

Research Paper

Attributes of Himalayan Forest Ecosystems: They are not Temperate Forests

S P SINGH

Forest Research Institute (Deemed) University, Dehradun 248 006, India

(Received on 27 August 2013; Revised on 26 February 2014; Accepted on 22 April 2014)

This paper describes how Himalayan forests are different from temperate forests with which they are often clubbed. The principal forest types in Himalayas are dominated by evergreen trees with about one year leaf life span (e-leaf type), which include as dissimilar genera as *Shorea*, *Pinus* and *Quercus*. Though several taxa are common with temperate forests, functionally Himalayan forest ecosystems have values closer to tropical than temperate forest ecosystems. The Himalayan trees have tendency to reach their peak physiological activities during autumn when soil moisture is high due to the monsoon precipitation, sunny and fairly long days, and mild temperatures. In contrast, in temperate broadleaved forests, leaves begin to senesce with the beginning of autumn. Therefore, models that use data of temperate forests for predicting responses of Himalayan forests to global change would fail to make accurate predictions. Furthermore, models that focus on temperature and precipitation in Himalayas, would inaccurately predict about these forests because different forest types can occur within same precipitation and temperature regimes in Himalayas. In many Himalayan tree species the regeneration strategy is geared to take advantage of monsoon, to the extent that their seeds show vivipary. Such species might be disturbed by climate change. The nutrient resorption efficiency during leaf senescence in Himalayan oaks is between 20-25% which are far lower than global averages for plants, 62.1% for N and 64.9% for P. Further, forest structure and distribution are variously modified by anthropogenic and natural disturbances, making predictions based on climate data of little value.

Key Words: Broadleaved Evergreen Trees With About 1-Year Leaf Life Span; Ecosystem Processes; Nutrient Resorption; Oaks; Sclerophyllous Leaves; Tree Water Relations; Tropical Forests; Vivipary

Introduction

Global analyses that concern forests, such as global carbon budget and impact of forests on global warming consider generally three latitudinal forest divisions, viz., tropical forests, temperate forests and boreal forests. All other forests, including those of mountains are treated as their parts. For example, most of the forests of mountains regions of tropical and subtropical latitudes between 2000 m and 3000 m altitudes are treated as temperate forests (e.g., Himalayan moist temperate forests (Champion and Seth, 1968)). Predicting responses of Himalayan forests to climate change by transferring data from unrelated temperate forests is highly risky. Similarly, if principal Himalayan forest types are not recognized

in the remote sensing data, getting accurate prediction about consequences of climate change on forests at the global level becomes remote. There are several evidences to indicate that the Himalayan forests differ from forests generally described in literature (Zobal and Singh, 1997). Occupying about 24% of the global area, and influencing a far larger area of the planet, mountains and their vegetation deserve separate treatment in biosphere level analyses.

The Himalayan forests have several more justifications for inclusion in the global analysis, such as high biodiversity, high species endemism and great

*Author for Correspondence: E-mails: surps@yahoo.com, spsecology@gamil.com

importance of their ecosystem services to adjacent plains where about 1.3 billion people (Singh and Thadani 2013) live. Himalayas and connected moist regions in the South Asia harbour extra-tropical broadleaved evergreen forest, a type generally ignored in analyses of forest responses to global change (Zobal and Singh, 1997). A widespread interest in global climatic change and the easy accessibility to remote sensed data have considerably promoted the analysis of large area level environmental patterns in recent years (Lavergne *et al.*, 2010; Morin and Thiller, 2009; Parmesan and Yohe, 2003). The attributes of Himalayan trees and forest ecosystems in relation to those of other major forest types of the world, particularly of temperate zone. The analysis also considers the role of anthropogenic factors in shaping the composition of forests and patterns of their distribution.

Methods

A meta-analysis approach was followed in which data generated by independent studies were assembled and analyzed. Both forest ecosystems and tree characters were considered. Much of the data on ecosystem structure and functioning and tree ecophysiology are of central Himalayan region, generated largely by ecologists of Kumoun University Nainital. In ecophysiology, data are available on tree water status in relation to seasonal and yearly variations for the major forest forming species of Kumoun region and eastern Nepal. Information are available on broad environmental patterns, forest distribution, and plant functional types. As regards anthropogenic factors, day-to-day biomass extraction from forests and shifting cultivation are fairly well documented. For comparison with temperate forests, dependence was largely on the information provided by Zobel and Singh (Zobal and Singh, 1997). In the present paper, temperate forests mean forests occurring in temperate latitudes. For forest ecosystem characters of Himalayas, summaries given in Singh and Singh (1987, 1992); Singh *et al.* 1994 and Zobal and Singh 1997 have been frequently used. Champion and Seth, 1968, Stainton 1972 and Ohsawa 1987 were followed for forest type and their distribution.

Environmental Background

Himalayas are young (30-40 million years old) and rising mountain system (it rose in phases, the altitude being 2500 m in the mid-Miocene, compared to several peaks being above 8000 m at present), highly vulnerable to landslips and landslides, and deposits of debris from broken, fractured and shattered rocks. Its physical dimensions are huge (~4 million square km is the area of Hindu Kush – Himalayas; (Hindu Kush is in and around Afghanistan), with 9 out of 14 tallest summits of the world, forming an arc, close to 2500 km long and 150-400 km wide, and representing 16° range in latitude and 25° in longitude.

The rise of Himalayas coincided with the establishment of the monsoon system of rain, precipitation between 300-400 cm being common in the eastern region where some pockets receive up to 1200 cm of annual precipitation. However, Himalayas have also some of the largest rain shadow areas of the planet in the north of main ranges. In general, precipitation decreases from east-to west, and generally about 80% of precipitation occurs in about three to four monsoon months, from mid-June to September. Called as the third pole and water tower, Himalayas have 61000 km² area under glaciers, and to it are connected 10 river basins, influencing over 1.3 billion population living in them. The mean annual temperature lapse rate per 100 m increase in altitude is relatively low: in Uttarakhand 0.45°C (Singh *et al.*, 1994); in Bhutan 0.54°C (0.42°C during summer and 0.62°C during winter (Eguchi 1987), and in Nepal 0.51°C (Bhattraai and Vetaas 2003).

Himalayas are warming at higher rates than average global rate, and the warming rate increases with altitude, peaking between 4800 and 6200 m altitudes (Singh *et al.*, 2011; Wolfe, 1979). Though still a issue of debate, the glacier shrinkage during last three decades or so has been widespread (Wolfe 1979).

The Himalayan ranges generally support forests up to 3000-4000 m altitudes. However, in some areas forests are located higher; the timberline in Himalayas up to 4700 m, is the highest in the world. Himalayas have a great-asylum value for species

migrating under the influence of climate change. Nearly 25000 plant species occur in Hindukush-Himalayas (HKH) region, of which 30-40% are endemic. The vascular plant species diversity per 100 x 100 km area ranges from 5000 species in eastern Himalayas to less than 500 species in Tibet plateau (Singh *et al.*, 2011).

The people have low carbon economy with per capita CO₂ emission being 0.2t per year. People, in general are poor; Himalayan countries such as Nepal are categorized as less developed. They depend on forests for their day-to-day living. The cultural diversity is high, nearly 600 languages and dialects being spoken across the region.

Domination of Evergreen Species with About 1-Year Leaf Life Span

In Himalayas evergreen broadleaved forests dominate as they do in much of the Asia (Wolfe 1979). Only in the higher part of the altitudinal gradient, towards timberline, evergreen conifers with several years of leaf life span and deciduous species form extensive forests (Singh *et al.*, 1994). Many of the dominant evergreen broadleaved trees have about one year leaf life span; leaves are shed each year as in deciduous species, but trees are never naked because of simultaneous leafing (here after referred to as e-leaf type). The leaf exchange takes place during dry summer/spring months, March-April, and much of

the leaf expansion thus occurs at the height of water scarcity. The e-leaf type evergreen category includes as dissimilar species as: a dipterocarp (*Shorea robusta*); a pine (*Pinus roxburghii*), the genus with species having with leaf longevity up to 40 years (*P. longaeva*) in some xeric parts of the world (Ewer and Schmid 1984); several oaks with sclerophyllous leaves (*Quercus leucotrichophora*, *Q. floribunda*, *Q. semecarpifolia* and *Q. lanata*); a maple (*Acer oblongum*) the genus which symbolizes deciduousness in temperate forests of America and Europe, and an alder (*Alnus nepalensis*), a pioneer deciduous genus in much of the northern hemisphere. Ecologists of temperate region are apt to disbelieve that a maple can be winter green or a pine has deciduous tendency (Table 1). Oaks in America and Europe are generally deciduous and ring porous. Obviously, in spite of similarity in genera, the Himalayan forest trees have different leaf phenology and morphology.

The monsoon pattern of rainfall, characterized by three to four months of rain, followed by long rainless spells during winters and early summer is a major climatic factor that influences greatly the selection of plant functional types and species. The autumn that follows monsoon is highly favourable for plant growth with sunny and fairly long (>10h) days; and high soil moisture. This is the time when broad-leaved trees in temperate regions start senescing or decrease their physiological activities

Table 1: Comparison of species characters in temperate regions (in Europe and America) and Himalayas

Character	Temperate region	Himalayan region
Leaf longevity and physiology of pines (<i>Pinus</i>)	1.6 years to 15 years longevity (in <i>P. aristata</i> and <i>P. longaeva</i> (Ewers and Schmid 1981)) with evergreen canopy throughout the year	~1 year longevity with a deciduous tendency during spring; old senescing needles give brown look to canopy because green new needles are still short
Maple (<i>Acer</i>) leaves	Always winter deciduous	<i>A. oblongum</i> is evergreen with somewhat reduced canopy during spring; leaf longevity ~ 1 year
Alder (<i>Alnus</i>) leaves	Winter deciduous	<i>Alnus nepalensis</i> is evergreen with a marked thinning of canopy over a few weeks
Oaks (<i>Quercus spp</i>) leaves longevity	Majority of oaks are deciduous	Mostly evergreen with ~ one year of leaf life span
Oaks (<i>Quercus spp</i>) xylem	Generally, ring porous with wide vessels, adapted to a short-term high water availability and high photosynthesis rate	Diffuse porous with narrow vessels, adapted to year round photosynthesis

because of cold temperatures and short day lengths. In these conditions characterized by mild winters with fairly long day length, a highly favourable monsoon period, and high relative humidity even during dry seasons, species which produce new leaves each year (e-leaf type) have competitive advantage over both deciduous and evergreen species with several years of leaf life span (conifers like *Cedrus deodara* and *Abies pindrow*). Though the number of deciduous species is similar to that of e-leaf type species, at least in western region, they remain confined to small pockets along water courses, like streams. Only birch (*Betula utilis*) dominates extensively in timberline areas. Conifers with multi-year leaves also dominate over a sizeable area above 2400 m altitude corresponding to the so called cold temperate belt of the Himalayas.

As we move to the east and forests become moist and diverse, the domination of e-leaf type species increases. The leaf life span gets slightly longer (average 1.3 years) (Singh and Singh, 1992), and species with sclerophyllous leaves become fewer. In moist forests of Arunachal Pradesh and Meghalaya of India, average tree species in a forest type exceeds 100 per ha, compared to about 30-35 per ha in western Himalayan forest types. Even pines which dominate widely between 1000-2000 m altitudes in the western part are replaced by broadleaved e-leaf type species, such as *Castanopsis* and *Schima*. The belt has widespread expression of many species of Fagaceae, Lauraceae and other such families example are *Castanopsis tribuloides*, *C. hystrix*, *Schima wallichii*, *Lithocarpus elegans*, black oaks, like *Quercus lamellosa* and *Q. glauca*, *Litsea cubeba*, *L. elongata*, *Neolitsea* spp., *Lindera* spp., *Machilus* spp., *Michelia* spp., *Engelhardtia spicata*, and *Cinnamomum* spp. Forests of this level of species richness, and mesophyllous leaves have little in common with temperate forests.

It may be pointed out that in Himalayas the upper altitudinal belt (above 3000 m) is fairly uniform throughout the arc having fir (*Abies* spp.), birch (*Betula utilis*) and rhododendrons. It is the so called temperate belt 2000-3000 m altitude in which most changes occur along the arc. From west to east, the

changes include: (I) decrease in the domination of conifers, (II) decrease in the domination of oaks with sclerophyllous leaves, (III) increase in diversity, and (IV) decrease in timber species like deodar (*Cedrus deodara*), pine (e.g., *Pinus wallichiana*), spruce (*Picea* spp.) and cypress (*Cupressus torulosa*).

The Himalayan vegetation is patchy in distribution because of diverse topography, frequent landslides, variation in rocks and frequent fires. Within a watershed, as contrasting forest types as ban oak (*Quercus leucotrichophora*) and chir pine (*Pinus roxburghii*) may occur on the same slope, chir pine occupying the ridge top and upper slope and ban oak hill base, often along a water course. Both may have a patch of alder (*Alnus nepalensis*) because of a landslide and of *Coriaria nepalensis* because of the presence of limestone as well as landslide. In this situation a model that considers climate data alone would fail to accurately predict climate change impact on community pattern and ecosystem processes.

Water Relation of Trees

The Himalayan trees show considerable osmotic adjustment (on average across all species 0.53 MPa) largely during autumn when soil is still moist (Fig. 1). It seems that the trees do so to ensure water availability to sustain high rates of water conductance and photosynthesis during autumn when days are sunny and still fairly long (>10 hrs a day), and temperatures mild. The osmotic adjustment was 0.77 MPa for *Q. leucotrichophora*, 0.94 MPa for *Q. floribunda*, and very high for the undercanopy species of oak forests, *Machilus duthei*, 1.41 MPa. It seems that in these species the gain due to increased water availability is higher than the cost of producing compatible solutes for osmotic adjustment (Singh *et al.*, 2006). Since tissue elasticity declines from summer to fall, this Himalayan broad leaved species seem to maintain turgour during fall and winter largely through osmotic adjustment. Average leaf conductance across species (10 species investigated across 16 sites) is the highest during autumn (Fig. 2). Osmotic adjustment depends on photosynthates for the supply of compatible solutes (Kramer and Boyer, 1995). During winters leaf conductance decreases,

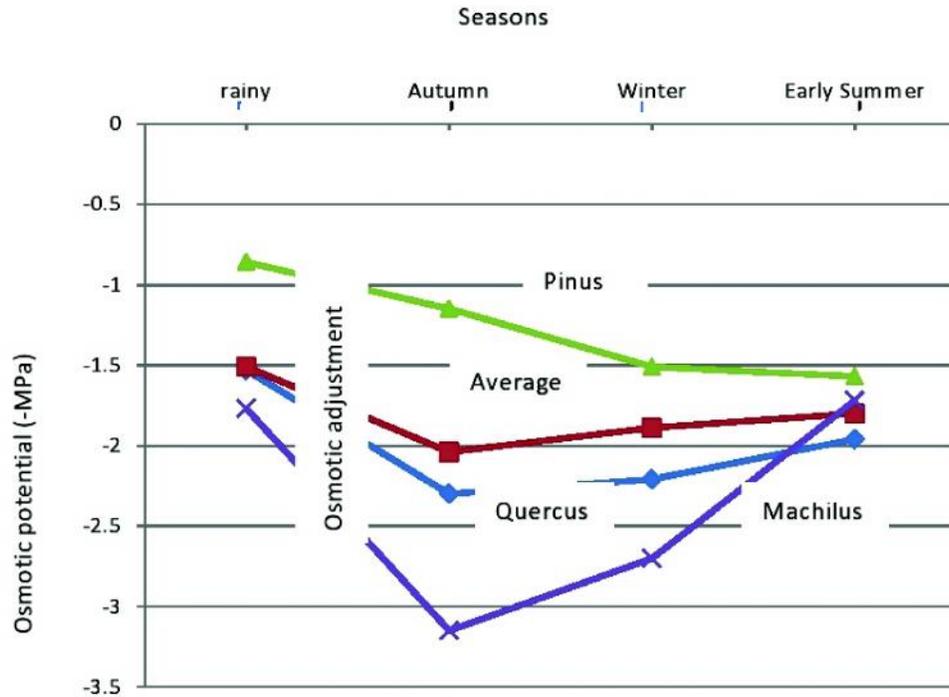


Fig. 1: Seasonal pattern of Osmotic adjustment (maximum osmotic potential-minimum-osmotic potential) at full turgour in trees of Kumaun Himalaya. Osmotic adjustment occurs largely from rainy season to autumn. However, in *Pinus roxburghii* and few other species it is continuous throughout the dry part of the year (Singh *et al.*, 2006)

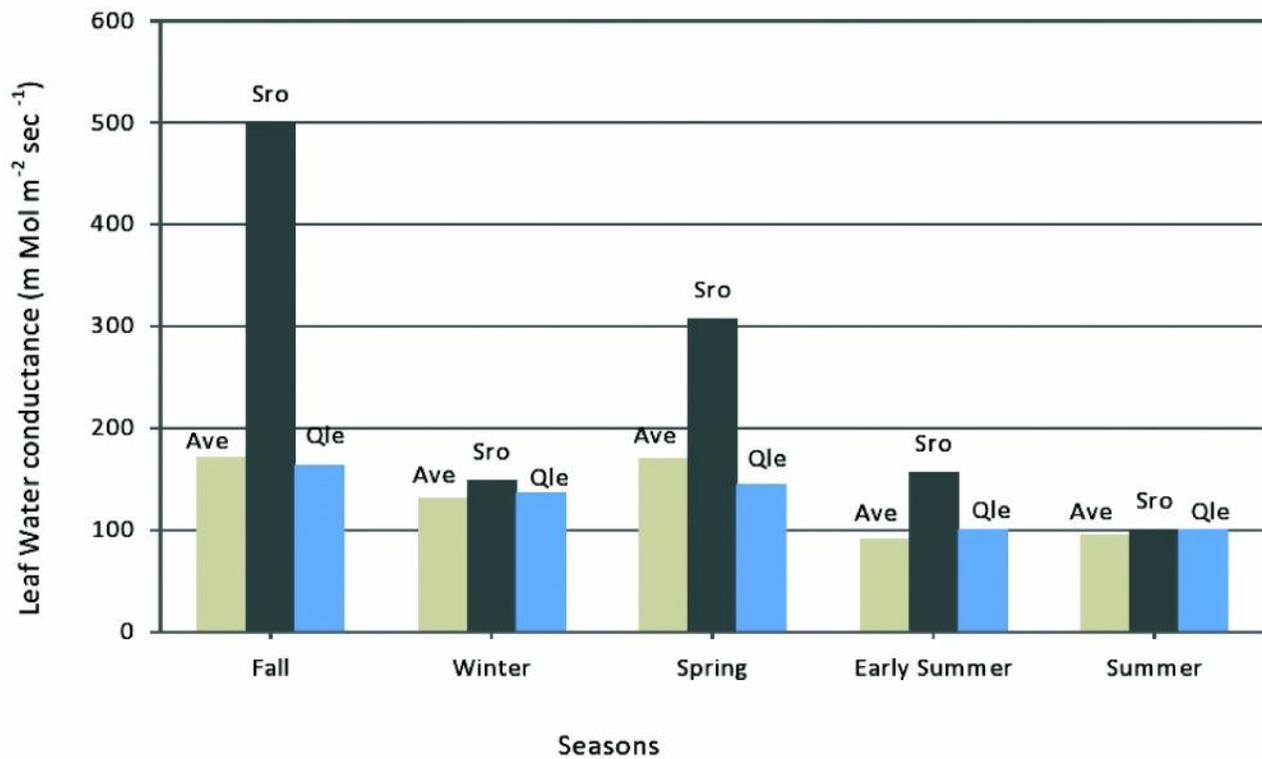


Fig. 2: Seasonal changes in leaf water conductance ($m\ Mol\ m^{-2}\ sec^{-1}$) in Kumaun Himalayan trees. Ave = average of all 11 species; Sro = *Shorea robusta* and Qle = *Quercus leucotrichophora*

but remains substantial and in broadleaved species such as *Quercus lanata* and *Machilus duthei*, it in fact increases from autumn to winter.

The e-leaf type Himalayan species fix carbon at reasonably high rates throughout the year, and replace foliage in time to maximize carbon gain during autumn (Singh *et al.*, 2006). While deciduous species fix little carbon during drought, evergreen species with multi-year leaves (e.g., *Cupressus torulosa*, with 1.47 MPa osmotic adjustment) can fix carbon round the year including drought periods, but their old leaves can take less advantage of highly favourable monsoon months; and sunny and moist autumn months. During this favourable period (July to October), nearly 84% of the annual net primary production has been recorded in *Q. floribunda* (e-leaf type) seedlings (Singh and Singh, 1992).

The predawn tree water potential values indicate substantial water deficit at some season for most species (Fig. 3). Of the total 66 predawn water potential values (11 species x 6 seasons) 15 were

below -1.0 MPa, of which 8 were during summer. Compared with this only 3 values were below -1 MPa in eastern Nepal (Poudyal *et al.*, 2006). Generally, the effect of monsoon precipitation lasts till autumn. Thereafter, tree water potential starts declining, reaching the lowest point during summer. The lowest mid-day water potential recorded in *Q. leucotrichophora* was -2.38 MPa, which is not severe when compared to oaks of temperate region. In eastern Nepal, where rain is more evenly distributed, the lowest tree water potential is -1.78 MPa indicating that trees suffer less water deficit (Poudyal *et al.*, 2006).

Seedlings and saplings are more vulnerable to water stress than trees. *Shorea robusta* seedlings are known to die back repeatedly, and it is accounted for by water stress (Garkoti *et al.*, 2003). In these seedlings stems die back to the ground level and before that a certain portion of photosynthate is translocated to their bulbous roots. This pattern is repeated year-after-year until roots are large enough

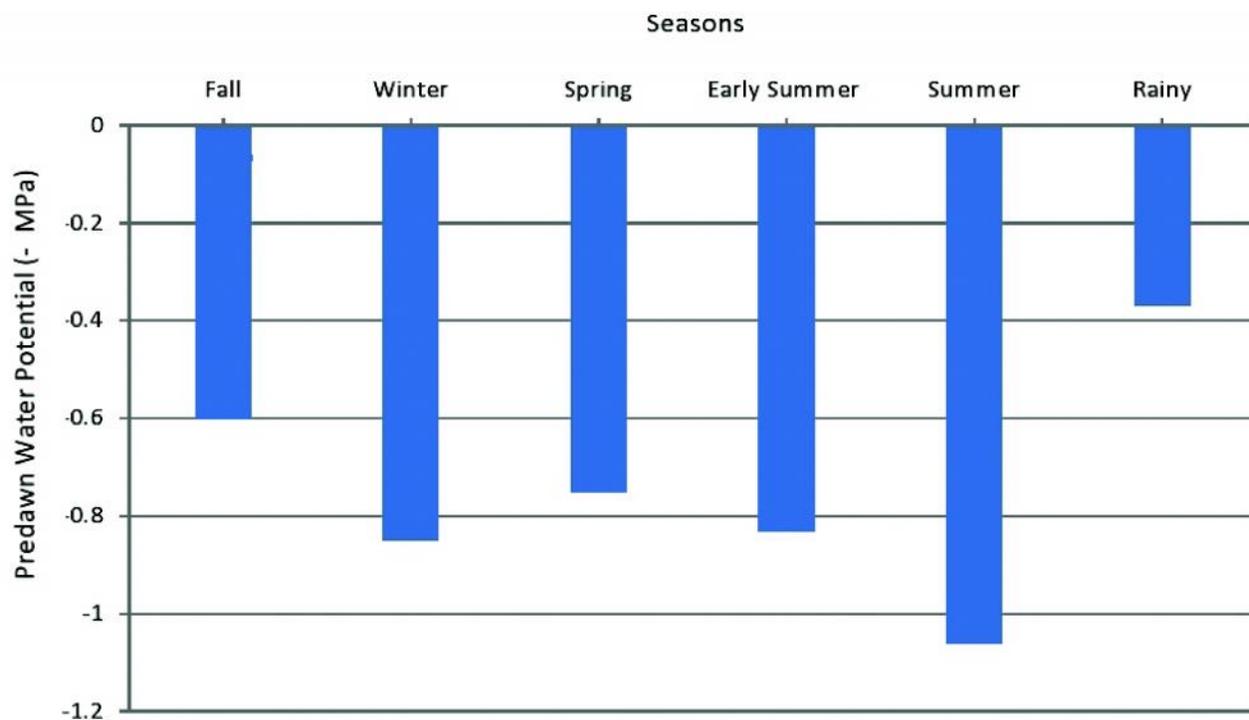


Fig. 3: Seasonal pattern of predawn tree water potential in Himalayas. Each value is average of 11 tree species (from Singh *et al.*, 2006) occurring from 540 m to 2260 m altitudes in Kumaun Himalaya. Each species was sampled at 2-3 sites with 3-5 tree per site (derived from Singh *et al.* 2006). During summer only *Shorea robusta* (-0.5 Mpa), *Machilus duthei* (-0.69 Mpa) and *Cornus oblonga* (-0.68 Mpa) had predawn water potential higher than -1 Mpa, all others had more negative values than -1 Mpa.

to have access to moist soil. A stage comes when seedlings reach a healthy water balance and die-back stops. Die back seems to be an effective strategy to survive in a climate with strong seasonality of precipitation.

How Himalayan species are going to respond to climate change? Climate change is predicted to increase the frequency of extreme events, such as drought and heavy precipitation, apart from rise in temperature, particularly during winters. Under severe drought conditions in 1999 in Nainital the predawn water potential of a population of *Q. floribunda* declined to -5.5 MPa. It killed most of buds, and delayed leaf production by 72 days (Singh *et al.*, 2003). New leaves were formed only after a spell of several days of rain. The severe drought, however, revealed that *Q. floribunda* in Nainital consisted of at least two populations. The other population maintained its normal leafing time (mid-March) as its trees suffered less severe drop in tree water potential (predawn water potential -3.1 MPa). The impact of 1999 drought indicates that tree species can adapt to climate change through their diverse populations. However, a severe drought can result in marked stress on trees, threatening their survival. That year the severely affected population produced only small seeds that too when conditions were not favourable for seed germination (Singh *et al.*, 2003).

Leaf Nutrient Resorption and its Ecological Implications

In e- leaf type evergreen species, leaf litter fall is fairly concentrated with 37-53% of annual fall occurring in the peak month, generally April (Zopal and Singh, 1997). These evergreen broadleaved species resemble those of dry tropical forests in this regard, and differ from tropical rain forest trees in which leaf fall occurs during most of the year (Reich, 1993). Since in these species leaf shedding is induced by new shoot growth, its magnitude and rate determine the duration of litter fall or how concentrated it is. In oaks leaves may continue to maintain low but sizeable rate of photosynthesis until a few days before leaf fall. They hardly senesce before getting shed. To what extent this pattern of leaf fall influences nutrient resorption

Table 2: Nutrient resorption in oaks and other Himalayan tree species in comparison to global mean as compiled by Vergutz *et al.* (Gordon and Jackson 2003)

Plants groups	Nutrient resorption (%)			
	N	P	K	Ca
Himalayan forests Oaks				
(Broadleaved evergreen)	23.5	24.6	25.8	7.8
Conifer				
(<i>Pinus roxburghii</i>)	53.5	49.2	44.3	9.7
Broadleaved deciduous species	57.1	64.4	50.0	21.3
Global Means				
Conifers	62.7	77	79.1	2.9
Broadleaved deciduous	61.2	58.5	56.1	5.3
Broadleaved evergreen	56.1	58.4	54.2	14.8
All forests	62.1	64.9	70.1	-

from oak leaves is worth investigating. The major Himalayan oaks, *Q. leucotrichophora*, *Q. floribunda* and *Q. lanata* occupy the lower side of the global range of nitrogen and phosphorus resorption during leaf senescence. The nutrient resorption efficiency in Himalayan oaks is roughly only one-third of the global averages: 62.1% for N, 64.9% for P, 70.1% for K (Vergutz *et al.*, 2012). However, *Pinus roxburghii* and several deciduous species match the global means (Table 2). Nutrient resorption efficiency is important from modelling nutrient cycling and for quantifying productivity (Vergutz *et al.*, 2012). In oak forests of Himalayas the amount of nutrients which return through litter fall is clearly higher than other forests (e.g., 90.5 kg N per year, compared 69 kg N per year in chir pine forests (Singh and Singh, 1987). The nutrient rich litter and the rich microbial and faunal diversity that oaks support are likely to contribute to soil formation and soil fertility. The oak litter is highly preferred for maintaining crop field fertility in Himalayan states, and this should be regarded as a major ecosystem service of local significance.

The Himalayan oaks have highly diverse and well developed ectomycorrhizal network, clearly more than in other Himalayan forests, such as pine forest (Singh and Singh, 1992). The carbon gain that results from a short leaf senescence period, perhaps takes care of the carbon cost required to support an extensive ectomycorrhizal network, which in return, might help retaining nutrients and water within the soil pool. In brief, the Himalayan oak forest ecosystems seem to create a highly species-rich soil system, with an effective control over nutrient cycling, but with little intra-plant conservation. In contrast, with an efficient nutrient resorption, chir pine forest has more of intra-plant cycling. A tendency of aggressively colonizing newly opened up sites, and tolerance to fire, and water and nutrient stresses have enabled chir pine to expand over large areas, including the sites potentially suitable for oaks and other broadleaved forests. Factors, such as these remain outside the preview of climate change modelling, therefore limit accuracy of predictions and the usefulness.

Ecosystem Processes

In general, leaf nitrogen concentration in Himalayan species is higher. For example, in evergreen species the average nitrogen concentration is 1.29%, compared to the global mean of 0.78% in evergreens (based on 32 species (Gordan and Jackson 2000; Killingbeck, 1996)). With regard to forest floor litter mass and nutrient turn over Himalayan forests are closer to tropical forests than temperate forests (Fig. 4). Because of rapid decomposition the forest floor litter mass in Himalayan forests remain low up to 3000m altitude : 2.5-12.5t ha⁻¹, compared to 0.4-39.9t ha⁻¹ in temperate forests and 1.7-14.7 ha⁻¹ in tropical forests (Zobal and Singh, 1997). In sal (*Shorea robusta*) forest the forest floor litter is small also because of termites (Singh and Singh, 1992). The global warming may further reduce forest floor mass by increasing decomposition, and by promoting fire through increased evapotranspiration loss and desiccation. The eventual gainers of this would be fire tolerant pine and sal.

Though Himalayan forests differ a great deal among themselves in biomass and production

efficiencies of leaves they attain a relatively stable and fairly high (15-20t ha⁻¹yr⁻¹) net primary productivity up to 3000 m altitude. In pine and deciduous broadleaved forests the small leaf mass combines with a high net primary productivity per unit leaf mass, while in broadleaved evergreen forests the low primary productivity per unit leaf mass combines with a large leaf mass. Thus the conversion of one forest type into another because of global environmental changes is not going to affect regional primary production.

Two Broad Regeneration Strategies of Himalayan Trees

With regard to the timing of seed germination and conditions of early seedling growth, Himalayan trees are divisible into two principal types : (I) seeds mature and germinate at the beginning of monsoon, immediately after seed dispersal; and (II) seeds mature during autumn and winter, and germinate long after seed fall because of dormancy (Fenner and Thompson, 2005). The second one is a strategy to wait for favorable period for germination or avoid unfavorable condition that exists at the time of seed maturation. A comparative account of two strategies with regard to advantages and disadvantages are given in Table 3.

In one category seeds ripe just before or at the beginning of monsoon while in the other, the two are unrelated (hereafter referred to as strategy I and strategy II respectively). In strategy I seeds may germinate even while still on tree crown (vivipary) and seed viability is short, 1-2 weeks. Vivipary is a characteristic feature of mangroves, where seed germination is restricted by salty water. In Himalayas the basic advantage of vivipary is to maximize the advantage from monsoon condition, which is of a short-period compared to droughts. A seedling which is recruited at the beginning of monsoon would be ensured of water availability of the entire monsoon period. However, a delay in monsoon can be disastrous. Failure of regeneration in *Shorea robusta* in a year of delayed monsoon has been frequently observed (Singh and Singh, 1992). Climate change may worsen the uncertainty in the timing of monsoon,

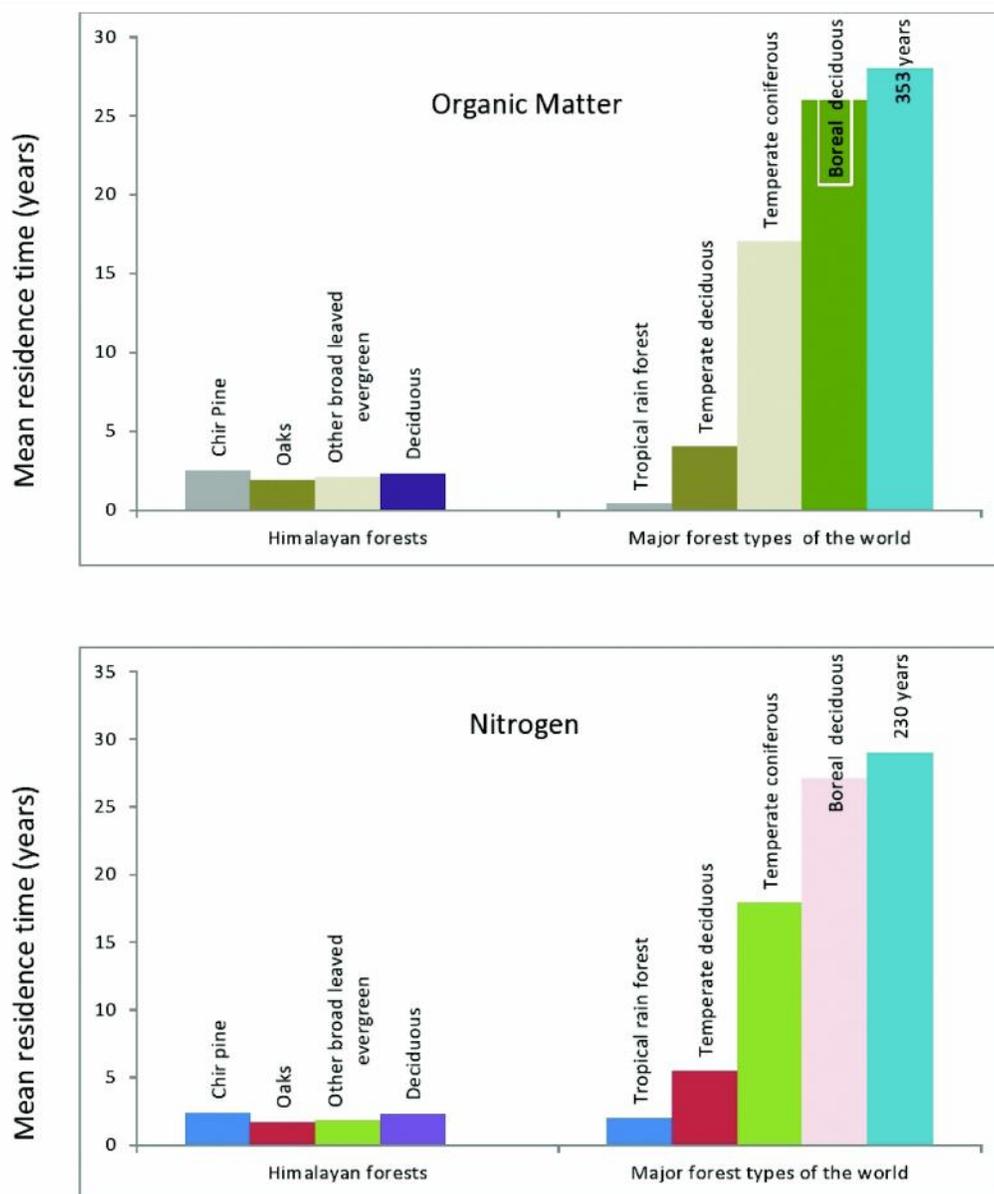


Fig. 4: Mean residence time for organic matter and Nitrogen in the floor litter of the Himalayan forests and principal forest type of the world. Patterns for D and K were similar, hence not shown (derived from Zobal and Singh 1997). All values of Himalayan forests are similar to tropical rain forest values (from Singh and Thadani 2013; Gordan and Jackson, 2003)

and thus disrupt the synchrony between monsoon and seed germination of these species. Further, due to warmer temperatures and water stress the seed maturation may get hastened well before the monsoon beginning.

Since vivipary in Himalayas is associated with seed masting, such species are able to recruit a large number of seedlings in the year of mashing. Seedlings

of species with this strategy survive in large numbers for 3-4 months if they can endure deep shade as luxuriant herbaceous growth protects them from herbivory. By the time winter arrives and soil water depletes, seedlings are well entrenched. The strategy II is also in common temperate forests because the seedling crop is small and since seedlings are not recruited in one go, they differ in age. Therefore, seeds remain over a long time on ground before they

Table 3: A comparative account of two principal regeneration strategies among the Himalayan trees

	Strategy I	Strategy II
Timing of seed germination in relation to monsoon	Seed germination and seedling recruitment synchronized with monsoon immediate seed germination/or germination while still in crown seed viability Short, 1-2 weeks	Seed germination and seedling recruitment unrelated to the monsoon delayed and staggered seed germination during winters-dry and cold
Examples	<i>Quercus floribunda</i> , <i>Q. semecarpifolia</i> <i>Shorea robusta</i> , <i>Populus ciliata</i>	<i>Q. leucotrichophora</i> , <i>Q. lanata</i> <i>Pinus roxburghii</i>
Moisture availability for seed germination	For seed germination moisture ensured	Moisture limiting; seeds should have capacity to wait for favorable moisture and temperature
Seed predation	Escape seed predation on ground as they are either already germinated or germinate soon	Seeds vulnerable to predation as they wait for a long period on ground for favourable time
Herbivory risk to seedlings	- Herbivory at early seedling stage low because of a large herbaceous cover - Risk high during winters and spring when herbaceous cover has perished	- Exposed to herbivory because of the little herbaceous growth during spring - Protected at later stage by herbaceous growth during rainy season
Competitive pressure -earlier stage	- High density at seedling recruitment and early growth stages; competition with herbs for light and space can be high	Little density-dependent competitive pressure because germination is staggered over several months, and herb cover is sparse.
- later stage	- Competition gets reduced at later stage after rainy season	Intense competition at later stage with herbs for light
Water stress	No stress in initial stage of seedlings when they are vulnerable Stress can be high at a later stage but established seedlings are less vulnerable	Water stress can be high in initial stage of seedling growth when they are more vulnerable Low stress where seedlings are also more tolerant

germinate during spring and summer and hence are vulnerable to predation. Whether the rise of winter temperature is going to break their seed dormancy and enable them to germinate earlier, needs to be investigated. Winter germination can limit seedling survival because of water stress and frequent frosts. The species that dominate Himalayan forests over large areas belong to both strategies; it would of great interest to investigate how climate change is likely to affect the existing balance. Of the two strategies described, strategy I is characteristic of the Himalayan forests as it separates them from forests of temperate region.

Anthropogenic Influence

Anthropogenic influence in shaping forest vegetation can be seen all over the world. Himalayan forests are no exception, despite their remoteness and isolation.

Broadly, there have been following types of forest use in Himalayas: (I) Collection of firewood for cooking food, tree leaves to feed livestock, and litter to provide nutrients to crops fields. The day-to-day biomass collection for these has been in practice since time immemorial in most of the Himalayas. Nearly 10 energy units are extracted from forests for each agronomic energy unit produced (Singh and Singh, 1992), (II) Burning of forests for shifting cultivation which utilizes soil fertility created by forests in the eastern parts of Himalayas, (III) Grazing both local and transhumance that is now rapidly declining, (IV) Timber harvest both for local use and commercial which started in an organized way during the British rule, (V) Collection of Non-Timber Forest Products (NTFPs) throughout the region, (VI) Selective killing of big mammals like tiger, leopard, elephant, rhino and bear, thus affecting trophic structure. Apart from local use, timber was extracted from Himalayan

forests at a large scale for railways in the nineteenth century. Being termite-resistant, sal was a preferred species for it. Later on, deodar (*Cedrus deodara*) was transported from high altitude areas through rivers way back in the nineteenth century. In the organized forestry of British India, timber production and harvest received special attention in silvicultural practices. Efforts were made to expand chir pine at the expense of broadleaved species such as oaks and lauraceous species and rhododendrons. Being an efficient colonizer, chir pine was easy to plant with some assistance by foresters, while deodar (*Cedrus deodara*) and cypress (*Cupressus torulosa*) were planted. The ban clamped on tree cutting above 1000 m altitude in 1989 has greatly reduced tree cutting for timber in mountains. In a way the ban on tree cutting resulted in the expansion of chir pine forests, because lopping of branches of oaks and other broadleaved species continued. In oak forests with disturbed canopy chir pine expanded taking the advantage of increased light condition.

There seems to be a relationship between the use of forest for shifting cultivation and their low timber value. Shifting cultivation is common in tropical moist forests which are not known for their timber species as is the case with temperate forests. In such areas animal domestication is limited and is largely for meat. As long as cumulative area that shifting cultivation affects is not large, it gives time for forest ecosystems to recover, though for a short period. There is nothing like a large-scale forest clearance of several miles, the disturbance is not truly acute, but the impact of small-scale disturbances of shortened shifting cultivation cycles accumulated over the years degrade landscapes at a sizeable scale. There can be a substantial carbon loss without much decrease in forest area. In the settled agriculture landscape, on the other hand, there is no let up; the ecosystems hardly getting time to recover in spite of the fact that on a given day biomass removal from a piece of forest land is hardly visible. It may be in a form of a few head loads of tree leaves lopped from an oak tree, or of leaf litter from ground, or of branches for cooking food. Trampling and grazing, frequent fires in small patches, erosion of exposed soil, land dissected by gully formation, all these

agents of chronic disturbance keep the landscape in a perpetual degradation state (Singh, 1998). Trees lopped repeatedly by different individuals on different days are left with little foliage and seeds, and might lose more carbon in respiration than they gain in photosynthesis. In such a degraded forest, the ratio of canopy cover to stem basal area is low (trees are denuded of leaves, but not cut), therefore remote sensed data which are based on canopy underestimate wood stocks. Such degraded patches among the remains of all growth oak forests are common in western Himalayas.

In the case of landscape affected by shifting cultivation the situation is just opposite. The reason being that remote sensed data may overestimate forest wood stock, as a regrown forest on eroded slopes generally has abundance of young and stunted trees, bushes and exotic invaders which have less stem area for a given canopy cover. The shifting cultivation results in land with degraded secondary forests. In contrast, in landscapes affected by settled agriculture the remains of old growth oak forests with denuded trees are common. These two types of degraded landscapes would require different interventions for restoration. For example, in western Himalayas where domestic animals and milk production are integral component of agriculture, grass and legume-based fodder would be needed to replace the practice of damaging tree crowns for collecting leaves which make a poor quality of fodder low quality tree leaf fodder. In shifting cultivation affected forest areas, a strategy to lengthen the shifting cycle and building up of no-tillage agriculture on the existing system may be rewarding both ecologically and economically.

It is apparent that the forest degradation in Himalayas is a common feature, and there is a lot of scope for undertaking REDD+ activities. Assuming that areas under less than 40% forest cover are substantially degraded; 8,4892 km² of forest area is suitable in Indian Himalayas for the REDD+ programme. Since forest degradation has a poverty angle (Skutch, 2011), we need programmes which link forest carbon and livelihoods. It may call for policy changes which promote such linkages. For

example, when tree leaves are collected for fodder, it adversely affects animals as generally tree leaves do not make a proper fodder and their removal reduces carbon sequestration. It should be replaced with a grass and legume-based fodder developed on ground. It would (I) improve animals nutrition, (II) give forests opportunity to recover and improve carbon stock, and (III) decrease women drudgery as they climb trees to collect leaves.

From policy stand point, there is a need to recognize the value of broad leaved evergreen forests for their carbon sequestration and other ecosystem services. These forests are not important in a timber-focused forestry, but they can turn out to be permanent carbon sink and providers of other ecosystem services, with some initiatives to address livelihood issues of local people. In terms of traditional revenue, forest importance declines from west to east with the decreasing of conifer content that is why shifting cultivation has not been a major forestry issue. However, payment for ecosystem services might increase their importance.

References

- Bhattraï K R and Vetaas O R (2003) Variation in plant species richness of different life forms along a subtropical elevation gradient in the Himalayas, east Nepal. *Global Ecol and Biogeogr* **12** 327-340
- Champion H G and Seth S K (1968) *The Forest Types of India*. Forest Research Institute, Dehradun
- Eguchi T (1987) Synoptic analysis of temperature precipitation and moisture conditions in Bhutan Himalayan. In: *Life Zone Ecology of the Bhutan* (Ed: Ohsawa M) pp 2009-242, Himalayan Laboratory of Ecology, Chiba University
- Ewer F W and Schmid R (1984) Longevity of needle fascicles of *Pinus longaeva* (bristlecone pine) and other north American pines *Oecologia* **51** 107-115
- Fenner M and Thompson K (2005) *The Ecology of Seeds*, Cambridge University Press, Cambridge
- Garkoti S C, Zobel D B and Singh S P (2003) Variation in drought response of sal (*Shorea robusta*) seedlings *Tree Physiol* **23** 1021-1030
- Gordan W S and Jackson R B (2000) Nutrient concentrations in fine roots *Ecology* **81** 275-280

Conclusion

Himalayas represent a major centre of extra-tropical broadleaved evergreen forest type, with a marked domination of Fagaceae and Lauraceae, and ecosystem characters substantially different from both temperate and tropical forests. The influence of monsoon (a strong seasonality of precipitation) in terms of plant adaption and ecosystem processes are obvious, but equally evident are the impact of drought spells on them. A tendency of ecosystem processes to peak during autumn, clearly separates Himalayan forests from those of temperate latitudes. Their responses to climate change are going to be influenced by above ecosystem characters, complexities the Himalayan environment poses, and various anthropogenic factors including chronic forest disturbance.

Acknowledgement

The author is thankful to the Director, Forest Research Institute, Dehradun, India for providing facilities to develop this article.

- Killingbeck K T (1996) Nutrients in senesced leaves: keys to search for potential resorption and resorption proficiency *Ecology* **77** 1716-1727
- Kramer P J and Boyer J S (1995) *Water Relations of Plant, and Soils* Academic, San Diego
- Lavergne S, Monquet N, Thuiller W and Ronce U (2010) Biodiversity and Climate Change: integrating evolutionary and ecological responses of species and communities *Annu Rev Ecol Evol and Syst* **41** 321-350
- Morin X and Thuiller W (2009) Comparing niche-and process-based models to reduce prediction uncertainty in species range shifts under climate change *Ecology* **90** 1301-1313
- Ohsawa M (1987) *Life Zone Ecology of Bhutan* Himalayan Laboratory of Ecology, Chiba University Japan
- Parmesan C and Yohe G (2003) A globally coherent finger print of climate change impacts across natural systems *Nature* **421** 37-42
- Poudyal K, Jha P K, Zobel D B and Thapa C B (2006) Pattern of leaf conductance and water potential of five Himalayan tree species *Tree Physiol* **24** 689-699

- Reich P B (1993) Reconciling apparent discrepancies among studies relating life span, structure and function of leaves in contrasting plant life forms and climates: 'The Blind Men and the Elephant Retod' *Funct Ecol* **7** 721-725
- Singh J S and Singh S P (1987) Forest vegetation of Himalaya *Bot Rev* **53** 80-192
- Singh J S and Singh S P (1992) *Forests of Himalaya*, Gyanodaya Prakashan, Nainital India
- Singh S P (1998) Chronic disturbance, a principal cause of environmental degradation in developing countries *Environ Conserv* **25** 1-2
- Singh S P and Thadani R (2013) Valuing ecosystem services flowing from Indian Himalayan states for incorporating into National accounting. In *Tree Tops at Risk*, (Eds: Lowman M, Devy S and Ganesh) pp 423-432, Springer
- Singh S P, Adhikari B S and Zobel D B (1994) Biomass, productivity, leaf longevity and forest structure in the central Himalaya *Ecol Monogr* **64** 401-421
- Singh S P, Bassingnana-Khadka I, Karky B S and Sharma E (Eds) (2011) *Climate change in the Hindukush-Himalayas: the state of current knowledge*. ICIMOD, Kathmandu, Nepal
- Singh S P, Tiwari A, Singh S K and Pathak G C (2000) Significance of phenologically asynchronous populations of the Central Himalayan oaks in drought adaptation *Curr Sci* **79** 353-357
- Singh S P, Zobel D B, Garkoti S, Tewari A and Negi C M S (2006) Patterns in water relations of central Himalayan trees *Trop Ecol* **47** 159-182
- Skutch M (Ed) (2011) *Community Forest Monitoring for the Carbon Market: Opportunities Under REDD* Earthscan, London, Washington, DC.
- Stainton J D A (1972) *Forests of Nepal*, John Murray
- Vergutz L, Manzoni S, Porporato A, Fierreira N and Jackson R B (2012) Global resorption efficiencies and concentration of carbon and nutrients in leaves of terrestrial plants *Ecol Monogr* **82** 205-270
- Wolfe J A (1979) Temperature parameters of humid to mesic forests of eastern Asia and relation to forests of other regions of the Northern Hemisphere and Australasia. Washington (DC): US Department of Interior Geological Survey. Professional Paper No 1106
- Zobel D B and Singh S P (1997) Himalayan forests and ecological generalizations *Bio Science* **47** 735-743

