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Plant diversity in managed sal (*Shorea robusta* Gaertn.) forests of Gorakhpur, India: species composition, regeneration and conservation

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Abstract. The sal (*Shorea robusta*) forest vegetation of Sohagibarawa Wildlife Sanctuary, Gorakhpur, India was analysed to assess plant diversity, regeneration pattern and the status of species conservation. A total of 208 plant species representing 165 genera and 72 families were recorded. Species richness, mean density and basal area of individuals in the observed forest were compared with those of other sal-dominated forests of India. The sal forest was rich in Papilionaceae (23 species), which contributed maximally to the total number of individuals of <30 cm girth. After sal, density was maximal for a leguminous shrub, *Moghania chappar*. In addition to the usual recruitment by seed, a number of species also showed non-seed regeneration through storage roots, sprouts or ramet proliferation. The individuals regenerating as sprouts from underground stem or storage organs contributed significantly to the sum total of individuals/ha. As much as 45.5% of the total individuals were of ramet origin and shared 10.6% of the total species richness of the forest. In stands facing moderate to low disturbance, thickets of dense entangled mass of vegetation, predominantly composed of thorny lianas, were identified that usually contained less common and rare species like *Rauwolfia serpentina, Desmodium latifolium, Crotalaria alata* and *Gloriosa superba* in addition to the frequent ones. These thickets help to conserve the special habitat conditions and provide protection for natural regeneration of several infrequent and rare plant species and thus contribute towards the maintenance and *in situ* conservation of overall diversity of recurrently disturbed forest vegetation.

Introduction

The forest vegetation of Gorakhpur, India, is of the semi-evergreen type with a number of deciduous elements. Most of the natural-growth forest cover has largely been substituted by plantation forests of sal (*Shorea robusta* Gaertn.). The associated community of plantation forest fairly mimics the composition of natural sal-dominated forest of the region (Champion and Seth 1968). The recurrent anthropogenic disturbances have rendered the system inhospitable for the regeneration and growth of wild plant associates, causing a net loss in plant diversity (Pandey 2000). As the cover of natural-growth forests is receding fast, managed forests are the only alternative for the conservation of wild plants (Halpern and Spies 1995). It is amply clear that the conservation of plant diversity for its present and future use is essential (Pimm et al. 1995).

Most of the studies on Indian sal forests are concerned with vegetation analysis of

Shorea communities (Gupta and Shukla 1991; Singh et al. 1995; Pande 1999; Pandey and Shukla 1999) and have compared plantation forests with natural sal forest vegetation (Uma Shankar et al. 1998). Observations on several Indian tropical deciduous forests have emphasized the impact of disturbance, especially on regeneration of tree species (Sukumar et al. 1992; Murali et al. 1996; Uma Shankar 2001). A few detailed studies on plant diversity of some tropical evergreen and deciduous forests in India are also available (Sukumar et al. 1992, 1998; Ayyappan and Parthasarathy 1999). Notwithstanding, a large-scale inventory of plant diversity of Indian sal forests is lacking. Further, the group of entangled mass of vegetation predominantly composed of woody climbers (thicket), which is of common occurrence in moist tropical forests (Richards 1952), was frequently encountered in moderately disturbed sal stands facing regular trampling and grazing by herds. These thickets, however, were largely covered by some liana species which possess deadly thorns and prickles. Several species uncommon to general forest vegetation were commonly found within these thickets. The present study was, therefore, undertaken to assess the plant diversity with emphasis on regeneration pattern and species conservation in managed sal forests of Gorakhpur. The observations have been analyzed to know the composition of taxa like families and species and the pattern of abundance of species of different growth forms, and the data have been compared with those for other sal forests of the country. The probable role of thickets in *in situ* conservation of less common species within a vegetation facing recurrent biotic interference is also discussed.

Study site

The study was conducted in Sohagibarwa Wildlife Sanctuary, Gorakhpur Forest Division in eastern Uttar Pradesh, India. The sanctuary is located between 27°05′ and 27°25′ N latitude and 83°20′ and 84°10′ E longitude, and at 95 m altitude. The climate of the region is seasonal and sub-tropical. The total average annual rainfall is about 1814 mm, 87% of which occurs during the wet summer or monsoon season (July–October). During the relatively dry periods of about 8 months (December–June), the monthly rainfall is less than 100 mm. The mean maximum temperature during wet summer, winter and dry summer is 35, 27 and 39 °C, while the mean minimum temperature is 26, 12 and 34 °C, respectively. The annual mean relative humidity is about 87% in the morning and 74% in the evening. The soil comprises Gangetic alluvium brought down by rivers like Ghaghara, Rapti, Rohin and Gandak from the Himalayas in the north. The texture is sandy loam and the soil reaction is near-neutral. The terrain is mostly flat with a gentle slope of 0–5° at some places. The forest cover of the sanctuary may be identified into three zones: (1) the peripheral zone, consisting of sal stands on fringes, bordered by cropland and facing maximum biotic interference, (2) the buffer zone, forming the middle layer vegetation of the sanctuary which faces regular but low to moderate disturbances, and (3) the core zone, characterized by dense vegetation facing only low and infrequent disturbance. These zones have been marked on the map by a different density of dots (Figure 5). Of the total 428.2 km^2 forested area of the sanctuary, 2.32% still has the natural, semi-evergreen forest vegetation.

Vegetation

Sal forests in global context

The woodlands of the world are categorised into 117 representative sites called the IBP (International Biological Programme) Woodland Data set (De Angelis et al. 1978), in which the tropical forests are represented by 26 sites. Of these, 18 are managed plantations at two locations in northeastern India and the remaining eight sites have been divided into true rain forests and broad-leaved deciduous forests on the sub-tropical fringe. The latitudinal span of tropical forests represented in the Woodland Data set ranges from Zaire to Gorakhpur, India (Burgess 1978). The 18 Indian broad-leaved plantations (site nos. 18–35) also include Gorakhpur Division and consist mostly of sal plantations of different age. Geographically, the sal occupies two main regions, the northern and central Indian regions separated by the Gangetic Plain. In the northern region, there is almost a continuous belt of sal stretching along the sub-Himalayan tract from Punjab to Assam. At some places, the sal extends some distance into the Plains of the *terai* region.

Sal forests of Gorakhpur

The forests of the eastern *terai* region (Gorakhpur Division) have been described as northern Tropical Moist Deciduous and Semi-evergreen Forests (Champion and Seth 1968). The plantation forests, mostly of sal, have replaced the natural sal-dominated forest vegetation which still exists in patches within the core zone. Thus, most of the patches of natural sal forest stands on the northern side of the Gorakhpur Forest Division had never been clear-felled. These patches, after selective cutting of sizable and mature trees, were left to regenerate naturally along with leftover sal trees. As a result, their composition matches the natural climax vegetation of the sal-dominated moist semi-evergreen forest. On the other hand, the forests towards the southern side of the Division (nearer to town) were generally clear-felled for growing plantation forests of sal. Evergreen elements are mostly confined to understorey, which keeps the forest floor moist and cool for most of the year. Sal is grown exclusively for timber. The age of harvest depends upon the use of timber and the availability of plantations. Sporadic and selective cutting for thinning is allowed up to the age of 40–60 years. No sal plantation in the Gorakhpur Division has so far been clear-felled. The maximum timber volume and the annual growth increment in sal wood have been observed at around 100 year of age under plantation. Flowering occurs at the age of nearly 15 years and the maximum life-span of the tree exceeds 160 years (Champion and Seth 1968).

Sal plantation

Sal has been planted in this region mostly through the *taungya* system, a type of shifting cultivation which, in India, started in Bengal and extended to Uttar Pradesh for sal plantations in Gorakhpur in 1923. In this system, the natural-growth forests are cut and the ground is cleared. The ploughed site is sown with freshly collected sal seeds in lines at intervals of about 10 feet between any two adjacent lines. The cultivation of cereals, pulses and vegetables is done between the lines for 2–3 consecutive years. Once the sal saplings get established, they cast shade to the cultivated food crops which can no longer be harvested. Now the field is abandoned, the sal saplings grow naturally and the old-field succession sets in. As the sal ages, the associated vegetation, developing naturally as a result of ecological succession, gains considerable species diversity. Several over- and understorey trees, a number of lianas and shrubs, perennial herbs and climbers may grow as sal associates (Working Plan 1991–1992). The resultant community, developing largely under the overstorey of sal trees, fairly mimics the composition of the characteristic natural-growth forests of the region.

Methods

Twenty-four sal stands were identified along a 30-km long forest belt, starting from near human habitation (southern boundary) and extending up to the core (northern side) of zonal forest of the Sohagibarwa Wildlife Sanctuary. The identified stands lay on both sides of a transect which traversed from the periphery to the core zone across the forest vegetation of the sanctuary (Figure 1, left, also cf. Figure 5). The age of the identified stands was approximated on the basis of forest record (Working Plan 1991–1992), girth size of the tree and growth features like branching pattern based on branch scars (Shukla and Ramakrishnan 1986), and was found to be 50 ± 5 year. The area of marked stands varied from 3 to about 10 ha. A hectare-plot, showing average vegetation for the stand, was marked for sampling in each of the 24 stands. Thus, every marked plot lay at least 500 m apart from the nearest one. Almost all the species were accounted and identified on the basis of the Departmental Herbarium and the regional Flora (Srivastava 1976).

The forest stands of this belt faced disturbance mainly in the form of cutting trees and branches for fuel-wood and the grazing and trampling by domestic herds. To quantify the degree of disturbance, a simple disturbance index (DI) was developed as the ratio of the number of cut as well as severed individuals expressed as the percent of the total number of individuals of all the perennial plants occurring within a sample area of 100 m^2 (Pandey and Shukla 1999). For this, every shoot, distinct at the soil surface, was treated as a separate individual irrespective of any probable subterranean interconnections. A nearly gradual decrease in DI value for stands from periphery to core was taken as a disturbance gradient. The value of DI was maximum ($>$90) for stands near the periphery (southern boundary). It decreased consistently towards the core. The stands situated at intermediate positions of the

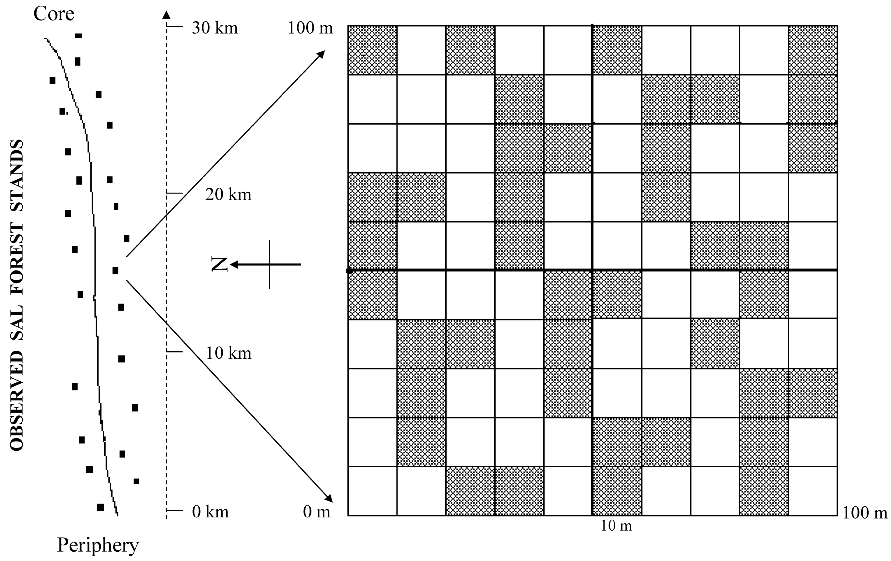

Figure 1. (Left) Detail of the situation of 24 sal stands and 1-ha plots within each stand marked along the side of the transect. (Right) 100 grids or quadrats each of 10 × 10 m^2 within a hectare plot. In each of the four quarters of the plot, which has 25 such grids, 10 random grids or quadrats, identified on the basis of a latin-square design, are hatched.

gradient were moderately disturbed (DI = 60–30). The last few stands situated near the core were the least disturbed (DI < 30) of all the 24 identified stands.

Each 1-ha (100 × 100 m^2) plot was divided into four quarters and each quarter was further subdivided into 25 grids or quadrats of 10 × 10 m^2 size (Figure 1, right). The trees (≥30 cm girth) were sampled in all the 2400 quadrats. For the sampling of other individuals (<30 cm girth), however, only 10 random quadrats in each quarter, i.e. a total of 40 quadrats per hectare plot, were marked on the basis of a 5 × 5 latin-square design. The occurrence was expressed as per 24 plots of 1 ha. The density and basal area of trees were calculated on the basis of all the 2400 quadrats and the values were expressed on a per hectare basis. For shrubs, lianas and perennial herbs, however, the values of density/ha and basal area/ha were derived from sampling of a total of 960 quadrats, i.e. 40 quadrats per hectare plot. The values for four growth-form components (trees, shrubs, lianas and perennial herbs) were pooled to calculate their Importance Value Indices. Very few individuals of annual herbs could be encountered and only under large openings, which were rare. The meagre annual herbs, which occurred only during wet summer, formed no significant part of the perennial plant community during the year and were, therefore, ignored. For trees and lianas which had a clear and clean trunk or bole, the basal area was calculated on the basis of their girth at breast height (gbh = 1.37 m from the ground surface). The basal area of other individuals which hardly had any sizable trunk was measured on the basis of their basal girth. The girth (g) was converted to basal area (a) by the formula $a = g^2/4\pi$. The individuals constituting forest vegetation were grouped among eight different girth classes (0–10, 10.1–20, 20.1–30, 30.1–60, 60.1–90, 90.1–120, 120.1–150, >150 cm) to observe the distribution of individuals among different girth classes.

Seedling, sapling and mature stages of individuals were determined mainly on the basis of the degree of trunk-crown differentiation and the crown-form. *Seedling*: young individuals, always of <1 year age and generally without any second order branching; *Sapling*: well established individuals with identifiable crown due to emergence of second and third order branches; *Mature*: individuals which have usually entered the reproductive phase were considered as mature. Trees and lianas showed a clear trunk and crown, but shrubs showed little differentiation. Their crown was supported by a small trunk, which was often branched. Perennial herbs generally became mature within the first year of their growth and developed much branched leafy-crown supported by a non-woody stem.

The non-seed regeneration was categorized into three types: by storage roots, by sprouting, and by ramet proliferation. A number of species could regenerate by their underground storage organs after the period of stress was over. Several species were able to send sprout-shoots from the remaining stump. The species producing 1–2 sprouts were treated as least-sprouters, those producing 3–5 sprouts were considered as moderate-sprouters and those producing more than 5 sprouts per stump were termed as high-sprouters. Saplings and mature individuals of several species could develop root-suckers on subterranean rootstock at a considerable interval from the parent shoot. These root-suckers developed into new individuals or ramets (Silvertown 1987). They were distinct over-ground but actually interconnected by subterranean spacers. The pattern of initial shoot growth of ramet was quite different from that of an individual originating directly from seed. Further, it could be easily examined by tracing the point of root–stem transition (Pandey and Shukla 2001).

Various phytosociological and diversity indices were calculated as follows: Importance Value Index (IVI) = relative frequency + relative density + relative basal cover, where the relative values of frequency, density and basal cover were derived as the value for a species expressed as percentage of the sum of these values for all the species of the community (Mueller-Dombois and Ellenberg 1974); Family Importance Value (FIV) = relative density + relative diversity + relative basal cover, where the relative diversity of a family was the number of species within the family expressed as percentage of the total number of species within all the families represented in the community (Mori et al. 1983). The dominance was determined as Simpson's index ($Cd = \Sigma p_i^2$), and diversity as Shannon's index ($\bar{H} = -\Sigma p_i \ln p_i$), where p_i represents the proportional abundance of the ith species in the community. Evenness was calculated by Pielou's index ($E = \bar{H}/\ln S$), where S is the species richness of the community (Magurran 1988). The dominance–diversity curve (species–individual curve) for the sal forest community as a whole and for different growth forms like trees, shrubs, lianas and perennial herbs were compared.

The sum of basal area and the sum of importance values were also compared among different growth forms of species. On the basis of relative abundance of individuals at the seedling, sapling and mature stages, the status of regeneration of the constituent species of different growth forms was determined as *Good* (seedlings

Table 1. General floristic and diversity characteristics of the forest vegetation of Gorakhpur.

Total no. of perennial plant species	208
Total no. of genera	165
Total no. of families	72
Species/genus ratio	1.26
Species/family ratio	2.89
Density of individuals/ha (having ⩾30 cm girth)	404
Density of individuals/ha (having <30 cm girth)	20413
Average species richness/ha	40.4 ± 12.5
Range of species richness	17–62
Shannon's Index ($\bar{H}$)	3.960
Simpson's Index (Cd)	0.0656
Pielou's Index (E)	0.63

≫ saplings > mature individuals), *Fair* (seedlings > saplings ≥ mature individuals), *Poor* (seedlings < saplings and saplings ≥ mature individuals) and *Very poor* (seedlings ≪ saplings < mature individuals).

In stands facing lesser but regular disturbance, the understorey vegetation was frequently clumped in the form of thickets of different size. The boundary of the thicket could easily be demarcated by passages made by grazing animals. The composition of different thickets and the density of species constituting these thickets were determined and their ground area coverage was also measured.

Results

A total of 208 species, representing 165 genera and 72 families, were recorded within 24 ha of sal stands. The average number of species per hectare sample plot was 40.4 ± 12.5, ranging from 17 for a highly disturbed stand to 62 for the least disturbed stand. The number of species per genus was 1.26 and that per family was 2.89. In general, the sal stands showed a fairly high Shannon index of species diversity ($\bar{H}$ = 3.96). On the other hand, the dominance, expressed as Simpson's index, was quite low (Cd = 0.0656; Table 1). Among the four different growth forms, viz. perennial herbs, shrubs, lianas and trees, the species richness was maximum for trees (93) followed by shrubs (50), lianas (34) and perennial herbs (31). The individuals were grouped into two categories: those having ⩾30 cm girth and those having <30 cm girth. Thus, the mean density of individuals having ⩾30 cm girth was only 404/ha while that for individuals having <30 cm girth was 20413/ha. Evidently, tree species contributed significantly to the density of individuals of <30 cm girth (Table 2).

Shorea robusta was the most frequent species. After *S. robusta*, the next most frequent species were *Mallotus philippensis* and *Ichnocarpus frutescens*, followed by *Clerodendrum infortunatum* and *Desmodium gangeticum*. The species which showed over 60% occurrence were *Schleichera oleosa*, *Holarrhena antidysenterica* and *Flacourtia indica* among trees, *Moghania bracteata*, *M. chappar*, *M. lineata*,

Table 2. Density/ha, basal area and IVI of different growth forms (percent values are shown in parentheses).

Habit-groups	Density/ha		Basal area (cm^2/ha)	IVI
	Individuals of ≥30 cm girth	Individuals of <30 cm girth		
Trees	402	8449.6 (41.4)	222318 (96.4)	181 (60.4)
Shrubs	–	7562.6 (37)	5600 (2.4)	61 (20.3)
Lianas	2	2261.9 (11.1)	2015 (0.9)	30 (10)
Perennial herbs	–	2138.6 (10.5)	679 (0.3)	28 (9.3)
Total	404	20412.7	230612	300

Desmodium pulchellum and *Hemidesmus indicus* among shrubs, *Piper* sp. among climbers and *Curculigo orchioides* among perennial herbs (Table 3).

The mean density per hectare of individuals of ⩾30 cm girth was maximum for sal (306), followed by *Mallotus* (61). It was, however, less than 3 for *Bridelia retusa, Cassia fistula, Tectona grandis* and *Terminalia tomentosa*. *Mallotus philippensis, Holarrhena antidysenterica, Schleichera oleosa, Flacourtia indica, Antidesma ghaesembilla, Terminalia tomentosa* and *Streblus asper* contributed much to the numerical strength of individuals of <30 cm girth and to the sum of basal area on a per hectare basis. *Desmodium latifolium, Kirganelia reticulata* and *Glycosmis pentaphylla* were the rarest shrubs (<0.1 individuals/ha). On the other hand, a number of shrubs showed a very high mean density: *Moghania chappar* – 2669/ha, *M. bracteata* – 994/ha and *Leea alata* – 686/ha. *Gloriosa superba, Mezoneurum cuculatum* and *Scindapsus officinalis* were the rarest lianas (<1 individual/ha). More common lianas (mean density >100/ha) were *Tiliachora acuminata* and *Ichnocarpus frutescens*. A few rare perennial herbs like *Careya herbacea* and *Crotalaria prostrata* were strictly localized in a single sal stand which was situated at the periphery; it was highly disturbed and had grassy undergrowth. After *Shorea robusta* and *Mallotus philippensis*, only *Holarrhena* among trees, *Clerodendrum* and *Moghania* spp. among shrubs and *Ichnocarpus* among climbers had an IVI of >5. All other species showed much smaller importance values (Table 3).

The vegetation of sal stands comprised 72 families, 37 of which were represented by a single genus. The species richness of some families was quite high: Papilionaceae had 23 species; Euphorbiaceae 13; Caesalpiniaceae 11; Moraceae 9; and Verbenaceae 8 species. These five families together accounted for 30.8% of the total species, 19.6% of the total individuals having >30 cm girth and 51.4% of total individuals having <30 cm girth. They shared 12.1% of the sum of basal area and 31.3% of the sum of FIV. The family Dipterocarpaceae obviously contributed the maximum density, as sal belongs to this family. Papilionaceae, on the other hand, had the maximum number of individuals below 30 cm girth, followed by Euphorbiaceae and Apocynaceae. Nine poorly represented families had less than 10 individuals of >30 cm girth and 10 such families were represented by a single individual. Thirty-eight families had no individual having >30 cm girth and 21 of these had a FIV of <1 (Table 4).

Among 177 woody perennials, the regeneration status, expressed on the basis of

Table 3. The species composition of sal forest showing constituent species of different habits (T: tree; S: shrub; L: liana; H: perennial herb) and their families.

Species	Family	Habit	Occur-rence	Density/ha		Basal area (cm^2/ha)	IVI
				≥30 cm gbh	<30 cm gbh		
Abrus precatorius L.	Papilionaceae	L	2	–	1.8	9.22	0.244
Abutilon indicum (L.) Sweet	Malvaceae	S	3	–	27.5	55.0	0.494
Acacia nilotica (L.) Del	Mimosaceae	T	1	–	0.3	0.28	0.111
Acacia catechu Willd.	Mimosaceae	T	1	0.04	0.41	6.82	0.115
Achyranthes aspera L.	Amaranthaceae	S	3	–	10.7	7.70	0.399
Adhatoda vasica Nees.	Acanthaceae	S	1	–	0.8	2.30	0.115
Adina cordifolia (Roxb) Hook. f.	Rubiaceae	T	2	0.21	10.8	26.05	0.294
Aegle marmelos (L.) Correa	Rutaceae	T	1	0.04	2.2	8.38	0.124
Aganosma caryophyllata G. Don.	Apocynaceae	L	1	–	0.21	0.78	0.111
Ageratum conyzoides L.	Asteraceae	H	14	–	154.9	111.53	2.380
Alangium salvifolium (Linn.f.) Wang	Cornaceae	T	1	0.04	0.41	5.06	0.114
Alstonia scholaris (Linn.) R. Br.	Apocynaceae	T	4	0.04	0.41	5.82	0.468
Anthocephalus cadamba (Roxb) Miquel	Rubiaceae	T	1	0.12	2	33.8	0.140
Antidesma ghaesembilla Gaertn.	Euphorbiaceae	T	10	1.67	170.4	369.5	2.120
Ardisia solanacea (Poir.) Roxb.	Myrsinaceae	S	1	–	0.3	0.40	0.111
Aristolochia indica L.	Aristolochiaceae	L	4	–	2.1	1.50	0.462
Arundo donax L.	Poaceae	H	5	–	14.7	4.70	0.642
Asparagus racemosus Willd.	Liliaceae	L	8	–	32.1	64.2	1.088
Aerva lanata L.	Amaranthaceae	H	2	–	44	14.1	0.446
Azadirachta indica A. Juss	Miliaceae	T	1	0.12	3	44.6	0.150
Bambusa arundinacea	Poaceae	S	1	–	4	54.1	0.154
Barringtonia acutangula Gaertn.	Lecythidaceae	T	2	0.42	3	79.5	0.285
Bauhinia malabarica Roxb.	Caesalpiniaceae	T	2	1.25	26.7	148.7	0.425
Bauhinia purpurea L.	Caesalpiniaceae	T	1	0.12	4.2	18.1	0.248
Bauhinia vahlii W. EA.	Caesalpiniaceae	L	10	0.12	105.4	84.54	1.687
Bauhinia variegata L.	Caesalpiniaceae	T	6	0.12	1.4	12.4	0.692
Bischofia javanica Blume	Euphorbiaceae	T	1	0.12	2.0	30.3	0.133
Boerhaavia diffusa L.	Nyctaginaceae	S	2	–	6.7	3.35	0.262
Bombax ceiba L.	Bombacaceae	T	1	0.04	1.0	7.0	0.118
Bridelia retusa Hook. f.	Euphorbiaceae	T	12	2.5	226.3	704.5	2.766
Bridelia stipularis (L.) Blume	Euphorbiaceae	L	3	1.5	5.5	123.8	0.424
Butea monosperma (Lamk.) Tabu.	Papilionaceae	T	1	0.04	1	7	0.118
Caesalpinia bonducella Flem.	Caesalpiniaceae	L	3	–	31.3	90.1	0.53
Caesalpinia sepiaria L.	Caesalpiniaceae	L	2	–	3.3	12.9	0.256
Callicarpa macrophylla Vahl.	Verbenaceae	S	1	–	2.1	10.8	0.125
Calamus tenius Roxb.	Palmae	S	2	–	1.67	16.2	0.247
Capparis zeylanica L.	Capparidaceae	L	1	–	1.3	1.7	0.121
Careya arborea Roxb.	Lecythidaceae	T	2	0.83	3.3	105	0.296
Careya herbacea Roxb.	Lecythidaceae	H	1	–	0.08	0.02	0.11
Carissa spinarum L.	Apocynaceae	T	5	0.12	59.2	91.2	0.9
Casearia elliptica Roxb.	Samydaceae	T	1	0.12	6.4	25.9	0.151
Casearia tomentosa Roxb.	Samydaceae	T	10	0.83	281.2	564.1	2.75
Cassia fistula L.	Caesalpiniaceae	T	7	2.75	51.7	235.2	1.162
Cassia nodosa Buch.-ham.	Caesalpiniaceae	T	2	1.92	4.6	151.1	0.326
Cassia tora L.	Caesalpiniaceae	S	3	–	4	5.12	0.362
Centella asiatica (L.) Urban	Apiaceae	H	4	–	64	5.1	0.772
Cissampelos pareira L.	Menispermaceae	L	1	–	1.3	0.9	0.12
Clematis paniculata	Rananculaceae	S	1	–	2.2	1.7	0.121
Clerodendrum infortunatum Auct.	Verbenaceae	S	22	–	1097.1	789.9	8.113
Clerodendrum indicum (L.) Ktze.	Verbenaceae	S	2	–	2.4	2.8	0.241

Table 3. (*continued*)

Species	Family	Habit	Occurrence	Density/ha		Basal area (cm^2/ha)	IVI
				≥30 cm gbh	<30 cm gbh		
Colebrookia oppositifolia Sm.	Verbenaceae	S	4	–	15.4	30.8	0.543
Corchorus capsularis L.	Tiliaceae	S	1	–	1.8	0.1	0.12
Cordia dichotoma Forst.	Ehretiaceae	T	1	0.04	1	3.9	0.122
Costos speciosus (Koenig) Smith	Zingiberaceae	H	9	–	3.3	2.4	1.041
Crotalaria alata	Papilionaceae	S	3	–	2	0.64	0.35
Crotalaria prostrata	Papilionaceae	H	1	–	1	0.12	0.12
Crotalaria sp.	Papilionaceae	H	2	–	1	0.32	0.24
Croton oblongifolius Roxb.	Euphorbiaceae	T	4	0.12	30.8	37.3	0.626
Curculigo orchioides Gaertn.	Hypoxidaceae	H	16	–	1480	473.6	9.14
Dalbergia lanceolaria L. f.	Papilionaceae	T	3	0.04	12.1	15.8	0.407
Dalbergia sissoo Roxb.	Papilionaceae	T	1	0.08	2.0	185.1	0.2
Desmodium gangeticum (L.) Dc.	Papilionaceae	S	19	–	808.5	258.72	6.161
Desmodium heterocarpon (L.) Dc.	Papilionaceae	S	6	–	24.4	7.8	0.803
Desmodium latifolium Dc.	Papilionaceae	S	1	–	0.08	0.02	0.11
Desmodium pulchellum (L.) Benth.	Papilionaceae	S	16	–	621.3	447.3	5.004
Desmodium triangulare (Retz.) Merr.	Papilionaceae	S	2	–	17.0	5.4	0.312
Dillenia indica L.	Dilleniaceae	T	4	0.42	8.8	39.1	0.515
Diospyros malabarica (Desr.) Kostel	Ebenaceae	T	6	1.5	39.6	307.2	1.01
Ehretia laevis L.	Boraginaceae	T	1	0.04	0.21	7.5	1.01
Elephentopus scaber L.	Asteraceae	H	7	–	122.1	22.0	2.208
Emblica officinalis Gaertn.	Euphorbiaceae	T	2	0.21	3.9	35.1	0.264
Erythrina indica Lamk.	Papilionaceae	T	1	0.12	0.12	15.5	0.117
Eugenia jambolana Lamk.	Myrtaceae	T	3	0.42	7.6	146.9	0.473
Eugenia heyneana Duthie.	Myrtaceae	T	10	1.67	94.5	549.0	1.84
Ficus benghalensis L.	Moraceae	T	2	0.12	8.6	72.4	0.30
Ficus carica L.	Moraceae	T	1	0.12	3.2	50.1	0.15
Ficus glomerata Roxb.	Moraceae	T	10	0.21	126.3	185.5	1.82
Ficus hispida L.	Moraceae	T	1	0.12	1.12	16.8	0.127
Ficus infectoria Roxb.	Moraceae	T	1	0.12	1.21	21.4	0.128
Ficus racemosa L.	Moraceae	T	1	0.12	–	23.1	0.121
Ficus religiosa L.	Moraceae	T	1	0.12	–	64.6	0.136
Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae	T	17	0.71	297.5	501.0	3.56
Fleurya interrupta (L.) Gaud.	Urticaceae	S	1	–	0.12	0.03	0.111
Gloriosa superba L.	Liliaceae	L	1	–	0.83	0.13	0.114
Gmelina asiatica L.	Verbenaceae	T	1	0.04	0.41	3.63	0.113
Glycosmis pentaphylla DC	Rutaceae	S	1	–	0.12	0.13	0.11
Grewia asiatica L.	Tiliaceae	T	1	–	0.21	19.6	0.119
Grewia elastica Royle.	Tiliaceae	T	1	–	0.21	20.7	0.119
Helminthostachya zeylanica L.	Ophioglossaceae	H	4	–	3	0.54	0.47
Hemidesmus indicus (L.) Sch.	Periplocaceae	S	16	–	261.3	188.2	3.153
Hemigraphis hirta (Vahl.) Anders.	Acanthaceae	H	3	–	1.7	0.54	0.35
Holarrhena antidysenterica (Roth) A Dc	Apocynaceae	T	16	0.21	614.2	773.0	5.11
Holoptelea integrifolia (Roxb.) Planch	Ulmaceae	T	1	–	0.12	0.1	0.111
Hygrophilla auriculata (Sch.) Heine	Acanthaceae	H	1	–	1	0.08	0.115
Hymenodyction sp.	Rubiaceae	L	2	–	33.8	10.8	0.394
Ichnocarpus frutescens (L.) Ait and Ait	Apocynaceae	L	23	–	1487.9	1071.3	10.23
Indigofera hamiltoni R. Grah.	Papilionaceae	S	3	–	22.1	28.3	0.461
Ipomoea fistulosa Mart.	Convolvulaceae	S	1	–	1	1.28	0.116
Jatropha gossypifolia L.	Euphorbiaceae	S	1	–	0.8	1.6	0.111
Jatropha curcas L.	Euphorbiaceae	S	1	–	0.3	0.4	0.111
Justicia sp.	Acanthaceae	S	1	–	0.41	0.5	0.112
Kirganelia reticulata (Poir.) Baill.	Euphorbiaceae	S	1	–	0.3	1.5	0.117
Kydia calycina Roxb.	Malvaceae	T	1	0.4	0.12	3.8	0.113

Table 3. (*continued*)

Species	Family	Habit	Occur-rence	Density/ha		Basal area (cm^2/ha)	IVI
				≥30 cm gbh	<30 cm gbh		
Lagerstroemia indica L.	Lythraceae	T	1	0.12	0.3	12.1	0.117
Lagerstroemia parviflora Roxb.	Lythraceae	T	1	–	0.12	0.11	0.111
Lannea coromandelina (Houtt.) Merrill.	Anacardiaceae	T	1	–	0.04	0.05	0.11
Lawsonia inermis L.	Lythraceae	S	1	–	1	0.32	0.115
Leea alata Edgew.	Vitaceae	S	13	–	686.8	879.1	4.203
Leea aspera Edgew.	Vitaceae	S	6	–	85.6	246.5	1.19
Leea macrophylla L.	Vitaceae	T	2	–	3.41	17.4	0.257
Lepidaghathis incurva Don.	Acanthaceae	H	1	–	0.3	0.1	0.112
Leucas cephalotes Spreng.	Lamiaceae	H	3	–	2.6	0.83	0.35
Litsaea monopetala Lamk.	Lauraceae	T	1	–	0.12	0.08	0.111
Lygodium sp.	Lygodiaceae	L	6	–	43	7.74	0.893
Macaranga indica Wight	Euphorbiaceae	T	1	–	0.12	0.08	0.111
Madhuca indica Gmel.	Sapotaceae	T	1	0.04	0.12	12.1	0.116
Mallotus philippensis Muell. Arg.	Euphorbiaceae	T	23	61	2145.4	18049.78	21.053
Malvastrum coromandelianum (L) Garcke	Malvaceae	H	2	–	8.6	2.75	0.271
Mangifera indica L.	Anacardiaceae	T	1	0.12	1	33.8	0.129
Melochia corchorifolia L.	Sterculiaceae	S	3	–	2.6	0.83	0.35
Melenthesa rhamnoides	Scrophulariaceae	S	1	–	0.4	0.3	0.112
Melia azadirachata L.	Meliaceae	T	1	0.12	1.4	20.8	0.125
Mezoneurum cucullatum W. and A. Prodr.	Papilionaceae	L	1	–	0.2	0.4	0.111
Miliusa tomentosa (Roxb.)	Annonaceae	T	10	0.83	39.9	63.8	1.365
Milletia auriculata Baker	Papilionaceae	L	10	0.12	35.8	148.9	1.368
Mimosa pudica L.	Mimoseae	S	2	–	2	0.64	0.24
Mitragyna parvifolia Korth.	Rubiaceae	T	7	0.42	89.7	213.3	1.313
Moghania bracteata (Roxb.) in Li.	Papilionaceae	S	17	–	994.2	974.3	7.19
Moghania chappar (Ham.Ex.Benth.) Ktze.	Papilionaceae	S	16	–	2669	1921.7	15.49
Moghania lineata (L.) Ktze.	Papilionaceae	S	18	–	959.2	306.9	6.78
Momordica Sp. (wild species)	Cucurbitaceae	L	1	–	0.5	0.16	0.112
Morinda exserta	Rubiaceae	T	1	0.04	–	5.12	0.112
Moringa pterygospermum Gaertn.	Moringaceae	T	1	0.04	–	6.48	0.113
Murraya koenigii (L.) Spreng.	Rutaceae	T	1	0.08	–	6.6	0.113
Morus indica L.	Moraceae	T	6	0.83	31.4	86.1	0.734
Nausturtium sp.	Brassicaceae	L	4	–	31.4	2.5	0.601
Nicotiana plumbaginifolia Viv.	Solanaceae	H	2	–	2.2	0.7	0.24
Naravelia zeylanica DC.	Rananculaceae	L	1	–	1	.72	0.115
Ocimum cannum Sims	Lamiaceae	H	2	–	3.2	1	0.25
Ophioglossum sp.	Ophioglossaceae	H	9	–	16.2	1.3	1.101
Oplismenus compositus (l.) Beauv.	Poaceae	H	11	–	49.5	4	1.492
Ougeinia dalbergioides Benth.	Papilionaceae	T	1	0.04	–	6.5	0.113
Oxalis corniculata L.	Oxalidaceae	H	8	–	56.4	4.5	1.182
Oxystelma secamone (L.) Shum	Asclepiadaceae	L	1	–	1	0.72	0.115
Peltophorum pterocarpum (Dc.) Baker	Caesalpineae	L	1	–	0.04	0.1	0.11
Peristrophe bicalyculata (Retz.) Nees.	Acanthaceae	S	2	–	3	1	0.244
Piper sp.	Piperaceae	L	18	0.12	9.2	15.2	2.101
Pithecellobium dulce (Roth.) Bth.	Mimoceae	S	1	–	5.0	10	0.134
Phyla nudiflora L.	Verbenaceae	L	11	–	41.5	13.3	1.455
Physalis minima L.	Solanaceae	H	3	–	2	0.2	0.35
Plesminium sp.	Araceae	H	1	–	0.43	0.03	0.112
Pogostemon plectranthoides Desf.	Lamiaceae	S	6	–	43.2	55.3	0.912
Porana paniculata Roxb.	Convolvulaceae	L	1	–	0.43	0.03	0.112
Pongamia pinnata (L.) Pierrc	Papilionaceae	T	1	0.12	2.4	11.1	0.124
Pothos sp.	Araceae	L	5	–	39.4	12.6	0.765
Psidium guajava L.	Myrtaceae	T	1	0.12	1.2	9.4	0.124

Table 3. (*continued*)

Species	Family	Habit	Occurrence	Density/ha ≥30 cm gbh	Density/ha <30 cm gbh	Basal area (cm^2/ha)	IVI
Pterocarpus marsupium	Papilionaceae	T	1	0.04	–	21.5	0.118
Pterospermum acerifolium Willd.	Sterculiaceae	T	1	0.04	–	29.5	0.122
Putranjiva roxburghii Wall.	Euphorbiaceae	T	4	0.12	11.4	92.2	0.551
Randia uliginosa (L.) DC.	Rubiaceae	T	1	0.12	–	19.4	0.119
Rauwolfia serpentina (L.) Benth.	Apocynaceae	S	1	–	0.4	0.12	0.112
Rosa involucrata	Rosaceae	S	3	–	1.3	0.42	0.346
Rungia repens (L.) Nees.	Acanthaceae	H	10	–	57	4.6	1.412
Saccharum spontaneum L.	Poaceae	H	8	–	32.0	10.24	1.064
Schleichera oleosa (lour.) Oken.	Sapindaceae	T	17	1.6	347.5	382.1	3.76
Scindapsus officinalis Schott.	Araceae	L	1	–	0.21	0.4	0.111
Semecarpus anacardium L. f.	Anacardiaceae	T	2	0.83	2.9	158.3	0.312
Shorea robusta Gaertn.	Dipterocarpaceae	T	24	306	2085.4	191616.8	97.29
Sida rhombifolia L.	Malvaceae	S	2	–	1.4	0.5	0.24
Sida acuta Burrm. f.	Malvaceae	H	5	–	4.6	9.2	0.594
Sida cordifolia L.	Malvaceae	H	3	–	2.3	0.74	0.35
Smilax macrophylla Roxb.	Smilaceae	L	4	–	40.3	116.1	0.695
Smilax prolifera Roxb.	Smilaceae	L	14	–	82.5	59.4	2.013
Solanum indicum L.	Solanaceae	S	2	–	1	1.3	0.236
Solanum torvum Sw.	Solanaceae	S	1	–	0.5	0.36	0.112
Solanum xanthocarpum Schrad.	Solanaceae	S	1	–	0.8	1.02	0.114
Spondias pinnata (L. f.) Kurz.	Anacardiaceae	T	1	0.12	–	15.4	0.117
Stephania japonica Thumb.	Menispermaceae	L	2	–	0.12	0.5	0.231
Stereospermum suaveolens Dc.	Bignoniaceae	T	2	0.21	4.2	118.4	0.296
Streblus asper Lour.	Moraceae	T	12	0.43	114.6	407.1	2.07
Strychnos nux-vomica L.	Loganiaceae	T	1	0.04	0.12	8.2	0.111
Tamarindus indica L.	Caesalpinaceae	T	1	0.12	0.12	78.1	0.142
Tectona grandis L.	Verbenaceae	T	7	2.1	40.4	1272.2	1.55
Terminalia arjuna (Roxb. ex Dc.) W and A	Combretaceae	T	2	0.12	16.6	149.4	0.37
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	T	1	0.12	2.0	62.0	0.139
Terminalia chebula Retz.	Combretaceae	T	7	0.12	41.4	145	0.862
Terminalia tomentosa W. and A.	Combretaceae	T	13	2.58	139.6	1973.2	3.021
Thespesia lampas Dalz. & Gibs.	Malvaceae	T	6	1.25	52.1	173.6	1.008
Tiliacora acuminata Lamk.	Menispermaceae	L	13	–	218.75	157.5	2.592
Tinospora cordifolia willd.	Menispermaceae	L	3	–	8.2	6	0.382
Toona ciliata Roem.	Mileaceae	T	1	–	1.3	2.6	0.117
Trewia nudiflora L.	Euphorbiaceae	T	1	0.42	1.7	197.0	0.2
Trianthema portulacastrum L.	Aizoaceae	H	1	–	2	0.6	0.12
Trichosanthes cucumerina L.	Cucurbitaceae	L	1	–	1.3	1	0.116
Triumfetta pentendra A Rich.	Tiliaceae	S	4	–	68.2	21.8	0.449
Typhonium trilobatum (L.) Sch.	Araceae	H	3	–	5	1.6	0.361
Uraria picta (Jaeq.) Desv.	Papilionaceae	S	1	–	0.5	0.2	0.112
Urena lobata L.	Malvaceae	S	4	–	84.3	27	0.881
Vitex negundo L.	Verbenaceae	L	1	–	0.12	0.12	0.111
Vitis trifolia L.	Vitaceae	L	1	–	0.12	0.12	0.111
Weindlandia heynei Santapau and Merchant	Rubiaceae	T	1	0.04	–	0.8	0.11
Woodfordia fruiticosa (L.) Kurz.	Lythraceae	T	3	0.8	17.5	118.6	0.476
Xanthium strumarium L.	Asteraceae	H	3	–	113.4	18.7	0.922
Zephyranthes rosea Lindle.	Amaryllidaceae	H	3	–	3	1	0.35
Zizyphus mauritiana Lamk.	Rhamnaceae	T	7	0.12	33.9	94.6	0.997
Zizyphus oenoplia (L.) Mill.	Rhamnaceae	T	1	0.12	4.1	26.1	0.14
Unidentified 1		T	1	0.04	–	26	0.121
Unidentified 2 (local name – Madhuri)		T	1	–	3.3	6.6	0.133

The occurrence of different species is listed out of 24-ha plots. Their density (separately for individuals of ≥30 cm girth and for individuals of <30 cm girth), basal area and IVI are also listed.

Table 4. Species richness and FIV of different families and their contribution to the sum of density and sum of basal area cover for the whole of the sal forest.

Family name	Species richness	Density (individuals/ha)		Basal area (cm^2/ha)	FIV
		≥30 cm girth	<30 cm girth		
Dipterocarpaceae	1	306	2085.4	191616.8	95
Papilionaceae	23	0.6	6175.7	4372.72	42.7
Euphorbiaceae	13	67.66	2598.92	19643.06	28
Apocynaceae	6	0.37	2162.31	1942.22	14.2
Verbenaceae	8	2.14	1199.43	2123.53	10
Hypoxidaceae	1	–	1480	473.6	7.8
Caesalpiniaceae	11	6.4	232.76	836.36	7.3
Vitaceae	4	–	775.93	1143.1	6.2
Moraceae	9	2.19	286.4	927.1	6
Malvaceae	8	1.65	180.92	272.59	4.9
Rubiaceae	7	0.95	136.3	309.27	4.2
Acanthaceae	7	–	64.21	9.12	3.7
Combretaceae	4	2.94	199.6	2329.6	3.7
Asteraceae	3	–	390.4	152.23	3.4
Menispermaceae	4	–	228.37	164.9	3.1
Samydaceae	2	0.95	287.6	590	2.6
Solanaceae	5	–	6.5	3.58	2.5
Poaceae	4	–	100.2	73.04	2.4
Myrtaceae	3	2.21	103.3	705.3	2.3
Sapindaceae	1	1.6	347.5	382.1	2.3
Tiliaceae	4	–	70.42	62.2	2.3
Flacourtiaceae	1	0.71	297.5	501	2.1
Araceae	4	–	45.04	14.63	2.1
Anacardiaceae	4	1.07	3.94	207.55	2
Lythraceae	4	0.92	18.92	131.13	2
Mimosaceae	4	0.04	7.71	17.74	2
Periplocaceae	1	–	261.3	188.2	1.8
Lamiaceae	3	–	49	57.13	1.7
Lecythidaceae	3	1.25	6.38	184.52	1.6
Smilaceae	2	–	122.8	175.5	1.6
Meliaceae	3	0.24	5.7	68	1.5
Rutaceae	3	0.12	2.32	15.11	1.5
Amaranthaceae	2	–	54.7	21.8	1.2
Rhamnaceae	2	0.24	38	120.7	1.2
Cucurbitaceae	2	–	1.8	1.16	1
Liliaceae	2	–	32.93	64.33	1
Ophioglossaceae	2	–	19.2	1.84	1
Convolvulaceae	2	–	1.43	1.31	0.9
Ranunculaceae	2	–	3.2	2.42	0.9
Sterculiaceae	2	0.04	2.6	30.33	0.9
Apiaceae	1	–	64	5.1	0.8
Ebenaceae	1	1.5	39.6	307.2	0.8
Annonaceae	1	0.83	39.9	63.8	0.7
Oxalidaceae	1	–	56.4	4.5	0.7
Lygodiaceae	1	–	43	7.74	0.7
Brassicaceae	1	–	31.4	2.5	0.6
Nyctaginaceae	1	–	6.7	3.35	0.6

Table 4. (*continued*)

Family name	Species richness	Density (individuals/ha)		Basal area (cm^2/ha)	FIV
		≥30 cm girth	<30 cm girth		
Aizoaceae	1	–	2	0.6	0.5
Amaryllidaceae	1	–	3	1	0.5
Aristolochiaceae	1	–	2.1	1.5	0.5
Asclepiadaceae	1	–	1	0.72	0.5
Bignoniaceae	1	0.21	4.2	118.4	0.5
Bombacaceae	1	0.04	1	7	0.5
Boraginaceae	1	0.04	0.21	7.5	0.5
Capparidaceae	1	–	1.3	1.7	0.5
Cornaceae	1	0.04	0.41	5.06	0.5
Dilleniaceae	1	0.42	8.8	39.1	0.5
Ehretiaceae	1	0.04	1	3.9	0.5
Lauraceae	1	–	0.12	0.08	0.5
Loganiaceae	1	0.04	0.12	8.2	0.5
Moringaceae	1	0.04	–	6.48	0.5
Myrsinaceae	1	–	0.3	0.4	0.5
Palmae	1	–	1.67	16.2	0.5
Piperaceae	1	0.12	9.2	15.2	0.5
Rosaceae	1	–	1.3	0.42	0.5
Sapotaceae	1	0.04	0.12	12.1	0.5
Scrophulariaceae	1	–	0.4	0.3	0.5
Ulmaceae	1	–	0.12	0.1	0.5
Urticaceae	1	–	0.12	0.03	0.5
Zingiberaceae	1	–	3.3	2.4	0.5
Unidentified family 1	1	0.04	–	26	0.5
Unidentified family 2	1	–	3.3	6.6	0.5
Total	208	403.69	20412.73	230612	300

The families (Engler and Prantl 1964) have been arranged in decreasing order of their FIV.

the relative proportion of individuals at the seedling, sapling and mature stages, was Good for 18.6% species, Fair for 31.6%, Poor for 19.8% and Very poor for 29.9% of the species. All the herbaceous perennials were good at regeneration. The majority of tree species showed fairly high regeneration. More than half of the shrubby species showed poor to very poor regeneration. In general, the regeneration of lianas was also poor, though species like *Tiliachora acuminata, Ichnocarpus frutescens* and *Smilax prolifera* regenerated well (Table 5). The girth size was used to assess the maturity status of individuals, which were distributed among eight different girth classes. More than 53% of individuals belonged to the minimum girth class range of 0–10 cm and 45% of individuals belonged to the next higher range, 10.1–20 cm. Still higher girth classes were represented by less than 2% of the total individuals (Figure 2).

The relative abundance of species within the community was represented by dominance–diversity curves. The general curve for the regional sal forest was initially steep and fairly convex or flat afterwards. The curves for trees and for woody climbers were initially much steeper as compared to that for shrubby individuals. Woody climbers, however, showed a near vertical cascade (Figure 3).

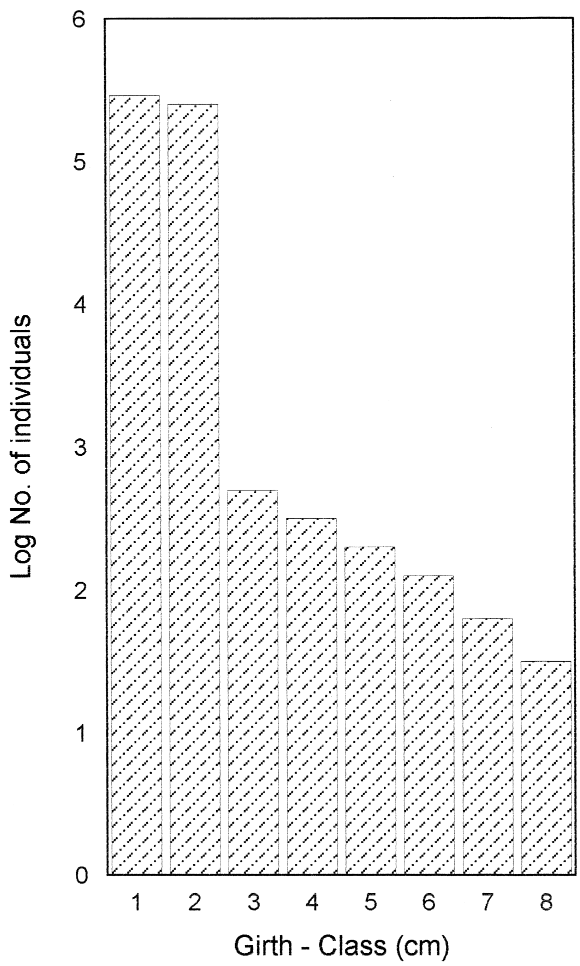

Figure 2. Distribution of individuals among eight different girth classes: [girth class (1) 0–10 cm; (2) 10.1–20 cm; (3) 20.1–30 cm; (4) 30.1–60 cm; (5) 60.1–90 cm; (6) 90.1–120 cm; (7) 120.1–150 cm; (8) >150 cm].

Table 5. Regeneration status of species under different habit groups (trees, shrubs, lianas and herbs) in sal forest.

Regeneration status	Trees	Shrubs	Lianas	Herbs	Total
Good (seedling $\gg$ sapling $>$ mature)	17	12	4	31	64
Fair (seedling $>$ sapling $\geq$ mature)	39	11	6	–	56
Poor (seedling $<$ sapling $\geq$ mature)	16	11	8	–	35
Very poor (seedling $\ll$ sapling $<$ mature)	21	16	16	–	53
Total	93	50	34	31	208

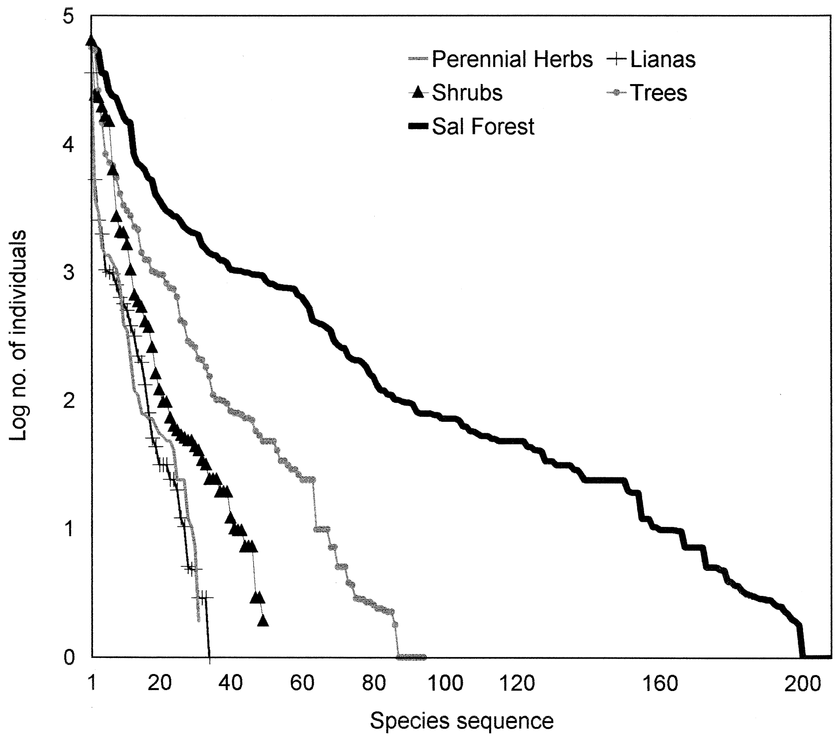

Figure 3. Dominance–diversity (species–individual) curve for the sal forest of Gorakhpur and for different growth form components: trees, lianas, shrubs and perennial herbs of the forest.

In addition to the usual recruitment by seed, a majority of species also showed non-seed regeneration. A comparison of different modes of non-seed regeneration in sal forest vegetation shows that 123 species were least-sprouters and produced only one or two sprouts, 41 were moderate-sprouters and generally produced up to 5 sprouts. A few species were high-sprouters and produced >5 sprouts per stump. Two other modes of non-seed regeneration were (i) by underground storage, and (ii) by ramet proliferation. Sixteen species had storage roots, while 22 species were ramet producers. As many as 45.5% of the total individuals were of ramet origin but belonged only to 10.6% species of the forest. High-sprouters showed a much smaller species share (2.4%) but a considerable proportion of individuals (10%). These values were quite similar for species regenerating through storage roots (Figure 4).

Forest stands which faced low but regular disturbance, included several identifiable thickets which were more dense and entangled as compared to the general vegetation of that stand. They looked like vegetation tips or miniature 'groves' generally bordered by conspicuous but narrow passages, caused mostly by grazing animals. Based on their ground cover, the thickets were grouped into three different size categories. The small-sized thickets covered a mean ground area of 30 ± 9.5 m^2. The constituent species were *Aegle marmelos, Pithecolobium dulce, Smilax*

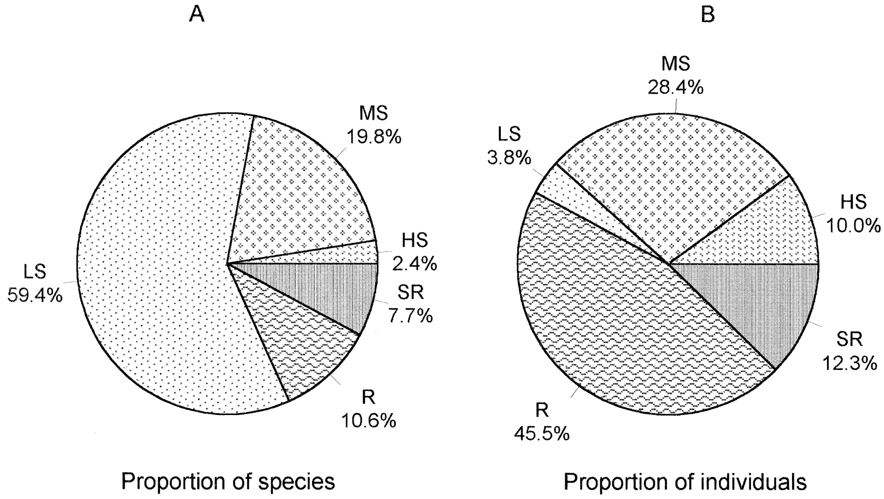

Figure 4. Pie-charts showing the proportion of species (A) and the proportion of individuals (B) grouped under different categories of non-seed regeneration. LS – least-sprouting; MS – moderate-sprouting; HS – high-sprouting; SR – storage roots; R – ramet producing roots.

prolifera and *Solanum indicum*. The species richness of these thickets ranged from 6 to 9 and their density from 7.4 to 12.1/m^2. The species of less common occurrence belonging to genera like *Aristolochia, Vitis, Narvelia, Capparis, Gloriosa*, and *Glycosmis* were often present. The larger thicket had a mean ground area of 63 ± 12.7 m^2, constituted by a few to several lianas with profuse thorns and prickles. They were *Caesalpinia bonducella, Caesalpinia sepiaria, Calamus tenuis* and *Mezoneurum cuculatum*. The individuals of a few understorey trees like *Carissa spinarum* and *Streblus asper* were also involved quite often. The species richness of these thickets ranged from 5 to 14 and their density from 5.2 to 13.2/m^2. Some lianas and undertrees like *Caesalpinia crista, Kydia calycina, Melenthesa rhamnoides, Macaranga indica* and *Alangium salvifolium*, which were generally infrequent, occurred quite frequently within these thickets. The largest-sized thickets showed a mean ground area of 168 ± 44 m^2 and were generally composed of several thorny lianas with an elaborate and complex canopy like *Milletia auriculata, Caesalpinia bonducella* and *Abrus precatorius* or with a less elaborate one like *Rosa involucrata* and *Smilax macrophylla*. The species richness of these thickets ranged from 15 to 21, whereas the density ranged from 5.8 to 17.2/m^2. Some valuable plant species, like *Rauwolfia serpentina, Clematis paniculata, Adhatoda vasica, Gloriosa superba, Centella asiatica* and *Scindapsus officinale*, occurred quite frequently within these thickets (Table 6).

Discussion

The species richness of sal forest in this region was quite high (208 species in 24 ha)

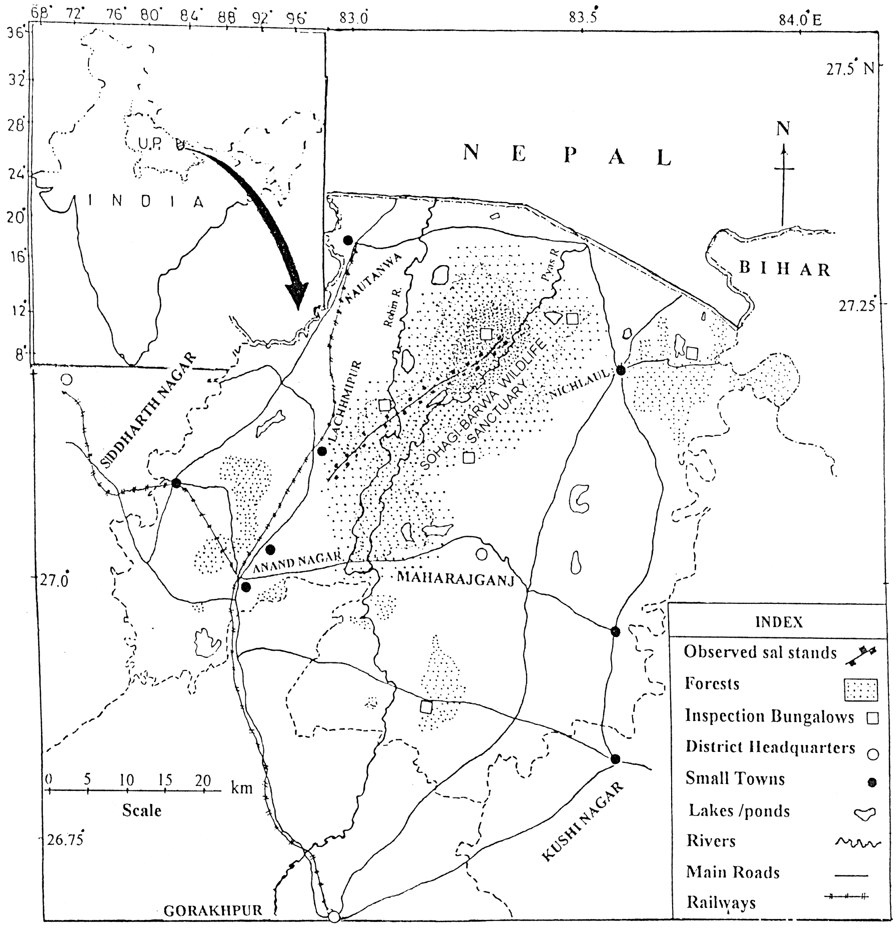

Figure 5. Study site shown within the Sohagibarwa Wildlife Sanctuary in the Gorakhpur Forest Division of northeastern Uttar Pradesh, India. The transect across the forest vegetation falling within three zones of the sanctuary also shows the position of sal stands observed.

as compared to those of the Central Himalayas (Singh and Singh 1987) and of central India (Jha and Singh 1990). Table 7 compares the observed sal forest with the above mentioned sal forest vegetation. The species richness of sal forest in this region was higher as compared to those of the Central Himalayas and Central India (Singh and Singh 1987; Singh et al. 1995). The total number of tree species was 93, which is much higher than for the sal forest of the Eastern Himalayas (Uma Shankar 2001). The sample area in the above mentioned studies, however, was quite variable and small, ranging from 0.2 to 2.9 ha. The observed sal forest was particularly rich owing to a much greater number of perennial herbs, shrubs and lianas. In fact, the number of perennial herbs at the forest floor was quite high towards the periphery as compared towards the core of the sanctuary, probably due to a decrease in canopy

Table 6. Species richness, mean area cover and mean density/m^2 of differently sized thickets observed in sal forest vegetation.

Type of thicket	Species richness	Area (m^2; mean ± SD)	Mean density/m^2	Species composition
Small thickets				
Solanum thicket	6	40.7 ± 4.3	7.4	*Ichnocarpus, Callicarpa, Jatropha gossypifolia, Kirganelia, Porana, Solanum indicum*
Smilax prolifera thicket	9	24.6 ± 3.1	12.1	*Asparagus, Bridelia retusa, Gloriosa, Hygrophilla, Mallotus, Typhonium, Careya herbacea, Smilax prolifera, Vitis*
Large thickets				
Calamus thicket	5	88.2 ± 10.1	11.2	*Careya arborea, Ficus carica, Centella, Hemigraphis, Helminthostachya,*
Caesalpinia bonducella thicket	13	63.6 ± 8.4	9.2	*Ardisia, Clerodendrum infortunatum, Bridelia retusa, Caesalpinia bonducella, Corchorus, Crotalaria prostrata, Centella, Hemidesmus, Mallotus, Mitragyna, Phyla, Plesminium, Uraria*
Streblus thicket	13	60.8 ± 4.9	5.2	*Allangium, Aristolochia, Asparagus, Streblus, Bridelia retusa, Cassia fistula, Clerodendrum infortunatum, Ficus, Flacourtia glomerata, Glycosmis, Hemidesmus, Mallotus, Mellitia*
Mezoneurum thicket	14	58.1 ± 4.5	7.6	*Abrus, Aganosoma, Bauhinia malabarica, Centella, Clerodendrum infortunatum, Desmodium triangulare, Ficus glomerata, Hemidesmus, Holarrhena, Macaranga, Mallotus, Mezoneurum, Milletia, Thespesia*
Carissa thicket	14	55.4 ± 5.4	7.7	*Alstonia, Ardisia, Bridelia retusa, Carissa, Crotalaria alata, Desmodium gangeticum, Clerodendrum infortunatum, Gloriosa, Holarrhena, Hymenodyction, Mallotus, Miliusa, Moghania chappar, Rauwolfia,*
Capparis thicket	11	52.8 ± 6.4	13.2	*Alstonia, Bauhinia vahlii, Caesalpinia crista, Capparis zeylanica, Crotalaria prostrata, Ficus hispida, Hemidesmus, Holarrhena, Kydia, Mallotus, Rauwolfia*
Bridelia stipularis thicket	9	50.4 ± 7.3	7.9	*Antidesma, Aristolochia, Bridelia stipularis, Casearia tomentosa, Costos, Naravelia, Mallotus, Stephania, Tinospora,*
Very large thickets				
Rosa thicket	21	206.1 ± 32.4	17.2	*Abutilon, Achyranthes, Adhatoda, Asparagus, Rosa, Barringtonia, Bridelia retusa, Calamus, Casearia tomentosa, Cissampelos, Clerodendrum infortunatum, Clematis, Ficus glomerata, Gloriosa, Hemidesmus, Ichnocarpus, Mallotus, Moghania chappar, Pothos, Scindapsus, Centella*
Flacourtia thicket	15	128.6 ± 13.6	5.8	*Abrus, Antidesma, Bischofia, Bridelia retusa, Clerodendrum infortunatum, Ficus infectoria, Hemidesmus, Ichnocarpus, Mallotus, Tinospora, Moghania lineata, Moghania chappar, Flacourtia, Dillenia, Milletia*

The thickets or groves have been named on the basis of the dominant lianas.

Table 7. Comparison of vegetation characteristics of the observed sal forest with other forests in India.

Forest type and location	Plot size (ha)	Size class (cm)	Species richness	Stand density (per ha)	Basal area (m^2 per ha)	Source
Sal forest of Gorakhpur division	24	≥30 gbh	93	404	22.23	Present study
Sal forest of Gorakhpur division	24	<30 gbh	115	20413	0.83	Present study
Sal forest of Eastern Himalayas	2	>10 gbh	87	484	26.3	Uma Shankar (2001)
Sal forest of Central Himalayas						
Doon Valley	0.2	>10 gbh	13–21	1150–1920	22.3–37.8	Pande (1999)
Corbett National Park	2.9	>31.5 gbh	3–20	180–860	14.5–71.8	Singh et al. (1995)
Sal forest in Central India						
Dry tropical, Vindhya region	?	>30 gbh	?	294–559	7–23	Jha and Singh (1990)

gbh – girth at breast height; (?) – values are not available at the source.

gaps (Chandrashekara and Ramakrishnan 1994). In general, shrubs dominated the understorey vegetation. Lianas were more common towards the core and a few herbaceous climbers were more common in peripheral stands. This is in sharp contrast with the Central Himalayas, where sal undergrowth is herbaceous and grasses predominate (Singh and Singh 1987). Further, the sum total of species was higher than that for natural sal forest in the Doon Valley (Pandey and Shukla 1999). On the other hand, the species richness of the observed sal forest was much lower than that for Barro Colorado Island (Knight 1975).

Papilionaceae stood first in the observed forest, followed by Euphorbiaceae, Caesalpiniaceae and Moraceae, in that order. The prevalence of Leguminosae (Fabaceae) in several deciduous forests in south India has been reported by Sukumar et al. (1992). The sal forest was found to be remarkably consistent with the neotropical deciduous forests of the world, in which Fabaceae are the most speciose family (Gentry 1995). The latter is regarded as one of the most successful families of flowering plants due to its extreme flexibility in the adaptive responses of legumes to different environments (Rundel 1989). Because the planted timber tree, *Shorea robusta*, belongs to the Dipterocarpaceae, the family obviously contributed the maximum to the total tree density, sum of basal area and IVI.

The observed forest stands were considerably dense, as also evident from their sum of basal area, which was comparable to other sal-dominated forests of India. Individuals of trees and lianas of >30 cm girth together amounted to a mean stem density of 404/ha. Among different growth forms, lianas were the least abundant. Most of the tree species like *Antidesma ghaesembilla, Bridelia retusa, Casearia tomentosa, Holarrhena antidysenterica, Mallotus philippensis, Streblus asper, Thespesia lampas* etc. were least represented in tree-form (>30 cm gbh) and readily acquired shrubby habit in response to disturbance. The density of individuals of tree-form within the observed forest was quite comparable with sal forests in central India (Jha and Singh 1990). Shannon's index of diversity ($\bar{H}$) for the observed sal forest was greater than that for the Eastern Himalayan sal forest (Uma Shankar 2001) and was well within the reported range (0.83–4.1) for the forests of the Indian sub-continent (Jha and Singh 1990; Ayyappan and Parthasarathy 1999; Pandey 2000). The value of dominance (Cd) in the present study falls within the reported range for other sal forests in India (Pande 1999). A meaningful comparison among sites is, however, difficult because of the difference in area sampled, lack of uniform plot dimension and the stand maturity. Conventionally, the calculation of $\bar{H}$ depends on a genet-based measurement and, therefore, may widely vary if each of the several ramets of a single genet is treated as a separate individual. It has been observed that when each superficially distinct individual is considered separately, the value of the diversity index becomes greater for stands facing high disturbance (Pandey and Shukla 2001). In fact, a high value of the evenness index reflects that much of the value of diversity is attributable to the species that are relatively rare. Further, Simpson's index is heavily weighed towards the most abundant species in the sample and is less sensitive to species having only a few individuals (Magurran 1988).

In general, the dominance–diversity curve for the sal community was fairly convex or flat. While the general curve for the sal community was quite different from the idealized dominance–diversity curve of Grime (1998), those for trees and woody climbers were quite comparable. In marked contrast to the subordinates, the transient species were quite heterogeneous and lacked fidelity of association with particular dominants (Grime 1998).

The mechanism of regeneration may differ for different species as determined by their growth features and nature of disturbance. Most of the species in the observed forest were least-sprouters with a considerable number of moderate-sprouters as well, but only a few of them belonged to the high-sprouter or ramet-producer groups. Paradoxically, the latter two groups were dominant in terms of number of individuals. In general, most of the ramet-producers were also prolific sprouters. Species that showed poor sprouting were generally absent from peripheral stands. These stands had moderate- and high-sprouters as also reported elsewhere (Rao et al. 1990). It may be argued that at a critical level of disturbance, the species lacking an asexual regeneration strategy might have gradually been pushed towards rarity or even disappearance (Daniels et al. 1995).

The regeneration in the sal forest was not satisfactory at the community level, as evident from the population structure of the common species (Pandey 2000). Among woody perennials, only 18.6% showed good regeneration and 31.6% showed fair regeneration, as determined by seedling fractions of the species population. The rest of the species exhibited very poor regeneration through seeds. In most of the species, this mode of regeneration was quite staggered. Since the scrutiny of the seed versus non-seed nature of seedlings was limited to the surface soil, any weak ramet or sprout, originating from deep seated root-stock, could easily be mistaken and treated as being of seed-origin. The pattern of distribution of individuals among several girth classes reveals the maturity status of sal forests and also indicates the extent of regeneration especially of trees. A sharp decline in the number of individuals of higher girths implies that most of the individuals of tree species never achieved >30 cm girth due to recurrent disturbance. The degree of steepness of the curve suggests considerable disturbance as compared to the 'L' shaped curve for the less disturbed evergreen forests of the Western Ghats (Ganesh et al. 1996). The fact that the majority of individuals is within lower girth classes is suggestive of higher density or abundance of some species.

Disturbance has been considered an important factor structuring forest communities (Foster 1980) and different levels and type of disturbance have a differential impact on forest communities (Halpern and Spies 1995). The observations on regeneration patterns of different species here suggest that a set of species may regenerate copiously even at sites where some degree of recurrent disturbance is inevitable. Some of the undertrees, which could produce sprouts and ramets effectively, were able to capitalize upon the vacant space produced by uncertain physical conditions and biotic disturbance. A number of species like *Antidesma ghaesembilla, Bridelia retusa, Casearia tomentosa, Clerodendrum infortunatum, Croton oblongifolius, Holarrhena antidysenterica, Mallotus philippensis* and *Moghania chappar*, which showed prolific sprouting and ramet production, were common associates of sal (Pandey and Shukla 1999). In several moderate to less disturbed stands, the locally dense and entangled mass of vegetation, mentioned here as thickets or miniature 'groves', were circumscribed by narrow gaps or passages. As evident from their composition and growth features of constituent species, the thickets were rendered largely impenetrable by grazing animals. The protective cover of thorny lianas provided a safe habitat for seed germination and establishment of several uncommon or rare species like *Atistolochia indica, Glycosmis pentaphylla, Gloriosa superba, Rauwolfia serpentina*, etc., which could not regenerate in the presence of recurrent disturbance. This is mainly because they did not show any effective mode of non-seed regeneration. The number of such species increased linearly with the size of thickets, as also reported elsewhere (Puyravaud et al. 1995). The large thickets were characterized by a few gigantic lianas, viz. *Abrus precatorious, Caesalpinia bonducella, Calamus tenuis, Mezoneurum cucullatum, Milletia auriculata* and *Smilax prolifera*, which had stiff thorns on the entire plant body, often including leaves and fruits. Owing to these species the thickets were simply impenetrable for large animals, especially herd cattle. The importance of thickets or miniature groves may be emphasized with regard to *in situ* conservation of valuable wild species which are currently at the verge of disappearance or local extinction. Sparing these thickets may ensure the conservation of a number of less common and rare plant species of the region without much effort or investment.

Conclusions

As evident from the above observations, the managed or plantation forests may show considerable diversity of wild plants which regenerate naturally in association with planted timber species. Since they are the last resort for the perpetuity of wild plants, their management as a forest ecosystem is obligatory for the conservation of an array of species occupying different niches within the system. In disturbed forest, non-seed regeneration and growth through ramet proliferation and basal sprouting yield sufficient understorey cover, which enables the survival of associated minor flora and fauna. A set of such species may, therefore, be identified for reforestation of degraded forest sites where some degree of disturbance is inevitable. Several forest stands, facing low to moderate disturbance, showed a number of thickets or miniature groves, predominantly composed of gigantic thorny and prickly lianas which inhibit any major biotic interference. The habitat within these thickets provides a safe site for regeneration, growth and *in situ* conservation of plant species which can hardly survive the disturbance prevailing outside these groves. Since thickets repel the onset of biotic disturbance, their miniature but effective role in conservation of several rare species must be emphasized.

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