Ecological and anthropogenic niches of sal (*Shorea robusta* Gaertn. f.) forest and prospects for multiple-product forest management – a review

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Summary

Sal (*Shorea robusta* Gaertn. f.) forests cover over 11 million ha in India, Nepal and Bangladesh, and these forests are conventionally managed for timber. Recently, interest in producing multiple products from sal forests has increased; accordingly, a silvicultural regime for managing sal forest for multiple products is a central concern. Forest managers need a comprehensive scientific understanding of natural stand development processes and anthropogenic factors affecting sal forest when designing silvicultural regimes for multiple-product management. We review ecology and productivity plus anthropogenic niches of sal forests. Information on edaphic factors, phenology and stand development processes (regeneration, growth characteristics, soil nutrient requirement, growth allocation, nutrient cycling, stand structure and successional stages) is important for designing scientific forest management of sal forest; likewise, knowledge of anthropogenic factors associated with use of sal forest is also required for effective implementation of the recently paradigmed management efforts. Sal forest silviculture has been evolving since the beginning of the twentieth century mainly concentrating on timber production, though the sal forests have always been used also for grazing and collection of fodder, fuelwood, litter and many other products. Instead of integrating these products in sal forest management, governments have attempted to control these additional uses through enforcing forest legislation. These attempts resulted in the persistent conflicts between the interests of local people and the government, and the deteriorating condition of sal forests. Community-based forestry in this region emerged in response to the severe degradation of forest resources, and local people initiated protection practices and demonstrated the success of sal forest from coppice. The coppice systems allow managing forests with intermittent products (non-timber forest products, including fodder and litter) while producing timber in the long term. Accordingly, a policy has been developed to manage coppice sal forest for multiple products. Managing the sal forest for multiple products is, however, a relatively recent development and scientific investigations on various aspects of multiple-product forest management need to be

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initiated. Ecological processes indicate good prospects of managing sal forest for multiple products. The review indicates that the ecological processes and anthropogenic factors form sound basis for developing multiple-product management.

Introduction

Sal (*Shorea robusta* Gaertn. f.) occurs gregariously on the southern slopes of the Himalayas and is distributed in Bangladesh, India and Nepal (Figure 1). Its presence is indicated in Bhutan (D. A. Messerschmidt, personal communication) and South China (Fu, 1994; Zhao *et al.*, 1994), too. Broadly, sal's natural range lies between the longitudes of 75° and 95° E and the latitudes of 20° to 32° N. Within this range, the distribution is controlled firstly by climate and then by edaphic factors.

Sal forests are distributed on the plains and lower foothills of the Himalayas including the valleys (Gautam, 1990). It penetrates through mid-mountain range (Mahabharat region) to the far north along river slopes and valleys. Sal forests cover ~110 000 ha in Bangladesh (Alam, 1996), 10 million ha in India (Tewari, 1995) and 1 million ha in Nepal (HMG, 1989). This forest type extends from a few metres to 1500 m above mean sea level.

In the past, sal forests were managed solely in the interests of the ruling elite; accordingly, management norms were developed to maximize

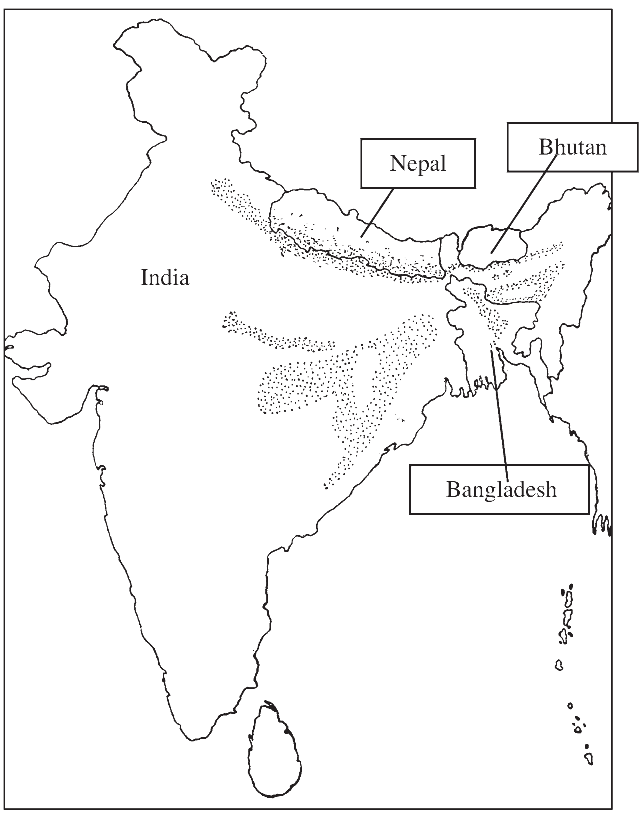

Figure 1. Natural zone of sal forests (shaded dots for sal forests, after Stainton, 1972; FAO, 1985).

revenue (Gadgil, 1990; Gautam, 1991b; Gadgil and Guha, 1993). As timber emerged as an important commodity, the government attempted to manage sal forests for commercial timber production in order to increase revenue. Eventually, the governments saw sal forests more as a timber source rather than for other forest products. But the sal forests, to the contrary, extend to the most heavily populated zones and local people access sal forests for different uses, irrespective of whether they are designated as protective (Kumar *et al.*, 1994; Lehmkuhl, 1994; Bhat and Rawat, 1995; Aryal *et al.*, 1999) or productive forests (Nair, 1945; FRIB, 1947; Mathauda, 1958; Verma and Sharma, 1978; Rana *et al.*, 1988; Maithani *et al.*, 1989; Patnaik and Patnaik, 1991; Rajan, 1995; Tewari, 1995; Gupta *et al.*, 1996; Ganeshaiah *et al.*, 1998; Melkania and Ramnarayan, 1998; Gautam and Devkota, 1999; Pokharel *et al.*, 1999; Pokharel, 2000). It is evident that sal forests have the potential to yield other forest products, too. A sal tree in addition to timber and fuelwood, produces fodder (Panday, 1982; Gautam, 1990; Pandey and Yadama, 1990; Mathema, 1991; Upadhyay, 1992; Thacker and Gautam, 1994; Fox, 1995; Shakya and Bhattarai, 1995; Edwards, 1996; Gautam and Devkota, 1999); leaves for plates (Rajan, 1995; Gautam and Devkota, 1999); seed for oil (Verma and Sharma, 1978; Sharma, 1981); feed (Rai and Shukla, 1977; Sinha and Nath, 1982), resin or latex from heartwood (FRIB, 1947) and tannin and gum from bark (Narayanamurti and Das, 1951; Karnik and Sharma, 1968). Besides, associates of sal are known to produce edible fruits, fodder and compost, fibres, leaves for umbrellas, medicinal plants, thatch, grass, brooms and many other products depending on the species composition (Stainton, 1972; Jolly, 1976; Panday, 1982; Amatya, 1990; Gautam, 1990; Gilmour and Fisher, 1991; Mathema, 1991; Chettri and Pandey, 1992; Upadhyay, 1992; Schmidt *et al.*, 1993; Bhatnagar and Hardaha, 1994; Chandra, 1994; Jackson, 1994; Tamrakar, 1994; Thacker and Gautam, 1994; APROSC, 1995; Fox, 1995; Shakya and Bhattarai, 1995; Tewari, 1995; Edwards, 1996; Sah, 1996; Dwivedi, 1997; Melkania and Ramnarayan, 1998; Poudyal, 2000; Webb and Sah, 2003). Moreover, there are interesting facts of traditional practices of lopping, browsing and litter collection in sal forests of Nepal and elsewhere (Dinerstein, 1979; Agrawal *et al.*, 1986; Prasad and Pandey, 1987a; Chopra and Chatterjee, 1990; Pandey and Yadama, 1990; Mukhopadhyay, 1991; Upadhyay, 1992; Saxena *et al.*, 1993; Sundriyal *et al.*, 1994; Bahuguna and Hilaluddin, 1995; Bhat and Rawat, 1995; Nepal and Weber, 1995; Banerjee and Mishra, 1996; Rao and Singh, 1996; Melkania and Ramnarayan, 1998).

The evidence of such diverse products from sal forest indicates that many associate species of sal forests are capable of producing products given the appropriate management. Ecosystem-based management, i.e. ‘managing ecosystems in ways compatible with both ecological processes and people’s needs’ (Oliver and Larson, 1996:397), could be the best option for sal forests producing ‘product mixes’, as required for community forestry development. Any deviation from ecosystem-based management would be neglecting the forests for the majority of the users, and eventually threatening the ecological processes of sal forests. Thus, ecosystem-based management is the present concern for sustainable management of sal forests used and managed by their local communities.

Efforts are needed to design silvicultural regimes for sal forest to produce a range of products including timber. Designing silvicultural regimes to produce multiple products over the large range of species and sites requires an understanding of the ecology and productivity of sal forests, and the influences of anthropogenic factors on its ecology and productivity. We aim to bring together the published information on ecology, productivity and anthropogenic factors relating to sal forest management. Furthermore, we are aware of the efforts to integrate various non-timber products, which are used by local communities from sal forests, into sal forest management, and have attempted to review and discuss these efforts.

Ecology and productivity of sal forest

Stand structure

Sal is gregarious and dominant in its stand (Champion and Osmaston, 1962; Troup, 1986).

It is considered to be deciduous as it changes leaves every year, and evergreen as the tree is hardly leafless. A sal tree was recorded with 45 m height, 25 m clear bole and a girth of 8 m in Nepal (Troup, 1986). Sal forest's top canopy reaches a height of 30–35 m and trees have a girth of 4 m in favourable localities, and the forest consists of many other layers of trees and shrubs. Stainton (1972) recorded species in various strata of Bhabar/Tarai and Hill sal forest (Table 1), and Rana *et al.* (1988) noted species in two types (by age) of sal forests (Table 2). The other species reveal the various types of sal forests, i.e. dry, moist or wet, and are found in varying densities depending on the edaphic and biotic conditions, and constitute a stratified height structure.

Webb and Sah (2003) classified the canopy of natural and successional sal forests ('successional' refers to the forest regenerated naturally after clear cutting) into tree, sapling and ground flora, and recorded average densities of, respectively, 607, 1763 and 193 555 ha^{-1} for natural forests and 857, 1326 and 375 074 ha^{-1} for successional forests. The study found a basal area of 25 and 15 m^2 ha^{-1} for natural and successional forests, respectively, of which sal constituted 46 per cent in natural forest and 85 per cent in successional forest. Gautam (2001) stratified the vertical structure of two sal forests into top, taller than 1.37 m (d.b.h.), 1-m height (1 m) and ground level (g.l.). Numbers of species recorded in 0.12-ha plots in two forests were 2 and 3 (top), 48 and 39 (d.b.h.), 52 and 48 (1 m) and 89 and 74 (g.l.).

Edaphic factors

Sal grows on a wide range of soil types, except in the very sandy, gravely soils immediately adjoining rivers and in waterlogged areas (Jackson, 1994). It can grow on alluvial to lateritic soils (Tewari, 1995), and prefers slightly acidic to neutral sandy loam (pH = 5.1–6.8) with organic carbon content between 0.11 and 1.8 per cent (Rana *et al.*, 1988; Gangopadhyay *et al.*, 1990).

Table 1: Species in different strata (from Stainton, 1972)

Canopy	Bhabar/Tarai	Hill
Top	*Shorea robusta*, *Terminalia tomentosa*, *T. belerica*, *T. chebula*, *Adina cardifolia*, *Anogeissus latifolia*, *Lannea grandis*, *Scleichera trijuga*, *Syzygium cumini*	*Shorea robusta*, *Lagerstroemia parviflora*, *Anogeissus latifolia*, *Adina cardifolia*, *Semicarpus anacardium*, *Bauhinia variegata*, *Dillenia pentagyna*, *Buchnania latifolia*
Lower	*Mallotus philippinensis*, *Semicarpus anacardium*, *Dillenia pentagyna*, *Kydia calycina*, *Apotosa dioca*, *Casearia tomentosa*, *Buchnania latifolia*	*Nyctanthes arbortristis*, *Kydia calycina*, *Leucomeris spectabilis*, *Glochidion velutinum*, *Symplocos racemosa*
Shrub	*Ardisia humilis*, *Zizyphus rugosa*, *Clausena* spp., *Barleria cristata*	*Hamiltonia suaveolens*, *Phoenix humilis*, *Indigofera pulchella*, *Flemingia strobiliferra*
Lianas	*Spatholobus roxburghii*, *Bauhinia vahlii*	*Spatholobus roxburghii*, *Bauhinia vahlii*

Table 2: Species in different strata in two sal forests (from Rana *et al.*, 1988)

Layer	Species in old-growth forest	Species in seedling-coppice forest
Tree	*Shorea robusta*, *Mallotus philippinensis*, *Cassia fistula*, *Lagerstroemia parviflora*, *Litsea polyantha*	*Shorea robusta*, *Mallotus philippinensis*, *Lagerstroemia parviflora*, *Litsea polyantha*, *Ehertia laevis*, *Syzygium cumini*, *Pterocarpus marsipium*, *Bauhinia variegata*
Shrub	*Murraya paniculata*, *Clerodendron infortunatum*, *Colebrookia oppositifolia*, *Flemengia semialata*, *Justicea pubigera*	*Murraya paniculata*, *Clerodendron infortunatum*, *Colebrookia oppositifolia*, *Flemengia semialata*, *Justicea pubigera*

Sal forests extend into the tropical and subtropical regions, and to the zones where precipitation ranges from 1000 to 2000 mm and above, and the dry period does not exceed 4 months (Tewari, 1995). Sal tolerates some frost, but annual heavy frosts occurring in frost hollows are detrimental to seedlings (Prasad and Pandey, 1987b). The maximum temperature recorded in sal forest is 49°C (Singh and Chaturvedi, 1983).

Phenology

Depending on edaphic factors and microclimate, a sal forest's phenology ranges from deciduous to evergreen and extends from tropical to subtropical. Leaf fall usually starts in late winter (February) and is completed by the end of April (Misra, 1969). As the sal forest consists of many other species in different layers, the phenology of the sal stand interacts with the phenology of these species (Table 3). Maximum leaf fall is from mid-February to mid-May (Pokhriyal *et al.*, 1987; Singh *et al.*, 1993a). Sal trees produce seeds every year; a good seed year is normally every third year. Seed production in sal varies (up to 500 kg ha^{-1} was recorded during the early 1980s) from year to year and from tree to tree (Tewari, 1995). Seeding is normally from mid-May to mid-June.

Regeneration

Sal forest is relatively rich in ground flora diversity. Besides tree and shrub, ground flora of sal forest included fern, herb, grass and liana. The number of species in ground flora ranged from 108 to 132 in 1.2-ha plots depending on the successional stage of the forest in central Nepal (Webb and Sah, 2003), and 94 and 120 species were recorded in 0.12-ha plots in two forests in western Nepal (Gautam, 2001). Other species constituted up to 29 per cent in regeneration inventories conducted between 1 and 3 years after felling (White, 1988; Rautiainen and Suoheimo,

Table 3: Phenology of some species of sal forest (based on Krishnaswamy, 1954; Krishnaswamy and Mathauda, 1954)

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Butea monosperma	–––	–––	–––	–––								
			+++	+++	+++							
	***	***	***	***								
				###	###							
Cedrela toona	–––	–––									–––	–––
			+++	+++								
				***	***							
				###	###	###						
Mangifera indica	–––	–––	–––	–––								
				+++	+++	+++	+++					
		***	***	***								
						###	###	###				
Shorea robusta			–––	–––	–––							
				+++	+++	+++	+++					
			***	***	***							
					###	###						
Syzygium cumini		–––	–––									
			+++	+++	+++							
			***	***	***							
					###	###	###					
Terminalia tomentosa			–––	–––	–––							
							+++	+++	+++			

–––, leaf fall; +++, new leaf; ***, flowering; ###, fruiting.

1997). However, regeneration studies in sal forests are mostly focused on sal species.

Sal regenerates from seed origin or by coppicing; sprouting from root suckers is also very common. Trees of both coppice and seed origin produce fertile seeds, and there is no difference in the vigour of the seedlings from coppice or seed origin (Troup, 1986). Yadav *et al.* (1986) noted middle-girth class (81- to 90-cm girth at breast height) as the best size for good-quality seed, but the size of the tree has no apparent effect on the viability of the seed (Troup, 1986).

Sal seeds have wings, and are dispersed by wind ~100 m from the mother tree (Jackson, 1994). The germination rate is very high (over 90 per cent), provided the seed gets rain within a week. A large number of seeds germinate annually. The seed loses its viability within a week, and so if the monsoon, which usually starts in late June, is delayed, the seed may fail to germinate.

Sal is a light-demanding species, and complete overhead light is needed in most cases from the earliest stages of its development (Champion and Seth, 1968; Kayastha, 1985). Opening of the canopy in a forest stand promotes regeneration, and the growth of understorey seedlings and saplings (Troup, 1986; Gautam, 1990). Some side shade, however, may be helpful under dry conditions, and young plants may require protection from frost and drought (Jackson, 1994; Tewari, 1995).

Sal tends to regenerate as a mass of seedlings where conditions (light, soil, moisture with good drainage) are favourable, and forms more-or-less even-aged crops, which are relatively pure, or it forms the bulk of the stock in mixed stands (Troup, 1986; Rautiainen and Suoheimo, 1997). Suoheimo (1999) observed 50 000–100 000 seedlings ha^{-1} after regeneration felling of sal forests under uniform shelterwood system. Besides, root development in the open is generally better than under shade. Root lengths were 35.8 and 53.1 cm in two plots in the open, as against 11.9 and 18.5 cm in two plots in the shade, indicating that the vigorous growth of seedlings could be obtained by the complete removal of the overhead canopy (Troup, 1986). Similar differences of growth performances were recorded in Nepal Tarai (Suoheimo, 1999).

Only 4 per cent of the seedlings in a profusely regenerated sal-dominated mixed forest were recorded from seed orign and the rest were coppice seedlings (Suoheimo, 1999), indicating the strength of coppice origin in sal forest regeneration. Moreover, sal has a remarkable character of perennating, such as ability to coppice, and can send out young shoots following felling or die back. This process repeats year after year, and allows the cut-over sal forest to regenerate. Protection against grazing of degraded (or cleared for agriculture) land that was previously a sal forest resulted in numerous young sal shoots of uniform height, arising from roots that had survived in the ground (Jackson, 1994). The die-back rate varied from 4 to 10 per cent depending on the number of shelter trees, but no die back was recorded among the tallest 2000 seedling ha^{-1} (Rautiainen and Suoheimo, 1997).

Regeneration, however, has been a serious problem in sal forest management in some parts of India, and efforts initiated since the beginning of last century have not yet been successful. Hole (1921) commenced a series of experiments in 1909 to investigate this problem and concluded that two main factors – high soil water content and poor aeration of soil in combination – were responsible for the failure of regeneration establishment. Soil water content is related to drought/precipitation and soil type, whereas bad soil aeration is caused by heavy rainfall, the presence of organic matter such as dead sal leaves and heavy grazing (Troup, 1986). The injurious actions of leaf litter were correlated with an accumulation of carbon dioxide in the soil solution and low oxygen content, and also the presence of toxic substances produced mainly by decomposition of organic matter (Troup, 1986). However, such actions and substances are injurious only under conditions of bad aeration coupled with high water content (*ibid.*). Sharma *et al.* (1985) suggested that poor or deficient soil aeration during monsoons and soil compaction especially during dry periods, and unfavourable topographic location, seem to be responsible edaphic factors in sal regeneration failure. Nevertheless, the information on the edaphic factors in relation to sal regeneration establishment is still scanty (Tewari, 1995).

Troup (1986) explored the mechanical effects of litter on sal seedling establishment and found that seed germinated on a layer of dead leaves under shade developed satisfactorily above ground during the first rains. In such instances, the tap roots, instead of descending into the mineral soil, spread laterally between the layers of wet leaves deriving sustenance from the moist earthy matter there, and sending out long fine lateral rootlets. All these seedlings died off when the leaf layer dried after the end of the rainy season. Such effects are reported for other species, too (Molofsky and Augspurger, 1992). On the other hand, seedlings germinated on bare ground adjacent to the plots, both under shade and in the open, produced long tap roots and achieved a firm hold in the mineral soil.

Qureshi *et al.* (1968) studied the effect of weeding and soil cultivation under three light regimes (open, partial shade and sal plantation) on the growth and establishment of sal seedlings, and found weeding and cultivation beneficial only in the open and in partial shade. Lack of light was apparently responsible for poor growth and survival in both treated and untreated areas under plantation. Khan *et al.* (1986) found higher survival and better growth of seedlings in the forest periphery than under dense canopy, signifying the role of light in forest regeneration and early growth. Light is thus very important in the development of sal stands. Light plays mainly two roles, increasing photosynthesis and ground temperature, which accelerates litter decomposition.

Growth characteristics

Growth of sal is relatively faster in the early stages; growth of 14-year-old natural regrowth mixed sal forest is given in Table 4. Rautiainen (1995) recorded current annual increment of stem volume from 17 to 18 m^3 ha^{-1} in 6- and 9-year-old uniform-seedling coppice sal stands. Protection of degraded sal forest produced a biomass of 53.56 t ha^{-1} in 4 years (Tamrakar, 1994).

Rautiainen (1999) collected growth characteristics from 28 permanent sample plots located in healthy almost-pure sal forests ranging in age from 5 to 120 years (Table 5); the characteristics varied with locations within a forest (Rautiainen *et al.*, 2000). Rana *et al.* (1988) reported on the net biomass production for sal old-growth forests and sal seedling-coppice forests (Table 6). Carbon fixation in the above-ground parts of these forests was found to be 9.3 (for old-growth) and 10.1 (for new-growth) t ha^{-1} $year^{-1}$, indicating greater carbon accumulation efficiency in young forest than in old forest (Rana *et al.*, 1989).

With an increase in age, the standing biomass increased in sal plantations (Singh and Ramakrishnan, 1981) and natural stands (Misra *et al.*, 1967), and non-photosynthetic : photosynthetic ratio increased (Table 7). The non-green : green ratios indicate three major shifts (1.94–5.43 for 9–13 years, 10.96–12.62 for 15–19 years and 40–41 for 30–50 years), and clearly show that dry matter accumulation is greatest between 30 and 50 years of age (Misra, 1969). However, increment on the basis of height, d.b.h. and mean annual increment (MAI) varies with site class, and a yield table for two site qualities is presented in Table 8, indicating that the MAI decreases slightly between 100 and 120 years.

Growth allocations

Boles, branches and roots, respectively, constituted 60, 24.9 and 14.7 per cent of total non-photosynthetic biomass (233.4 t ha^{-1}) in a forest dominated (70 per cent of total density and basal area, 95 per cent of non-photosynthetic biomass) by *S. robusta*, *Anogeissus latifolia*, *Buchnania lanzon* and *Terminalia tomentosa* (Bandhu, 1970). The weights of all tree components increased with increasing tree diameter, and of the total dry weight of the trees, bole accounted for most of the weight in all tree categories (60, 61 and 66 per cent in suppressed, average and dominant trees, respectively) in sal forest (Kaul

Table 4: Growth of 14-year-old sal forest (from Jackson, 1994)

Species	Stems ha^{-1}	Mean height (m)	Mean d.b.h. (cm)	Volume over bark (m^3 ha^{-1})	MAI over bark (0–14 years) (m^3) ha^{-1}
Sal	928	8.5	9.1	28.8	2.06
Other species	711	8.8	9.1	21.3	1.52
Total	1639	8.6	9.1	50.1	3.58

Table 5: Growth characteristics of almost-pure sal forests (based on Rautiainen, 1999)

Age (years)	Density (stems ha^{-1})	Mean height (m)	Mean d.b.h. (cm)	Volume over bark (m^3 ha^{-1})	MAI over bark (m^3 ha^{-1})
5	7633	5.5	6.2	68.4	13.68
6	4583	8.2	9.0	120.6	20.10
9	4583	9.1	9.5	148.7	16.52
13	2800	10.7	13.9	160.1	12.32
15	3416	12.8	12.1	203.9	13.59
21	1600	18.5	18.6	302.5	14.40
22	2400	15.2	15.2	224.7	10.21
40	528	24.7	33.5	413.2	10.33
45	224	25.9	36.6	250.6	5.57
80	257	20.6	41.6	170.7	2.13
120	288	34.4	49.8	704.7	5.87

Table 6: Total net biomass production in above-ground component of a sal forest (based on Rana *et al*., 1988) (t ha^{-1} year^{-1})

Layer	Sal old-growth forest	Sal seedling-coppice forest
Tree layer	15.3	18.5
Shorea robusta	12.8	15.4
Mallotus philippinensis	0.7	1.4
Other species	1.8	1.7
Shrub layer	1.2	1.1
Herb layer	2.1	1.3
Vegetation total	18.6	20.9

et al., 1979). In another study, Singh and Ramakrishnan (1981) partitioned the biomass of sal trees of different aged stands into bole, branch and leaf. Wood biomasses were 66, 71, 85, 91, 93 and 93 per cent (bole biomasses 53, 58, 79, 83, 88 and 88 per cent and branch biomasses 13, 13, 6, 8, 5 and 5 per cent) of the total biomass at the ages of 9, 11, 13, 15, 17 and 19 years, respectively; for the corresponding ages, the leaf biomasses constituted 34, 29, 15, 9, 7 and 7 per cent, respectively. Bole biomass and d.b.h. follow the same trend. Of the total above-ground biomass of the tree layers in sal forest, 77 and 70 per cent were found in the bole in old-growth and seedling-coppice forests, respectively (Rana *et al*., 1988).

Singh and Chaturvedi (1983) and Singh *et al.* (1993b) found a linear relationship between circumference at breast height and current or mean annual net productivity for the young natural sal forest. Although correlations between girth and height product and biomass were also significant, girth at breast height is used more frequently in establishing the allometric relationship with biomass for sal (Singh *et al*., 1993b).

Rana *et al.* (1988) found significant allometric relationships between biomass of the tree components (bole, branch, twig, foliage) and circumference at breast height. Similarly, positive correlation coefficients were recorded between height, girth at breast height and wood biomass and were highly significant (Suri and Dalal, 1963; Suri, 1968; Gangopadhyay *et al*., 1990). Rao and Chaturvedi (1971) found a linear relationship between the oven-dry foliage weight and d.b.h. for sal.

Productivity indices

Raman (1976) studied the productivity of sal plantations ranging from 8 to 26 years old, and noted the same trend between basal area and net primary productivity (based on annual litter fall and current annual increment in tree biomass). The study showed 14.62 t ha^{-1} year^{-1} (corresponding to basal area of 29 m^2 ha^{-1}) as the highest productivity indices attained at the age of 18 years. However, the productivity based on non-green : green ratio was reported greatest between 30 and 50 years of ages (see Table 7). Sharma *et al.* (1989) used the increment in stem timber volume as a productivity index for sal forest mixed with *Mallotus philippinensis*. The above-reviewed studies indicate that the parameters

Table 7: Proportion of green and non-green biomass in different stands of sal (from Misra *et al.*, 1967; Singh and Ramakrishnan, 1981)

	Proportion								
	9*	11	13	15	17	18	19	30	50
Non-green	1.20	6.88	19.82	28.41	37.72	122.10	54.53	228.40	566.80
Green	0.62	2.85	3.65	2.57	2.99	10.90	4.35	5.70	13.70
Ratio	1.94	2.41	5.43	10.96	12.62	11.20	12.54	40.00	41.00

Biomass in tonnes per hectare except for ages 18, 30 and 50 years, where it is kilogrammes per tree.
*Age in years.

Table 8: Growth of sal from Indian yield tables (from Jackson, 1994)

	Quality I			Quality II		
Age (years)	Height (m)	d.b.h. (cm)	MAI (m^3 ha^{-1} $year^{-1}$)	Height (m)	d.b.h. (cm)	MAI (m^3 ha^{-1} $year^{-1}$)
10	–	8.1	2.8	–	4.6	0.1
20	14.9	14.2	4.5	7.0	7.4	0.8
50	25.9	29.2	8.6	11.3	17.7	1.9
100	36.9	48.3	11.2	17.7	29.5	3.1
120	39.6	54.9	11.0	18.3	33.3	2.9

such as d.b.h., basal area and stem volume are good indicators of net productivity in sal forests.

Soil nutrient

Mineral nutrition appears to be an important factor in sal forest productivity. Kaul *et al.* (1963) calculated the nutritional uptake of a 35-year-old sal stand, on the basis of samples collected from different parts of India. They found that nutrient requirements for all site qualities decreased in the order of Ca, N, K, P and Mg. The Ca requirement (by percentage of oven-dry material) was determined to be 1.5 times that of N, 2 times that of K, and 5 and 7 times that of P and Mg, respectively. The study reflected that on better sites, or where the rate of stem timber production is greater, the nutrient requirements are much higher. On poor sites, nutrient status is lower, and a higher proportion of the uptake goes into the production of foliage.

Kaul *et al.* (1966) studied the effect of mineral (N, P, K, Ca, Mg and S) deficiencies in sal seedlings, and showed that the deficiency of each of these nutrient elements except sulphur causes prominent symptoms (e.g. smaller leaves, thin tap root, premature defoliation, slow shoot growth) both on shoot and root. Deficiencies of N, P and Mg affected height growth. Deficiencies of Ca and Mg produced a shorter tap root and sparse lateral roots while N- and K-deficient seedlings had thinner, longer tap roots.

Nutrient content and cycling

Bhatnagar (1957) analysed the mineral contents (ash, CaO, MgO, N, K_2O and P_2O_5) in sal foliage from different site quality classes, which were classified on the basis of top height at age 80 years (first quality being the tallest). First-quality trees showed the lowest concentration (per cent) of all minerals, whereas the lowest quality trees showed the highest percentage of N, P and K.

In a study of 21-year-old coppice sal forests, leaves contained the highest percentages of N, P, K and Mg, while the bark had the maximum percentage of Ca for all categories of trees, i.e. dominant, average and suppressed (Kaul *et al.*, 1979). The study calculated standing nutrient content in a sal forest (Table 9), and a comparison of leaf litter nutrients from different studies is presented in Table 10.

Table 9: Standing nutrient content of sal forest (kg ha^{-1}) (from Kaul *et al.*, 1979)

Plant part	N	P	K	Ca	Mg	Total
Leaves	59	6	18	40	7	130
Twigs	34	3	14	35	4	90
Branches	101	8	35	115	20	279
Bole	242	27	75	125	51	520
Bark	85	8	58	257	35	443
Total	521	52	200	572	117	1462

Table 10: Nutrients returned to the forest floor through leaf fall (kg ha^{-1})

Nutrients					
N	P	K	Ca	Mg	Sources
59	2	23	57	18	Singh *et al.* (1993a)
72	4	23	83	13	Pande and Sharma (1988)
46	9	19	77	10	Seth *et al.* (1963)
59	6	18	40	7	Kaul *et al.* (1979)

The nutrient rates calculated in the four studies show little differences in the estimates of each nutrient (Table 10). The climate of measurement years, age of the forest and methods of measurements may have contributed to these differences. One study (Kaul *et al.*, 1979) was in 21-year-old coppice forests, whereas the others were older than 35 years when they were measured. Similarly, the destructive method (trees were felled) was followed in the case of the study by Kaul *et al.* (1979) while the others followed the litter-plot method (collected throughout the year at monthly or quarterly intervals from the plots laid out in the forests).

Litter (leaves and twigs) production in sal forests ranged from 1010 to 6210 kg ha^{-1} year^{-1} depending on the species composition and canopy cover (Misra, 1969; Pokhriyal *et al.*, 1987). Leaf litter decomposition is faster than twig decomposition (Pande and Sharma, 1993). Maximum decomposition was in the rainy season, and turnover time to decompose the litter was 144 days (Munshi *et al.*, 1987). With the advent of rainfall usually in the last week of June, litter starts decomposing rapidly and by the time the next litter fall starts, most of it decomposed and incorporated into the soil (Misra, 1969).

Decomposition rate increased with increasing litter moisture and air temperature and decreased with increasing altitude and lignin content (Mehra and Singh, 1985; Upadhyay and Singh, 1986). After a period of 1 year, the loss of litter for sal was observed to be 56 per cent of initial dry weight. Of the total decomposition, 40–45 per cent of litter was lost from May to August due to higher temperatures and humidity (Singh and Ramakrishnan, 1982). Total loss reached over 85 per cent by 365–669 days depending on the site and species under study (Upadhyay, 1987). During the transformation from green foliage to raw humus some of the elements (Ca, Mg, K, Na and P) were leached out while others (Si and Fe) accumulated (Gangopadhyay and Banerjee, 1987).

Nitrogen translocation

Pokhriyal *et al.* (1987) recorded a progressive increase in the nitrogen content of canopy foliage from the bottom to the top. The nutrient moves towards the upper canopy, and leaves in the lower canopy start the translocation process earlier (Pokhriyal *et al.*, 1988). Pokhriyal (1988) studied the monthly changes in N content in the canopy and litter, and estimated the retranslocated N in a natural sal forest. Foliage nitrogen content in the sal canopy was greatest (90 kg ha^{-1}) in January/February and least (36 kg ha^{-1}) in April (Pokhriyal *et al.*, 1987, 1988; Pokhriyal, 1988). Monthly N content (in percentages) in canopy, litter and storage parts (retranslocated N that sustains the growth of new foliage) of sal foliage is shown in Figure 2. Leaf litter contributed the most nutrient return, release and accumulation. Sal trees translocate nutrients from the leaves prior to leaf fall (Sharma and Pande, 1989). Translocation of N to other parts is initiated once the live canopy content peaks in January/February before leaf shedding starts. From January to April, canopy nitrogen is either translocated (0 per cent in January to maximum 42.5 per cent in April) to other parts or returned to the ground through litter (Pokhriyal *et al.*, 1987).

Successional stages of sal forests

Broadly, the sal forest types are identified as dry sal, moist sal, coastal sal and wet sal (Champion

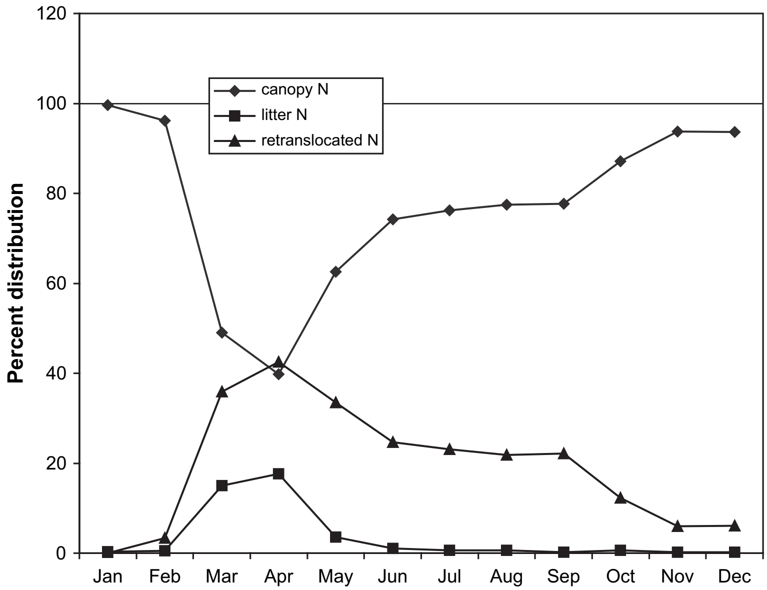

Figure 2. Monthly nitrogen mobility in sal foliage (based on data from Pokhriyal, 1988).

and Osmaston, 1962). However, they can be separated into two extreme types, the dry and the wet; between these, various gradations occur (Troup, 1986). These two types occur in a continuum from east to west; extreme wet sal forests are prevalent in the east and at the other extreme, dry, in the west. Based on the associated species, the distinction between these two types of forest appears to be a fine one (Stainton, 1972). However, Stainton (1972) classified the sal forests of Nepal into Bhabar and Tarai sal forest and Hill sal forest, and the situation outside Nepal supports this classification. Bhabar and Tarai sal grow to a considerable size, whereas in Hill sal much smaller trees are found. In a north–south transect, Hill sal is drier than the Bhabar and Tarai sal.

Sal forest's present status is the result of actions and interactions of environmental and biotic factors, and is explained in terms of plant succession theories (Champion and Osmaston, 1962; Troup, 1986). The developmental process involves progression and retrogression (Figures 3–5). Grazing and fire are prevalent in sal forests, and the extent of their presence affects the successional pathways into progression and retrogression (Lehmkuhl, 1994).

Anthropogenic factors

Stainton (1972) observed stunted pole-like sal trees in open forest area close to densely populated areas in many midland valleys of Nepal, where forests were under heavy pressure of repeated lopping and intense grazing. A phytosociological study (Kumar *et al*., 1994) looked at two sites (protected 'core part of tiger reserve' and disturbed 'buffer zone of tiger reserve') in peninsular sal forest (i.e. Peninsular India, which extends south from the drainage basin of the Ganges River). The study showed 20 and 21 tree species in protected and disturbed sites, respectively. It indicated changes in population structure due to disturbances, as seen in the main six tree species in the sub-classes of trees, saplings and seedlings (Table 11). Although regeneration density of the six species combined was higher at the disturbed site, tree and sapling densities were

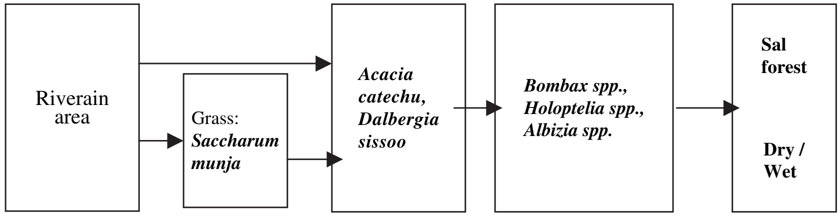

Figure 3. Successional phases of sal forest (based on Jacob, 1941; Champion and Osmaston, 1962; Troup, 1986; Maithani *et al*., 1989).

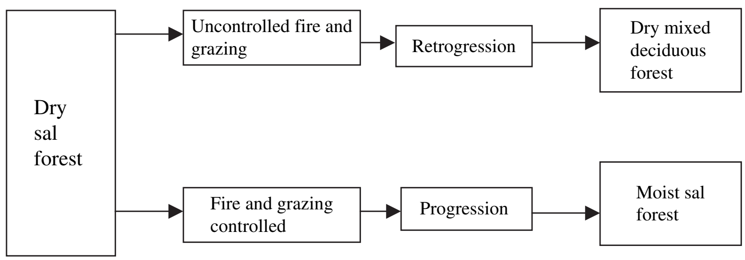

Figure 4. Progression and retrogression of dry sal forest (based on Jacob, 1941; Champion and Osmaston, 1962; Troup, 1986; Maithani *et al*., 1989).

higher at the protected site by 63 and 78 per cent, respectively. Moreover, the disturbed site was devoid of sal saplings, indicating either direct use of these by local people or indirect effects of their activities, e.g. grazing, fire or litter collection.

Fire

Fire has long been considered one of the main factors affecting (beneficially or injuriously) sal stand development (see Figures 3–5) depending on the forest type and local situation (Jacob, 1941; Champion and Osmaston, 1962; Maithani *et al*., 1986, 1989; Troup, 1986; Lehmkuhl, 1994). Fire was once considered the only weapon available to foresters for controlling weeds (Champion and Osmaston, 1962). Controlled burning was also prescribed to eliminate the injurious effect of dead leaves. Burning of leaf litter just before seeding was used to ensure good regeneration (Troup, 1986). Fire was extensively and intentionally used to promote regeneration and maintain the sal forest as the climax type in wet sal forest regions in India (Jacob, 1941).

Fire did not change the tree layer parameters (species composition and density) but changed the shrub structure (Rodgers *et al*., 1986). Ground vegetation, including regenerating trees, was modified, and some species disappeared while new ones appeared (Raynor, 1940; Jacob, 1941; Nair, 1945; Maithani *et al*., 1986; Rodgers *et al*., 1986). In all these instances, fire increased the number of herbs and shrubs, especially palatable plants. Fire also attracted additional grazing by reducing the height of many palatable shrubs (Maithani *et al*., 1986; Rodgers *et al*., 1986), and together these factors negatively affected sal regeneration. Eventually, fire and wildlife grazing controlled successional pathways (Lehmkuhl, 1994). Older trees were resistant to fire, but the wounds from fire in sal trees between 15 and 35 years of age resulted in infection and the trees became prone to heart rot due to fungi (Bakshi, 1957).

Most studies indicated that sal trees can resist fire once they have passed the sapling stage. Controlled burning or grazing is necessary to prevent the wet sal forest from becoming mixed

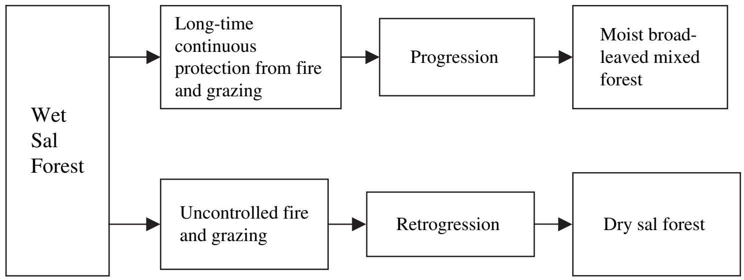

Figure 5. Progression and retrogression of wet sal forest (based on Jacob, 1941; Champion and Osmaston, 1962; Troup, 1986; Maithani *et al.*, 1989).

Table 11: Densities of trees (ha^{-1}), saplings (ha^{-1}) and seedlings ($10\ m^{-2}$) (from Kumar *et al.*, 1994)

	Protected site			Disturbed site		
Species	Tree	Sapling	Seedling	Tree	Sapling	Seedling
Shorea robusta	183	250	14	183	0	29
Terminalia tomentosa	167	0	8	92	0	0
Bauhinia variegata	75	260	4	33	188	1
Aegle marmelos	33	63	5	75	250	11
Diospyros melanoxylon	208	438	5	67	67	4
Emblica officinalis	117	0	1	33	63	1

broadleaved forest (Figure 5). Moreover, controlled burning creates opportunities for regeneration of many non-timber forest product (NTFP) species. In several instances, intentional forest fires have been recorded in sal forests normally ignited by the NTFP collectors, harvestors or gatherers.

Lopping and litter collection

Lopping for fodder and the collection of ground litter have been recorded in sal forests close to settlements (Stainton, 1972; Dinerstein, 1979; Agrawal *et al.*, 1986, 1991; Prasad and Pandey, 1987a; Chopra and Chatterjee, 1990; Malhotra *et al.*, 1990; Pandey and Yadama, 1990; Mukhopadhyay, 1991; Upadhyay, 1992; Saxena *et al.*, 1993; Jackson, 1994; Sundriyal *et al.*, 1994; Bahuguna and Hilaluddin, 1995; Bhat and Rawat, 1995; Nepal and Weber, 1995; Banerjee and Mishra, 1996; Rao and Singh, 1996; Melkania and Ramnarayan, 1998; Jashimuddin *et al.*, 1999; Rawat and Bhainsora, 1999), and these actions affected the regeneration and establishment of sal forests. Lopping by local people to meet their needs, such as for fodder, animal bedding or compost, reduced the litter on the forest floor. Besides lopping, local people collect ground litter for their use. Only recently, studies (Maithani *et al.*, 1989; Schmidt *et al.*, 1993; Melkania and Ramnarayan, 1998) reported that the removal of dead leaves from sal forests drained the nutrients and reduced the fertility. However, ground litter was considered for a long time to pose a mechanical problem in sal forest reproduction and accordingly, removal of dead leaves, by burning or otherwise, was strictly recommended for regeneration establishment (Champion and Osmaston, 1962; Troup, 1986), indicating the importance of lopping and litter in sal forest management, especially on regeneration. Gautam (2001) indicated that lopping and litter removal if wisely managed may not affect growth and regeneration adversely, but, to the contrary, it could contribute positively.

Grazing

Grazing was considered effective in checking the growth of *Imperata cylindrica* to secure the establishment of sal seedlings (Rowntree, 1940, 1942; Sarkar, 1941). Since sal is good fodder (Rathore *et al.*, 1991), heavy grazing is common and in many places converted sal forests into patches dominated by grasses such as *Eulaliopsis binata*, *Arundinella setosa*, *Phragmites karka*, *Heteropogon contortus*, *Desmostachya bipinnata* and *Cenchrus ciliaris* (Dinerstein, 1979; Dakwale and Lall, 1981; Gupta *et al.*, 1996). Grazing reduced the litter content in soil (255–385 to 56–104 g m^{-2}) and the sapling density (260–340 to 20–240 m^{-2}) in sal forest (Pandey, 1994). The detrimental effects of grazing have resulted in soil exhaustion, preventing regeneration in sal forests (Lehmkuhl, 1994; Gupta *et al.*, 1996).

Stunted trees, absence of regeneration and soil compaction have been taken as evidence of adverse impacts of grazing on sal forests. However, grazing is considered good to control the palatable weeds. Also grazing has been listed as a way to maintain the wet sal forest without turning them to mix broadleaved species. Furthermore, local people, who use sal forest for NTFPs, believe that grazing may expose soil to improve the germination of some NTFP species.

Other NTFPs

Sal forests have been used for several NTFPs (FRIB, 1947; Narayanamurti and Das, 1951; Karnik and Sharma, 1968; Stainton, 1972; Jolly, 1976; Rai and Shukla, 1977; Verma and Sharma, 1978; Dinerstein, 1979; Sharma, 1981; Panday, 1982; Sinha and Nath, 1982; Agrawal *et al.*, 1986; Prasad and Pandey, 1987a; Amatya, 1990; Chopra and Chatterjee, 1990; Gautam, 1990, 2001; Pandey and Yadama, 1990; Gilmour and Fisher, 1991; Mathema, 1991; Mukhopadhyay, 1991; Chettri and Pandey, 1992; Upadhyay, 1992; Saxena *et al.*, 1993; Schmidt *et al.*, 1993; Bhatnagar and Hardaha, 1994; Chandra, 1994; Jackson, 1994; Sundriyal *et al.*, 1994; Tamrakar, 1994; Thacker and Gautam, 1994; APROSC, 1995; Bahuguna and Hilaluddin, 1995; Bhat and Rawat, 1995; Fox, 1995; Nepal and Weber, 1995; Rajan, 1995; Shakya and Bhattarai, 1995; Tewari, 1995; Banerjee and Mishra, 1996; Edwards, 1996; Rao and Singh, 1996; Sah, 1996; Dwivedi, 1997; Melkania and Ramnarayan, 1998; Gautam and Devkota, 1999; Poudyal, 2000; Webb and Sah, 2003). Gautam (2001) grouped forest products, as identified by users of two sal forests, into 16 categorisies, such as compost, fibre, fishing tools, fodder, food, farm implements, medicines and ornaments. These products are gathered from different plants parts, including roots, seeds, bark and leaves. Use of products and preferences vary with ethnic group and availability. Harvesting of these products may have tremendous positive and negative effects on sal forest, but have not yet been investigated.

Encroachment

Sal forest is the forest type most affected by development efforts, such as resettlement and developmental infrastructure expansion programmes. The sal forests are considerably fragmented in all locations. The fringe effects as noted by Stainton (1972) are common, and encroachment on such forestland is widespread (Gautam, 1991a; Chakraborty, 2001). These instances reflect the accessibility of sal forests and availability of labour forces in sal forest regions. Besides depending on land resources, people living in and around the sal forests also heavily rely upon the NTFPs from these forests. Forest management efforts need to consider and assess these situations while planning and implementing any sustainable programme. To some extent, community-based forestry programmes (e.g. joint forest management in India and community and leasehold forestry in Nepal) in sal forest regions have been able to involve local people in forest management activities. The availability of work forces may be an opportunity for promoting labour-intensive management, particularly NTFP harvesting and collection within the prescriptions of sal forest management regimes.

Evolution of sal forest silviculture towards multiple-product forest management

Efforts are continuing since the early 1900s to develop appropriate silvicultural systems for sal forest management. Most of these efforts are building on judicious canopy opening to secure regeneration of sal (Hole, 1921; Troup, 1986; Tewari, 1995).

Sal forests are managed under both high forest and coppice systems (Champion and Griffith, 1948; Troup, 1952; Champion and Seth, 1968; Troup, 1986). Selection, clearfelling and shelterwood systems are implemented under the former and simple coppice, coppice with standards, coppice with reserves and selection coppice are followed under the latter. Improvement fellings, such as singling and thinning, and climber cutting, are sometimes prescribed for sal stand development, focusing mainly on removing less valuable trees (HMG, 1977; Tewari, 1995). In many cases, this has resulted in the deterioration of state-managed sal forests in Bangladesh, India and Nepal (Chatterjee, 1995; HMG, 1999; Islam and Weil, 2000).

On the other hand, community-based forestry in this region emerged in response to the severe degradation of forest resources and the persistent conflicts between the interest of people and the government. Local people started protecting the degraded sal forests, and demonstrated the success in improving them by use of coppice systems (Gautam, 1990, 1995; Conroy *et al.*, 2002). While coppice systems are still rarely practised in Nepal's government-managed sal forests, such systems have become popular in community-managed forests in Nepal (Tamrakar, 1994; Tamrakar and Danbury, 1997) and joint forest management in India (Melkania and Ramnarayan, 1998). Although sal forest rotations of 120–150 years are conventionally prescribed (Leslie, 1989), a coppice-with-standard system is used both in pure and mixed sal forests in the proximity of settlements, and such forests are managed under rotation of 40–60 years for timber, fuelwood, fodder and grazing (Tewari, 1995). Recently, silvicultural treatment schedules for even- and uneven-aged sal forests were presented for varying management objectives (Rautiainen, 1999; Rautiainen *et al.*, 2000).

Selective felling is mostly practised in sal forests by both community-based and government-owned institutions (Rautiainen and Suoheimo, 1997; Webb and Sah, 2003). Community-managed forests consist of all age groups, whereas government-managed forests comprise mainly two age groups – matured trees and newly regenerated seedlings (Gautam, 1990). Selection felling in inadequately protected government forest may lead to serious degradation, as establishment of new regeneration is poor. A recent study (Gautam, 2001) indicated the possibility of integrating multiple products in sal forest management, based on experimentations on lopping and litter removal; the experiment showed no adverse effect on tree growth but increased regeneration in quality and quantity, indicating positive effects on biodiversity.

Considering the communities' need and spirit of multiple-product forest management, HMG (1995) has made provision for thinning, pruning, cleaning and other forest improvement activities for community forests, including sal forests. The objectives underlying such silvicultural operations are threefold: supply of intermittent products, creation of an avenue for intercropping and hygienic operations for the main crop, which may vary depending on the species composition and their importance at the local and/or regional level. The coppice systems allow managing forests with intermittent products (NTFPs including fodder and litter) while producing timber in the long term.

Conclusion

Managing sal forest for multiple products is a relatively recent development with sporadic instances of local management for timber and non-timber forest products. Multiple-product forest management appears not only desirable but also essential for sustaining sal forests in the region, for both ecological and socio-economic reasons. Implementation of community-based forestry programmes requires a commitment from local communities as well as policy makers towards managing sal forest for multiple products. Despite the requirements for multiple-product forestry, scientific information is still scanty, and further forest research is needed. Silviculturists are expected to respond to the continually changing demands on existing stands (Oliver and Larson, 1996). Sal forests, seen historically as timber sources, are to be managed now for multiple products, and this necessitates evolving silvicultural regimes. Foresters must now increase productivity (in quality and quantity) through silviculture that is sustainable and protects sal forest biodiversity.

It is widely documented that the degradation of sal forests resulted from heavy and haphazard lopping, grazing and fire. The anthropogenic factors may influence edaphic and ecological factors, such as light, drainage, soil nutrient and nutrient cycling. Past efforts, instead of promptly addressing these interlinked issues, focused on enforcing forest laws to stop grazing, lopping, NTFP collection and fire – ignoring the importance of these products to the people living in and close to sal forests.

Ecological processes of sal forest stand development clearly show rich diversity at the ground level, but decreasing diversity with height and ultimately sal dominance at the top canopy. Edaphic factors, regeneration, growth characteristics, growth allocations, soil nutrient, nutrient cycling, nitrogen translocation, stand structure and successional structure of sal forests are contributors to the ecological processes. Sal ecology favours a mixture of species at lower level, where many of the NTFPs occur. It is clear that the ecological processes create opportunies for many NTFPs. Leaf shedding creates opportunities to regenerate many species of ground flora. Leaf nitrogen translocation before leaf fall, for example, could reduce the adverse effect of ground litter removal or ground fire.

Ecological issues of sal forest management are related to light (opening of the canopy), fire, litter, grazing, lopping and harvesting NTFPs. All these issues seem interrelated and could be addressed by integrating the multiple products in sal forest management. Regulating lopping, for example, may open the canopy for regeneration establishment, while producing fodder; fodder supply eventually reduces the grazing pressure. Perennating characteristics of sal could be an opportunity for supplying fodder and small poles. Regulation of litter, which is good for compost, may reduce the fire hazard while promoting seed germination. Likewise, adverse actions by NTFP harvesters could be reduced or avoided by regulating these products through scientific research.

Anthropogenic factors are influenced by the livelihoods of the population living in and around sal forests. Millions of people rely on the products from sal forests, and these populations are both challenges and opportunities for sal forest management. Neglecting the need of local community while focusing on timber-only forestry could threaten the sustainability (ecological and social) of sal forests, whereas integrating NTFPs could create the opportunity for local people to participate in forest management. Settlements in and around sal forests could provide a labour pool for multiple-product management, which requires large work force for silvicultural operations and NTFP harvesting. Increasing NTFP production may contribute towards the economic opportunities and ultimately lead to the economic prosperity of local communities. Thus, ecological processes and anthropogenic factors of sal forests are intertwined, and offer opportunities for developing any sustainable forest management regimes.

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