Gagar*	24.3	102.8
10,Gagar**	59.1	226.5
11b, Gagar**	61.6	165.4
6a, Jangliya*	24.6	189.4
6a, Lohakhan*	11.0	134.2
8a, Lohakhan*	9.0	187.9
10b, Jakh+	26.1	149.3
13a, Patlot+	121.7	279.2
14. Patlot+	53.2	161.2
6, Raikuna*	22.7	189.1
3a, Bhowali**	77.8	160.8
5, Bhowali*	21.4	253.0
10b, Bhowali**	21.8	129.2
11, Bhowali*	46.6	65.8
2a, Dolmar**	24.4	56.8
26, Garnath**	11.9	196.0
31, Sukhatal**	14.9	341.9

*Base year 1927; **Base year 1952; +Base year 1938

may tend tow

decomposers of litter of a high, dry matter: nitrogen ratio may immobilize available N from the soil solution. Weight loss and the N concentration of residual litter of pine and oak enclosed in litter bags and placed on respective forest floors were studied for one yr. Figure 6 indicates a marked immobilization of N in decomposing pine litter. The plant-available N pool in the soil at any point in time is usually only a small proportion, of total N and its immobilization by microbes may intensify the N shortage in nitrogen-poor ecosystem. This is the main reason why pine is able to resist reinvasion by oaks. Low N availability caused by the immobilization by microbes may lead to increased efficiency of N use and production of litter with still higher dry matter: nitrogen ratio. Recurring fires in the pine forest lead to marked N losses through volatilization, augmenting the N shortage.

Oak has a relatively high demand for N and cannot succeed in N-poor soil. Through the return of N-rich litter and rapid mineralization, oaks maintain high soil fertility. Heavy lopping of oaks for fodder and cutting for fuel cause large canopy gaps and reduce leaf fall and hence N return, making the conditions suitable for invasion by pine.

The retention of N is specially pronounced in the oak forest. Thus, in this forest the N-pool may be more severely altered by deforestation. In such systems, replacement of N reserves will be essential to avert a long-term decline in productivity following deforestation. This also raises the question whether or not the impending global warming will exacerbate the change in forest composition.

Water and Sediment Movement

Protection of soil and regulation of water yield are among the major functions of forest. Deforestation has exacerbated the problem of landslides and soil erosion. The river Ganga carries 340 million tons of sediment yr^{-1} (Valdiya 1985). The present rate of erosion in the catchment area of the Himalayan rivers (100 cm 1000^{-1}yr) is five times higher than the rate prevailing in the past 40 million yrs (21cm 1000^{-1} yr.) (Menard 1963). The construction of 44000 km long road in the Himalayan region generated 2650 million m^3 of debris. Each year 550m^3 of debris per km of the road is produced by landslides and rock falls, causing 24 million m^3 of sediment to slide down the slopes killing vegetation and choking mountain springs (Valdiya 1985).

The Central Himalayan catchments are subsurface flow systems and are prone to landslides (Singh et al. 1983). Pandey et al. (1984), Loshali (1989) and Loshali et al. (1990) have assessed the overland flow and soil loss from experimental micro-watersheds under forested, and landslide-damaged sites. The peak rate of discharge occurred during July. Average seasonal overland flow varied from 9.6-16.5 mm which accounted for, respectively only 0.49-0.84% of the total incident rainfall, indicating that a majority of water flows beneath the surface

Table 5 *Overland flow and sediment output in forested and damaged sites*

Site	Gross rainfall (mm)	Overland flow (mm)	Overland flow (%)	Soil loss (kg/ha)
Forested	1965.77	9.647	0.491	26/477
Landslide-damaged (without channel)	1965.77	16.498	0.839	81.890
Landslide-damaged (channel-dominated)	1965.77	206.680	10.514	9987.098

through the soil body - a characteristic of subsurface flow systems (table 5). In such systems, water can be transmitted laterally to the channel via a sub-surface 'quick flow' process which can produce typical storm by drographs in the main streams. Subsurface water may also emerge down the slope and when it joins a rill, cut, or wider track, it may initiate a gully. The nonforested sites produced seasonal overland flow greater than did the forested sites. Soil loss was dependent on the volume of overland flow produced. The average seasonal soil loss ranged from 26-82 kg/ha. In the landslide-damaged site dominated by surface channels, the overland flow (10.5% of incident rainfall) as well as sediment movement (9987 kg/ha) increased dramatically. In the deforested site, the soil-mass, devoid of structural integrity due to lack of organic matter inputs and deprived of biotic control by roots, gets detached easily leading to massive soil loss through siltation and accelerated landslides (Singh et al. 1983). With the nearly complete loss of soil cover and/or collapse of the structure of the soil body, aquifers may be disrupted and the system may tend towards surface flow, causing the springs to dry up. Valdiya and Bartarya (1991) have found several springs to have dried up in the catchment of river Gaula in Kumaun. This underlines the importance of maintaining the watersheds under well-stocked, deep rooted vegetation.

With the loss of protective forest cover, soil erosion and landslides are thus becoming more severe in the mountains; moving increasing amounts of silt and flood downstreams. The relationship of the frequency of active landslide with forest types and land-use was examined using maps interpreted from black-and-white aerial photographs (1:40, 000) taken in 1973 for the hilly parts of Naini Tal and Almora districts (Tiwari et al. 1986). The active landslide areas are distributed across all major land-uses. Most active landslide areas have a preponderance of *P. roxburghii* (<40% crown cover), followed by agricultural land, wasteland, barren land, and scrub (figure 7). The broadleaf forests show minimal signs of active landslides. Quantitative profile structures of these forests indicated a greater effectiveness of multistratal broadleaf forests in soil conservation as compared with mostly

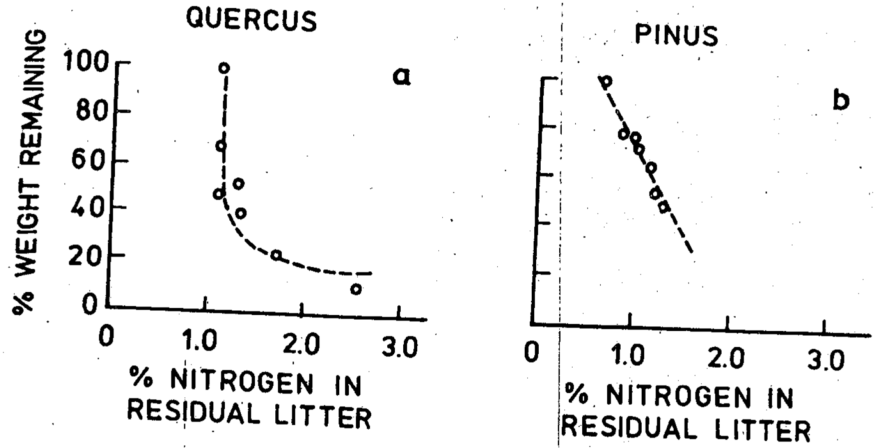


Figure 6 Relationship between per cent mass remaining and N concentration in residual litter during decomposition of (a) oak, and (b) pine litter (based on Singh et al. 1984b).

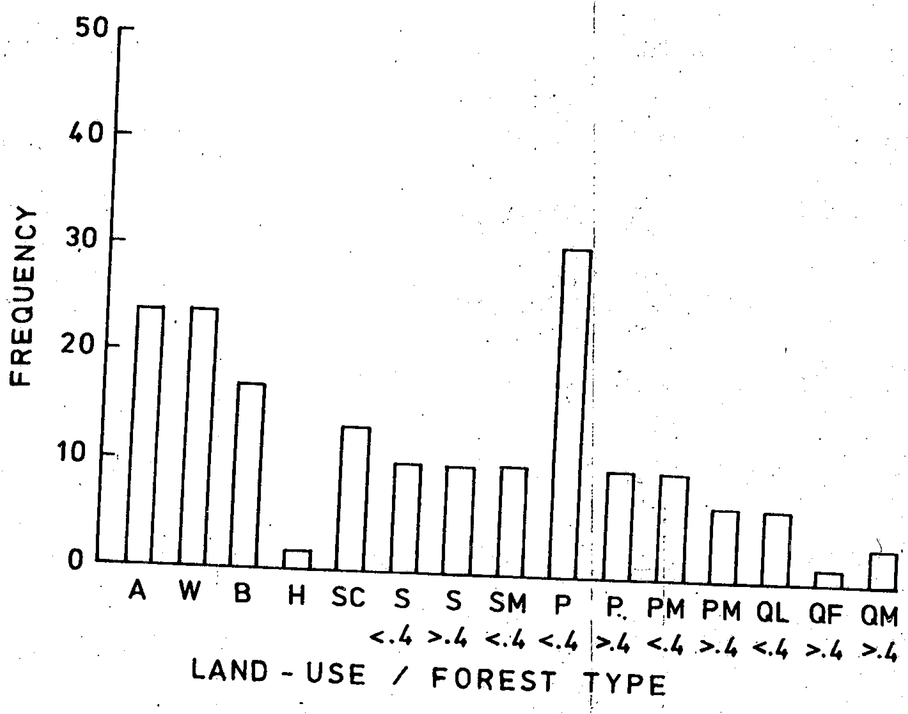


Figure 7 Percentage frequency distribution of various land-uses (and forest types) in active landslide zones. The values below the horizontal axis represent the crown cover of different forest types on an 0-1 scale. A, agriculture, W, waste/grassland, B, completely barren land with erosion, H, built-up-habitation, SC, scrub vegetation, S, *Shorea robusta*, SM, Mixed sal, P, *Pinus roxburghii*, PM, Pine-mixed broadleaf, QL, *Quercus floribunda*, QM, Mixed Oak

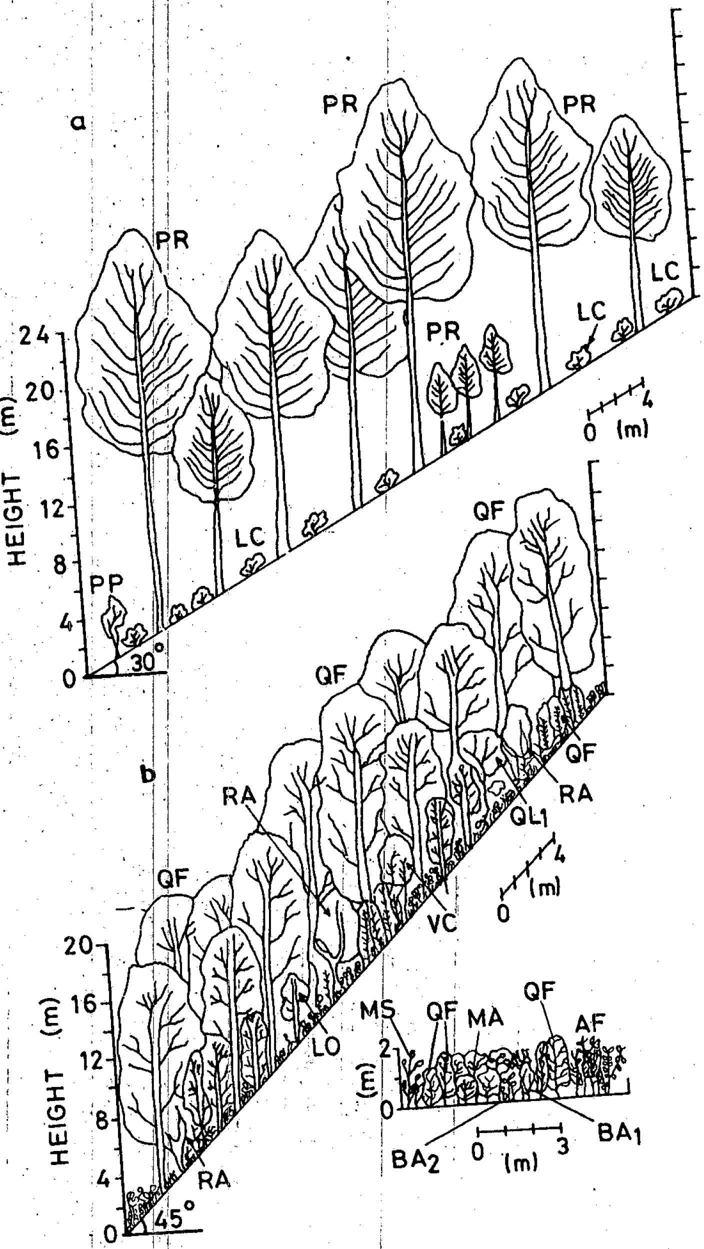


Figure 8 Profile diagrams of (a) *Pinus roxburghii*, and (b) *Quercus floribunda* forests. Inset in (b) is a close up of herb and shrub layers. Each diagram represents an area of 200m^2 (20x10m). *PR, Pinus roxburghii, PP, Pyrus pashia, LC, Lantana camara, QF, Quercus floribunda,* QL^1, *Quercus lanuginosa, RA, Rhododendron arboreum,* LO, *Lyonia ovalifolia,* VC, *Viburnum continifolium, MS, Myrsine semiserrata, MA, Myrsine africana, AF, Arundinaria falcata,* BA$_1$, *Boenninghausenia albiflora, BA$_2$, Berberis asiatica*

one-layered chir pine forests (Saxena & Singh 1982).

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 7.5m. 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 forest with trees confined only to the tallest stratum and having their canopies concentrated on the top (e.g. pine forest, figure 8a) will be relatively less protective for the soil. But when the trees in the tallest stratum are supported by deep and dense canopies in lower strata (e.g. oak forest, figure 8b), the vegetation becomes more protective for the soil.

Conclusions

The Himalaya supports a rich variety of forests. Many of these forests have high species diversity and are characterised by massive biomass and high net productivity. Apart from pecuniary benefits such as production of timber and minor forest products, these forests perform several vital ecological services. However, commercial exploitation and overuse related with agricultural activities and burgeoning human and cattle populations, have resulted in a depletion of forest cover, in converting them into a net source of CO_2, in species replacements and in accelerated soil and water movement.

References

Anonymous 1981 *Census of India, Ser.* 22, Uttar Pradesh. Paper 1 of 1981 Supplement Provisional Population Tables. Delhi, 120-121.

Atkinson E T 1882 *The Himalayan Gazetteer* Vols. **1-2** 404-946 (Delhi : Cosmo Publications)

Bhandari J S 1981 Structure and change among the borderland communities of the Kumaun Himalaya; in *The Himalaya: Aspects of Change*, eds., A D Moddie and J S Lall (Delhi: Oxford University Press) 204-216

Bose S C 1972 *The Geography of the Himalaya* (Delhi: National Book Trust) 79 pp

Champion H G and Seth S K 1968 *A Revised Survey of the Forest Types of India* (Delhi : Government of India Publication)

Dwivedi B N and Mathur R S 1978 *Working Plan for the Naini Tal Forest Division*, Kumaon circle, Uttar Pradesh (1978-79 to 1987-88). (Naini Tal : Working Plans Circle)

Guha R 1983 The nature of forestry science; Peoples' Particip; *Sci. Techn. Bull.* 3 191-113

Khanka S S 1983 *Labour force, employment and unemployment in a backward Economy : A study of kumaon region in U.P.* Ph.D. Thesis, Kumaun University, Naini Tal, India

Loshali D C 1989 *Certain Hydrologic Responses of Landslide Affected Forest Sites in Kumaun Himalaya*, Ph.D. Thesis, Kumaun University, Naini Tal, India

——, Upadhyay V P, Singh R P and Singh J S 1990 Overland flow and soil movement from forests in Kumaun Himalaya; *Can. J. For. Res.* **20** 606-608

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

Menard H W 1963 Some rates of regional erosion; *J. Geol.* **69** 154-161

Menard H W 1963 Some rates of regional erosion; *J. Geol.* 69 154-161

Moddie A D 1981 Himalayan environment; in *The Himalaya. Aspects of Change.* eds. A D Moddie and J S Lall (Delhi : Oxford University Press) 341-350

Molnar P 1986 The geologic history and structure of the Himalaya; *Amer. Sci.* 74 144-154

Monk C D 1967 Tree species diversity in the eastern deciduous forest with particular reference to north central Florida; *Am. Nat.* **101** 173-187

Odum E P 1983 *Basic Ecology* (Philadelphia : Saunders College Publishing)

Olivet J L, Goslin J, Beauzart P, Unternehr P, Bonnin J and Carre' D 1987 The breakup and dispersion of Pangea map; *Palaeobotanist* 37 1-25

Pandey A N, Pathak P C and Singh J S 1984 Water, Sediment and nutrient movement in forested and non-forested catchments in Kumaun Himalaya; *Forest Ecol. Manag.* 7 19-29

Pandey U and Singh J S 1984 Energy flow relationships between agro and forest ecosystems in Central Himalaya; *Environ. Conserv.* 11 45-53

Phillips O L and Gentry A H 1994 Increasing turnover through time in tropical forests; *Science* **263** 954-958

Rao R R 1994 *Biodiversity in India:* Floristic *Aspects* (Dehra Dun: Bishen Singh Mahendra Pal Singh)

Saxena A K and Singh J S 1982 Quantitative profile structure of certain forests in the Kumaun Himalaya; *Proc. Indian Acad. Sci. (Plant. Sci.)* **91** 529-549

—— and Singh J S 1984 Tree population structure of certain Himalayan forest associations and implications concerning their future composition; *Vegetatio.* **58** 61-69

——, Singh S P and Singh J S 1984 Population structure of forests of Kumaun Himalaya: Implications for management; *J. Environ. Manag.* **19** 307-324

Shah S L 1981 The dynamics of a changing agriculture in a micro watershed in the Kumaun hills of Uttar Pradesh; in *The Himalaya, Aspects of Change*, pp. 434-446; eds. J S Lall and A D Moddie (Delhi: Oxford University Press)

—— 1982 Ecological degradation and future of agriculture in Himalaya; *Indian J. Agric. Econ.* **37** 1-22

Singh J S, Pandey A N and Pathak P C 1983 A hypothesis to account for the major pathway of soil loss from Himalaya; *Environ. Conserv.* **10** 343-345

—— Pandey U and Tiwari A K 1984a Man and forests: A Central Himalayan case study; *Ambio.* **13** 80-87

—— Rawat Y S and Chaturvedi O P 1984b Replacement of oak forest with pine in the Himalaya affects the nitrogen cycle; *Nature* (London) **311** 54-56

—— and Singh S P 1987 Forest vegetation of the Himalaya; *Bot. Rev.* **53** 80-192

—— and —— 1992 *Forests of Himalaya: Structure, Functioning and Impact of Man* (Naini Tal: Gyanodaya Prakashan)

——, Tiwari A K and Saxena A K 1985 Himalayan forests: A net source of carbon for the atmosphere; *Environ. Conserv.* **12** 67-69

Singh S P, Adhikari B S and Zobel D B 1994 Biomass, productivity, leaf longevity, forest structure along an altitudinal gradient in the Central Himalaya; *Ecol. Monogr.* **64** 401-421

—— and Singh J S 1986 Structure and function of the Central Himalayan oak forests; *Proc. Indian Acad. Sci. (Plant Sci.)* **96** 159-189

—— and —— 1991 Analytical conceptual plan to reforest Central Himalaya for sustainable development; *J. Environ. Manag.* **15** 369-379

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

Tucker R P 1983 The British colonial system and forests of Western Himalaya, 1815-1914; in *Global Deforestation and Nineteenth Century World Economy* eds R P Tucker and J F Richards pp. 146-165, (Durham, North Carolina : Duke Press Policy Studies)

Valdiya K S 1985 Accelerated erosion and landslide-prone zones in the Central Himalayan region; in *Environmental Regenerative in Himalaya: Concepts and Strategies*, ed. J S Singh pp. 12-38 (Naini Tal : The Central Himalayan Environment Association and Gyanodaya Prakashan)

—— and Bartarya S K 1991 Hydrogeological studies of springs in the catchment of Guala river, Kumaun Lesser Himalaya, India; *Mountain Res. Dev.* **11** 239-258

Vishnu-Mittre 1984 Floristic changes in the Himalaya (southern slopes) and Siwaliks from the Mid-Tertiary to Recent times; in *The Evolution of the East Asian Environment*, Vol. II, *Palaeobotany, Palaeozoology and Palaeoanthropology* pp. 483-503, ed R O Whyte (Hong Kong: Centre of Asian Studies, University of Hong Kong)

West D C, Shugart H H Jr and Ranney J W 1981 Population structure of forests over a large area; *For. Sci.* **27** 701-710

Zobel D B, McKee A, Hawk G M and Dyrness C T 1976 Relationships of environment to composition, structure and diversity of forest communities of the Central Western Cascades of Oregaon; *Ecol. Monogr.* **46** 135-156