

forest types, with lowest potentials during winter at high elevations and during the pre-monsoon heat at low elevations.

2. Trees subject to low water potentials during leaf growth reduce the osmotic potentials and increase the leaf elasticity during that period; trees without water stress before the monsoon adjust their leaf properties much less.

3. Evergreen dominant trees, compared to co-occurring deciduous species, adjust their leaf properties (osmotic potential, elasticity, conductance) more as season and water availability change.

Himalayan data will also provide a valuable test of generalities about water relations of temperate-climate trees, most of which^{25, 26} were developed in areas with seasonality different from the monsoon climate, i.e. with no predictable dry season or with drought in June–August. We anticipate, for example, that there will be differences between water relations of trees that expand leaves during drought and then encounter monsoon rainfall in the Himalayas, and of trees that expand leaves in the wet season and then encounter drought during most of their growing season, as in the coastal western United States. Our data will also contribute to the understanding of the control of species' distributions, a topic recently emphasized out of the concern for the effects of (apparent) global climatic changes. If, for example, year-to-year fluctuations of monsoon rainfall increase, making dry years even drier, what might be the effects on Himalayan trees?

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Impact of fire on a dry deciduous forest in the Bandipur National Park, southern India: Preliminary assessment and implications for management

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The effect of fire was analysed in two plots in a dry deciduous forest of Bandipur National Park, Karnataka. The less fire-prone plot had a higher tree density (HD) and included more tree and shrub species than the more fire-prone plot with lower tree density (LD). The LD had fewer and smaller thickets, whereas in the HD the presence of thickets had resulted in closure of the vegetation with more abundant weeds. Regeneration was higher in the LD, despite the greater rate of sapling mortality. Fire is shown to have impact on the tree/grass equilibrium and weed control. Our study also corroborates that protection from fire allows colonization by semi-evergreen trees and shrub species, while frequent fire opens up the vegetation. Fire should be used as a management tool to avoid catastrophic rare fires, to regulate weed expansion and to maintain plant communities for the sustenance of the protected fauna.

In India, fire has been used since millennia to open up the vegetation for cultivation. Until recently, slash and

burn cultivation were being practised by some ethnic groups¹. Farmers routinely burn pastures in order to maintain good quality fodder and to check forest expansion². Fire has since then been considered as one of the human-caused disturbances and is strictly prohibited in national parks, with the objective of promoting a 'natural' vegetation for the fauna. Total protection against fire is appropriate for evergreen forests, where normally fire does not occur, but dry deciduous forests of Southeast Asia seem to be resistant to regular occurrences of fire³. In these ecosystems, fire at lower intensities does not drastically damage the vegetation and can accomplish the quality and quantity control of plant cover⁴.

Fire is known to have a major impact on plant communities. It kills the seedlings of fire-sensitive species⁵⁻⁷ and arrests succession towards a denser vegetation^{8,9}. Depending on its frequency and temperature, it reduces the tree cover and promotes the growth of grasses^{10,11}. When irregularly set, i.e. for the clearance of a patch of forest, fire-cleared sites get colonized by weeds such as *Lantana camara* and *Chromolaena odorata*. But paradoxically, as observed in savanna-like ecosystems, regular fires prevent total invasion by these weeds that are less fire-resistant than grasses^{12,13}. Along with the herbivores, fire controls the tree/grass mosaic^{11,14} and the resulting change in the species composition and richness has a tremendous impact on the carrying capacity of the ecosystem. Prevention of burning increases tree

cover, but at the same time the litter accumulates and the increasing amount of dead tree and grass fuel multiplies the vulnerability to accidental fire incidences⁶.

The major vegetational type of the Bandipur National Park/Mudumalai Wildlife Sanctuary region is dry deciduous forest¹⁵. Numerous studies have been done on the conservation¹⁶⁻¹⁸, vegetation structure^{15,19} and ecology of this region²⁰⁻²². Fire is prohibited, but is very often set illegally by the local people and consequently its frequency is not controlled, nor recorded. Because of its various effects on ecosystem dynamics, fire as a management tool should not be neglected whenever the objective is to maintain a suitable habitat for large herbivores⁴. There are no data available on fire management in the national parks and sanctuaries of southern India and the strict fire protection policies prohibit any experimentation.

In this study, we compared a low-fire-frequency area with a contiguous high-fire-frequency area in the Ainurmarigudi Reserve Forest, Bandipur National Park. Our objective was to assess the present conditions in relation to long-term sustainability of the ecosystem taking into account the parameters that are sensitive to fire frequency (species composition, tree physiognomy, tree regeneration and weed abundance). We attempt here to see if fire frequency affects (i) the species composition, (ii) the tree physiognomy and (iii) the number of seedlings/saplings per unit area.

The study area was chosen in the Ainurmarigudi

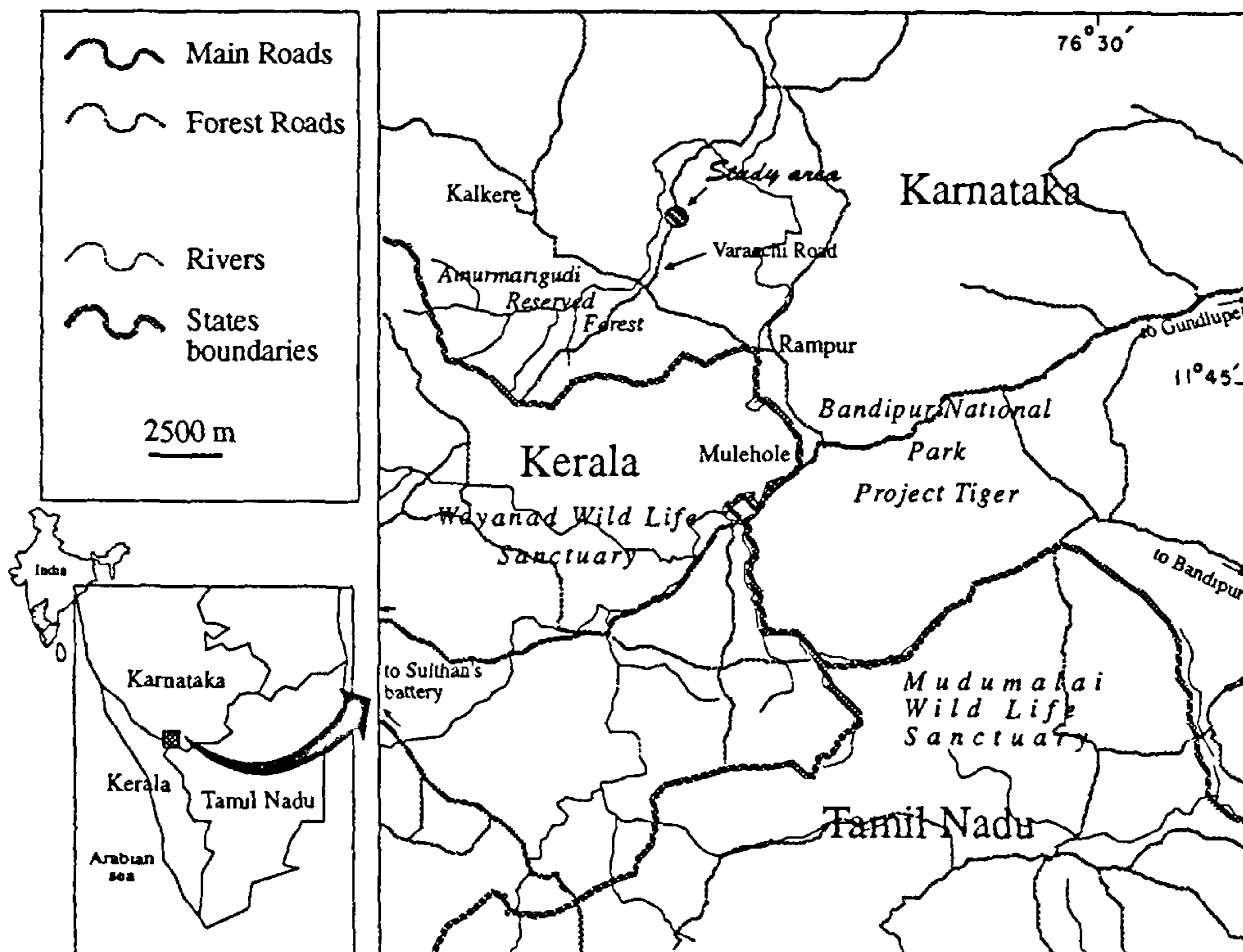


Figure 1. Location of the study area

Reserve Forest, Bandipur National Park, a Tiger Reserve. The plots in the study come under the compartment no. 26 (11°47'N, 76°23'E) of the Mulehole Range on the Varanchi road (Figure 1). The elevation is 830 m and the climate is monsoonal with one dry season spanning from December-end to mid-March. The mean annual rainfall is 1095 mm (data from the Karnataka Forest Department). The monthly mean maximum and minimum temperatures ranged between 32.4°C and 17.9°C and the humidity varied from 30% to 95% depending on the time of the day and season (D. Shridhar, unpublished data). The soil of this region is an intergradation between fersiallitic and ferrallitic²³, the parent material is a gneissic complex and the quantity of coarse material varies from one location to another. The C and N concentrations in the A horizon range around 2% and 0.1%, respectively (D. Shridhar, unpublished data).

The vegetation is a dry deciduous forest¹⁵, characterized by *Anogeissus latifolia*, *Tectona grandis*, *Terminalia alata* and *Dalbergia latifolia*. The herbaceous layer is dominated by the grass *Themeda triandra*. The study area is divided by the Varanchi road (Figure 1). On the left side of the road and between the river, the vegetation is dense. The surrounding river and road provide a fire-break to this area and fires have been observed to be infrequent (K. K. Kulla, personal communication), but no recorded data exist. On the right side of the road, the vegetation is more open and frequented by fire. The study was conducted in a plot with dense vegetation and another with open vegetation, in order to assess the effect of two different fire regimes, i.e. frequent and infrequent, on the vegetation. Topographical and pedological similarities of both plots allowed comparison of one fire regime with another.

One square plot (one hectare) within the area of high tree density (HD) and another of the same dimension was laid inside the area of low tree density (LD). All the flowering plants in the two plots were identified to the specific level. The two plots were divided into 100 subplots of 10 m × 10 m for the study of tree structure. The height of the trees in the LD and HD was measured and the GBH (girth at breast height) measured for all the individuals above 2 m in height. Below this height, in both plots, the regeneration was studied by counting the seedlings and saplings of each species in 10 quadrats of 25 m² taken at random. The seedlings and saplings were also counted in all the thickets of the plots. In each of the 100 subplots (10 m × 10 m), the percentage of weed (*Lantana camara* and *Chromolaena odorata*) cover was noted and assigned into 4 classes: 0%, 0–5%, 5–10% and 10–50%, based on visual estimation.

A total of 38 herbaceous species were enumerated belonging to 34 genera and 18 families (Table 1). The family Poaceae was represented by 14 species, followed by Fabaceae (7 species) and Asteraceae (2 species). The

Table 1. Herbaceous species list in the LD and the HD

Family	Species	LD	HD
Aizoaceae	<i>Mollugo nudicaulis</i> Lam.	+	+
Asclepiadiaceae	<i>Hemidesmus indicus</i> (L.) R. Br.	+	+
Asteraceae	<i>Blumea membranacea</i> Wall. ex DC.	+	+
	<i>Vernonia albicans</i> DC	+	+
Caesalpiniaceae	<i>Cassia mimosoides</i> L	+	+
Commelinaceae	<i>Cyanotis tuberosa</i> (Roxb.) Schultes	+	+
Cucurbitaceae	<i>Melothria maderaspatana</i> (L.) Cogn	+	+
Cyperaceae	<i>Mariscus paniceus</i> (Rottb.) Vahl	+	+
Euphorbiaceae	<i>Phyllanthus neruri</i> L	+	+
Gentianaceae	<i>Canscora decussata</i> Schultes & Schultes	+	+
Fabaceae	<i>Crotalaria calycina</i> Schrank	+	–
	<i>Desmodium brachystachyum</i> Grah.	+	+
	<i>Desmodium cephalotes</i> Roxb.	+	+
	<i>Desmodium dichotomum</i> Willd	+	+
	<i>Desmodium gangeticum</i> (L.) DC.	+	+
	<i>Rhynchosia rufescens</i> (Willd.) DC.	+	+
	<i>Vigna radiata</i> (L.) Wilczek.	+	+
Lamiaceae	<i>Ocimum adscendens</i> Willd	+	+
Liliaceae.	<i>Asparagus racemosus</i> Willd	+	+
	<i>Curculigo orchitoides</i> Gaertner	+	+
Malvaceae	<i>Sida rhombifolia</i> L	+	+
Oxalidaceae	<i>Biophytum candolleianum</i> (Wight) Edgew	+	+
Poaceae	<i>Apluda mutica</i> L.	+	+
	<i>Bambusa arundinacea</i> (Retz.) Roxb	+	+
	<i>Bothriochloa pertusa</i> (L.) A. Camus	+	+
	<i>Brachiaria paspaloides</i> (Presl) C. E. Hubb	+	+
	<i>Cymbopogon flexosus</i> (Nees) Wats.	+	+
	<i>Cynodon dactylon</i> (L.) Pers.	+	+
	<i>Digitaria adscendens</i> (H. B. K.) Henr	+	+
	<i>Heteropogon contortus</i> (L.) P. Beauv.	+	+
	<i>Panicum</i> sp	+	+
	<i>Paspalum flavidum</i> (Retz.) A. Camus	+	+
	<i>Setaria palmifolia</i> (Koen.) Stapf	+	+
	<i>Sporobolus wallichii</i> Munro	+	+
	<i>Themeda cymbaria</i> Hack.	+	+
	<i>Themeda triandra</i> Forssk.	+	+
Portulacaceae	<i>Portulaca pillosa</i> (L.) Hook.	+	+
Zingiberaceae	<i>Curcuma montana</i> Rosc	+	+

other families were represented by only one species. With the exception of *Crotalaria calycina*, which was absent in the HD, the two plots were otherwise equivalent in herbaceous species composition. The proportion of species contributing to the total phytomass in the two plots was: *Themeda triandra* 70%, *T. cymbaria* 10%, *Bothriochloa pertusa* 9% and *Heteropogon contortus* 8%; dicotyledons and Cyperaceae constituted the rest of the phytomass (D. Shridhar, unpublished data). A total of 45 tree, shrub and undershrub species belonging to 39 genera and 24 families were recorded in the two plots (Table 2). The family Fabaceae is the dominant one with 4 species, followed by Euphorbiaceae, Rubiaceae and Combretaceae, each represented by 3 species. The LD contained 35 species and the HD 39 species. The understory tree, *Grewia tiliifolia*, was the most common tree in both the plots, constituting up to 65% of the individuals, followed by the canopy species *Tectona grandis*, which constituted 10% of the trees in the HD and 13% in the LD. The Shannon–Wiener species diversity index (trees > 2 m in height) was 1.78 in the LD and 2.43 in the HD.

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Table 2. Tree, shrub and under-shrub species list in the LD and the HD. T = Tree, S = Shrub, Us = Undershrub. Deci. = Deciduous forest species, Semi-eve. = Semi-evergreen forest species

Family	Species	T/S/Us	LD		HD		Ecological preferences
			Station	Thicket	Station	Thicket	
Annonaceae	<i>Polyalthia cerasoides</i> (Roxb) Bedd.	T	-	-	+	-	Deci.
Asteraceae	<i>Chromolaena odorata</i> (L) King & Robinson	Us	+	+	+	+	Weed
Bignoniaceae	<i>Radermachera xylocarpa</i> (Roxb) K Schum	T	+	-	+	-	Deci.
	<i>Stereospermum personatum</i> (Hassk.) Chatterjee	T	-	-	+	+	Deci. to Semi-eve.
Bombacaceae	<i>Bombax ceiba</i> L.	T	+	+	+	-	Deci.
Boraginaceae	<i>Cordia macleodu</i> (Griff) Hook. f. & Thoms.	T	+	-	+	-	Deci.
Burseraceae	<i>Garuga pinnata</i> Roxb.	T	+	+	-	-	Deci.
Caesalpiniaceae	<i>Bauhinia racemosa</i> Lam.	T	+	-	+	+	Deci.
	<i>Cassia fistula</i> L.	T	+	-	+	+	Deci.
Combretaceae	<i>Anogeissus latifolia</i> (Roxb ex DC.) Wall.	T	+	+	+	+	Deci.
	<i>Terminalia alata</i> Heyne ex Roth.	T	+	-	+	-	Deci.
	<i>Terminalia paniculata</i> Roth	T	+	-	+	-	Deci.
Ebenaceae	<i>Diospyros melanoxylon</i> Roxb	T	+	-	+	+	Deci.
	<i>Diospyros montana</i> Roxb	T	+	+	+	+	Deci.
Euphorbiaceae	<i>Bridelia crenulata</i> Roxb.	T	-	-	+	+	Deci.
	<i>Bridelia retusa</i> (L) Spreng.	T	+	-	+	-	Deci.
	<i>Emblica officinalis</i> Gaertner.	T	+	-	+	+	Deci.
	<i>Givoua rottleriiformis</i> Griff.	T	+	-	-	-	Deci.
Fabaceae	<i>Dalbergia latifolia</i> Roxb.	T	+	+	+	+	Deci.
	<i>Dalbergia paniculata</i> Roxb.	T	+	+	+	+	Deci.
	<i>Erythrina suberosa</i> Roxb.	T	-	-	+	-	Deci.
	<i>Pterocarpus marsupium</i> Roxb.	T	+	-	+	+	Deci. to Semi-eve.
Flacourtiaceae	<i>Casearia elliptica</i> Willd.	T	-	-	+	-	Deci.
	<i>Flacourtia indica</i> (Burm.f.) Merr.	T	+	+	-	-	Deci.
Lecythidaceae	<i>Careya arborea</i> Roxb.	T	+	-	-	-	Deci.
Lythraceae	<i>Lagerstroemia parviflora</i> Roxb.	T	-	-	+	-	Deci.
Mimosaceae	<i>Acacia ferruginea</i> DC.	T	-	-	+	+	Deci.
	<i>Albizia marginata</i> (Lam) Merr.	T	+	-	+	-	Deci.
Moraceae	<i>Ficus benghalensis</i> L.	T	+	-	+	-	Deci.
	<i>Ficus religiosa</i> L.	T	-	-	+	-	Deci.
Oleaceae	<i>Schrebera swietenoides</i> Roxb.	T	+	-	+	-	Deci.
Rhamnaceae	<i>Ziziphus oenophia</i> (L.) Mill.	S	+	-	+	+	Deci.
Rubiaceae	<i>Catunaregam spinosa</i> (Thunb) Tirven.	T	+	-	+	-	Deci.
	<i>Haldina cordifolia</i> (Roxb.) Ridsdale	T	+	-	+	-	Deci.
	<i>Hymenodictyon excelsum</i> (Roxb.) Wall.	T	+	-	+	+	Deci.
	<i>Mitragyna parvifolia</i> (Roxb) Kunth.	T	-	-	+	-	Deci.
	<i>Pavetta tomentosa</i> Roxb	S	+	+	+	+	Deci.
Rutaceae	<i>Narengi crenulata</i> (Roxb.) Nicolson	T	+	-	-	-	Deci.
Sapindaceae	<i>Schleichera oleosa</i> (Lour.) Oken	T	+	-	+	+	Deci. to Semi-eve.
Sterculiaceae	<i>Eriolaena hookeriana</i> Wight & Arn.	T	+	-	-	-	Deci.
Tiliaceae	<i>Grewia abutifolia</i> Juss.	S	+	-	+	+	Deci.
	<i>Grewia ulhaefolia</i> Vahl.	T	+	+	+	-	Deci.
Verbenaceae	<i>Lantana camara</i> L.	S	-	-	+	+	Weed
	<i>Premna tomentosa</i> Willd.	T	+	-	+	-	Deci.
	<i>Tectona grandis</i> L. f.	T	+	-	+	-	Deci.

The LD and HD contained 992 and 1466 trees ha⁻¹, respectively (height ≥ 2 m). The total basal areas of both the plots showed a narrow difference (22.4 m² ha⁻¹ for LD and 23.6 m² ha⁻¹ for HD). The height class distribution pattern of the individuals was L-shaped for both the plots and the height distributions were not significantly different (Kolmogorov-Smirnov test $p = 0.1673$;

Figure 2 a), but the girth distributions were significantly different in the two plots (Kolmogorov-Smirnov test $p < 0.02$; Figure 2 b). The number of small trees is greater in the HD than in the LD (Figure 2 c, d), but there were no differences between the number of larger trees in the two plots.

The HD contained 18 thickets ha⁻¹, with area ranging

from 1 to 35 m², while the LD had 9 thickets ha⁻¹ with areas of 0.25–10 m². The mean surface area of the thickets in the HD was 10 m² whereas it was 5 m² in the LD. The total surface area occupied by thickets on the HD was 180 m² against 44 m² in the LD. The number of species increased linearly with the size of the thickets (Figure 3; $r^2 = 0.54$; $n = 26$; $p < 0.0001$). Most of the thickets were near or on termite mounds and harboured semi-evergreen forest species like *Schleichera oleosa* and *Pterocarpus marsupium* which are rare in open places.

Chromolaena odorata was present in the HD as well as in the LD (Figure 4). Its cover did not exceed 5% in the LD, whereas some patches were heavily colonized

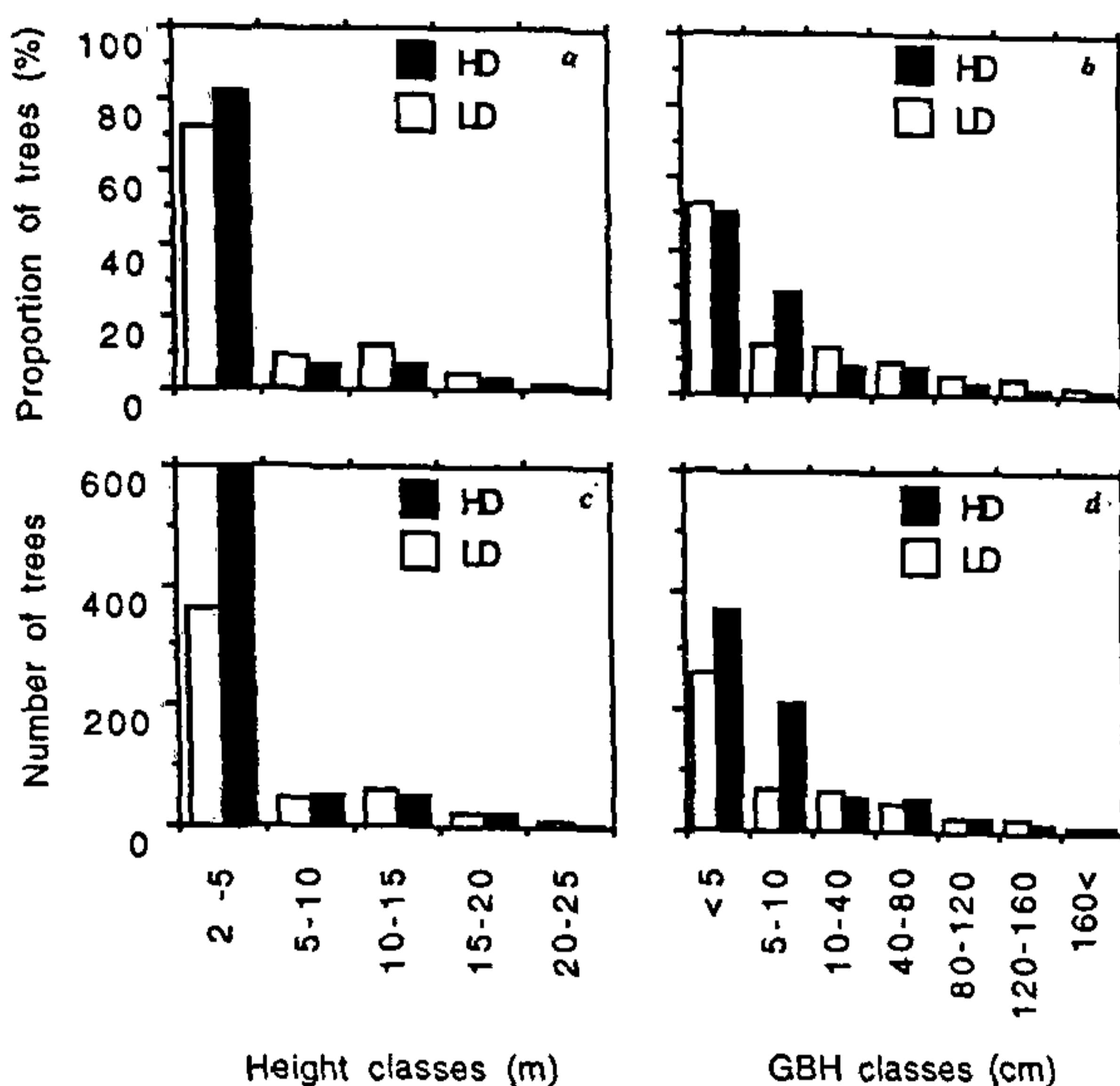


Figure 2. *a*, Proportion of trees per height classes; *b*, Proportion of trees per GBH classes; *c*, Abundance of trees per height classes, *d*, Abundance of trees per GBH classes.

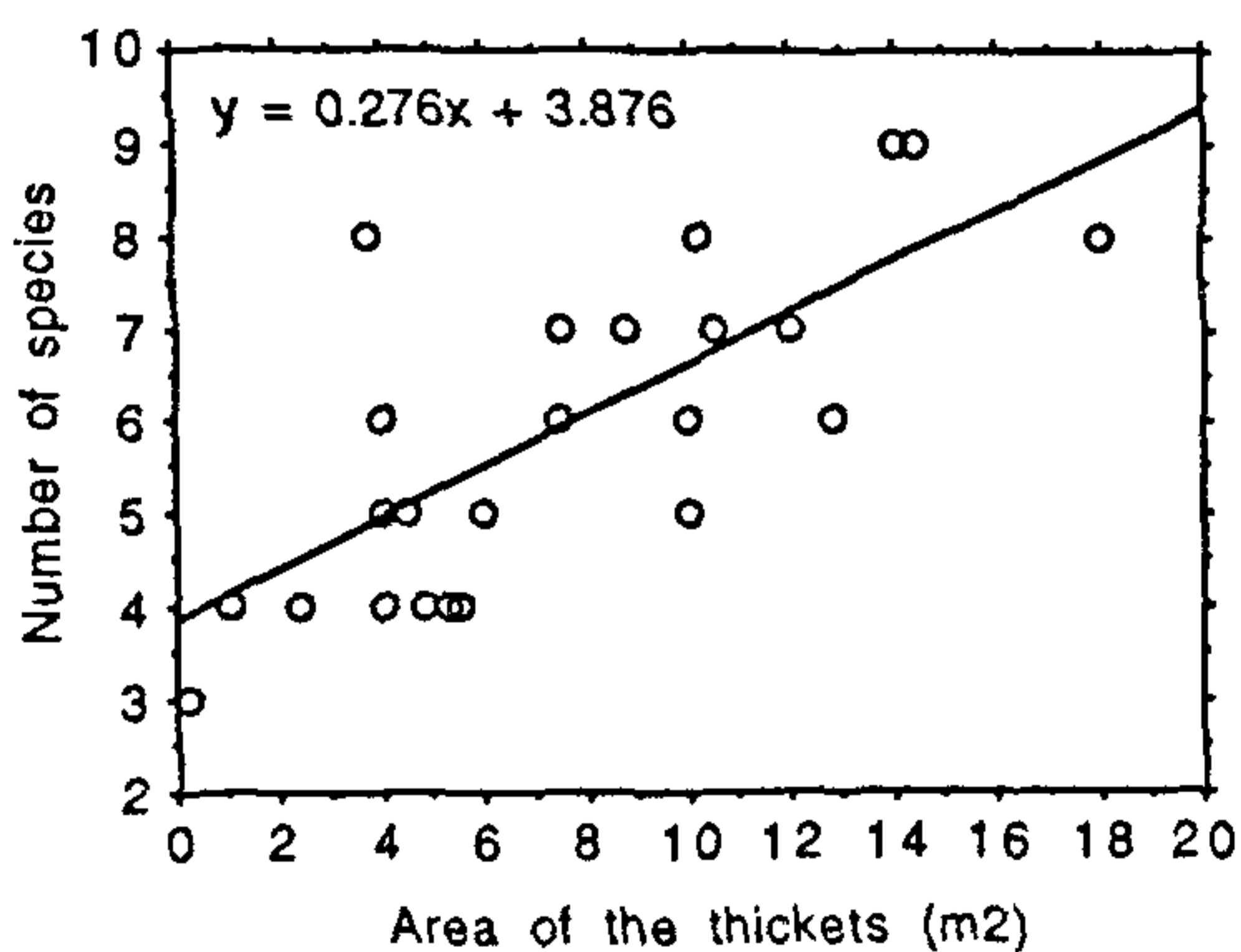


Figure 3. Relationship between the area of the thickets and the number of species per thicket (one outlier has been deleted).

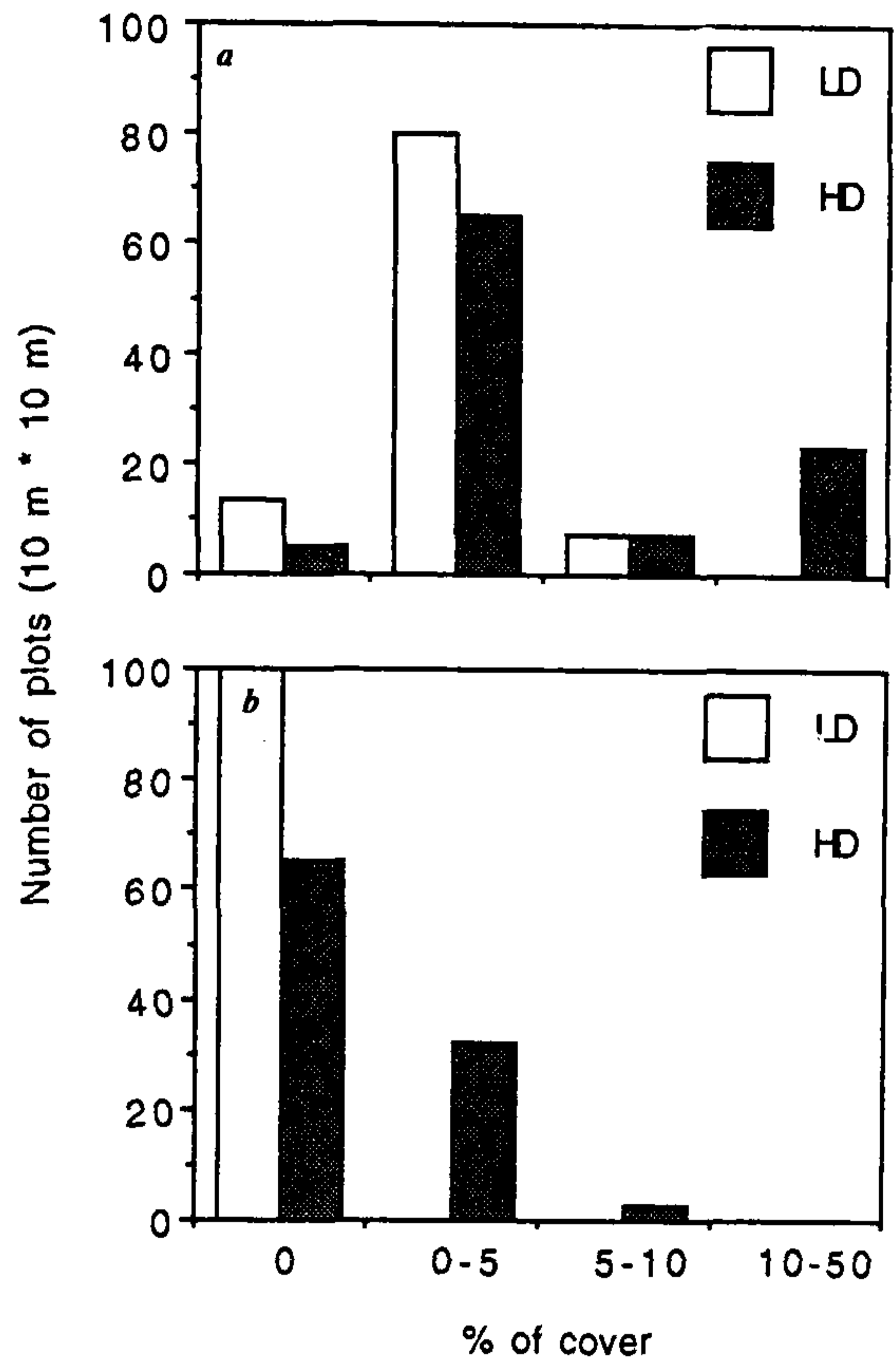


Figure 4. *a*, Number of plots (10 m x 10 m) by classes of percentage of cover by *Chromolaena odorata* in the LD and the HD, *b*, Number of plots (10 m x 10 m) by classes of percentage of cover by *Lantana camara* in the LD and the HD.

by this species in the HD. *Lantana camara* occurs only in the HD.

The total number of seedlings was estimated to be 12,400 ± 500 ha⁻¹ in the LD and 4700 ± 150 ha⁻¹ in the HD. The regeneration was higher in the LD than in the HD, despite the fact that the number of trees was higher in the HD. In the thickets, we found 12,460 seedlings ha⁻¹ (LD) and 4060 seedlings ha⁻¹ (HD). The estimations are given without standard deviation, which has no meaning in this case because the sampling area varied with the differing sizes of the thickets. The total number of seedlings per hectare was almost the same in the thickets as in the open areas of both the plots.

The rank abundance of the larger tree species was not the same as that of the seedlings (Figure 5). *Grewia tiliaefolia*, the most abundant tree, did not have abundant seedlings. The number of its seedlings ranged between 1000 and 2000 per hectare but were rare in the thickets of the HD. *Anogeissus latifolia*, a dominant tree, regenerated comparatively well in the LD (around 5000 seedlings per hectare), but did not do well in dense vegetation. The number of its seedlings dropped below

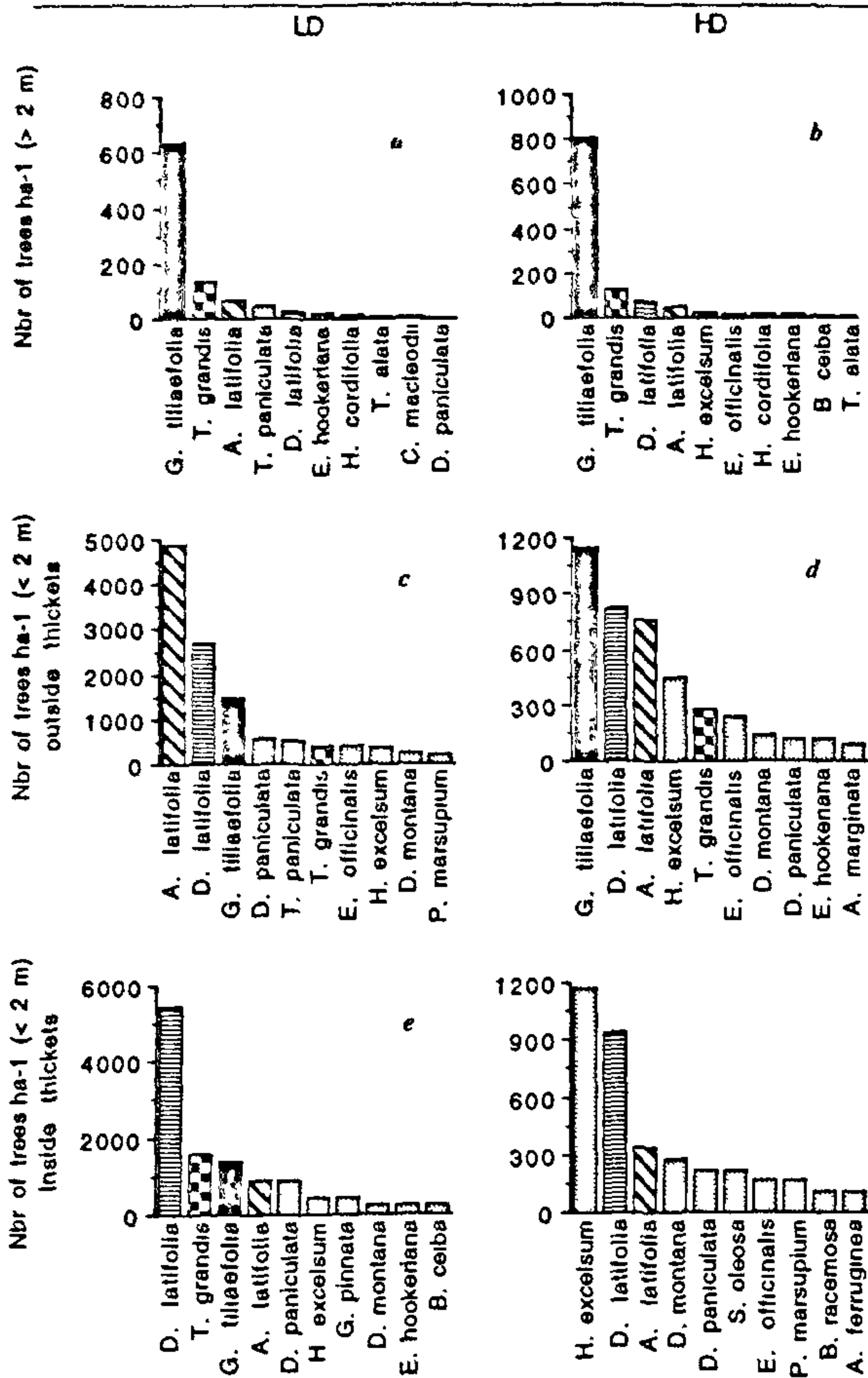


Figure 5. Rank abundance distribution of the dominant tree species. a, trees > 2 m in the LD; b, trees > 2 m in the HD, c, trees < 2 m in the LD; d, trees < 2 m in the HD, e, trees < 2 m inside the thickets, LD; f, trees < 2 m inside the thickets, HD. The four main species are presented with different patterns.

1000 per hectare in the HD and in the thickets. *Dalbergia latifolia*, another dominant tree, produced lesser number of seedlings than *Anogeissus latifolia* in the LD, but seemed less affected by dense vegetation since its seedlings were over 800 per hectare in the HD and in the thickets of the HD. The absence of the seedlings of *Tectona grandis* in the thickets of the HD may be suggestive of its shade-sensitivity at younger stages. *Dalbergia latifolia*, a species presenting a high number of young seedlings, had fewer individuals in the older seedling size classes, demonstrating a higher mortality in the LD than in the HD or the thickets (Figure 6).

It has been observed that frequent fires reduce the number of tree species²⁴. In Ainurmarigudi, the herbaceous species composition was not affected, but the HD contained more tree and shrub species than the LD. As stated in an earlier study¹⁹, the species richness varies at random from 19 to 39 species per hectare; so the observed differences may not be ecologically sig-

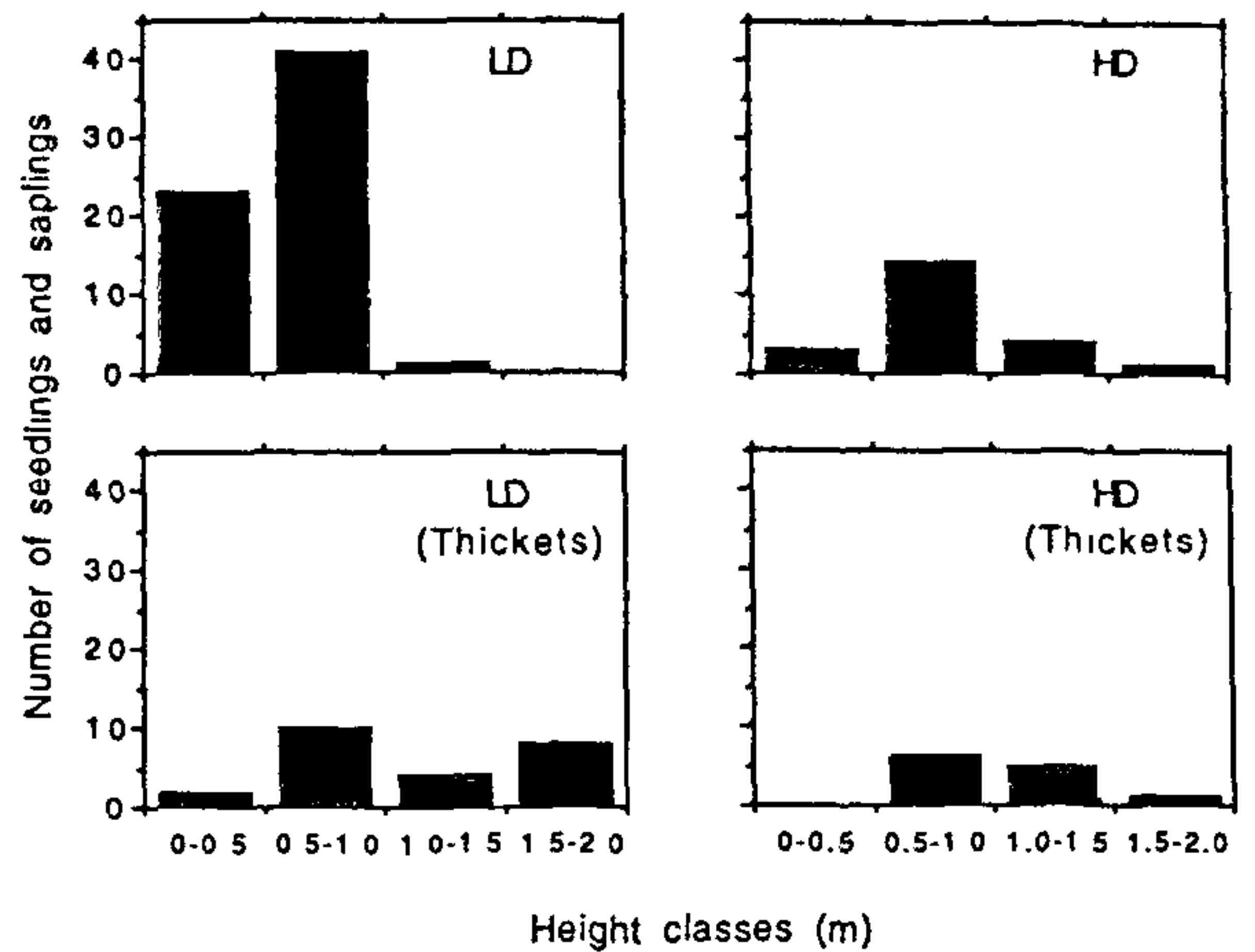


Figure 6. Number of seedlings and saplings per height classes of *Dalbergia latifolia*.

nificant. An overall decrease in tree density⁶ recorded since 1978 in the LD affects the younger stages of the tree community, as shown by the height and girth class distributions. The number of individuals was higher in the HD, the smaller trees being more numerous, but the basal area was not very different. Succession is proceeding towards a denser vegetation and new thickets are formed or are increasing in size, facilitating the establishment of semi-evergreen species. With total protection in savanna-like vegetation, the thickets coalesce into a closed shrubby vegetation from which a closed forest emerges²⁵⁻²⁷. In the HD, the process is at an initial stage. On the contrary, with frequent fires, the number and area of the thickets reduces. This implies loss of species as there exists a linear relationship between the total species number and the area of thickets. Semi-evergreen trees such as *Schleichera oleosa* may be sensitive to this structural change.

The seedling establishment of dry deciduous forest trees and shrubs is favoured by openings in the forest. In each plot, there was no noticeable difference between the number of seedlings inside and outside the thickets. The abundance of the seedlings in open areas is not the same specieswise, but as a general trend, the four common tree species establish well when the tree density is lower. Nevertheless, the survival of the seedlings seems to have been affected by fire, as shown by the height class structure of the seedlings of *Dalbergia latifolia*. Saplings of 2 m height were not represented in the samples taken in the LD.

The two weeds *Lantana camara* and *Chromolaena odorata* were more frequent in the HD than in the LD. They invade large areas of the Bandipur National Park and are suspected to block tree growth and reduce food availability to livestock²⁸. Their control is of primary importance for the management of the wild herbivores

and we underscore here the fire maintenance of these two species at a low density.

The present work supports the previous observations on the dynamics of this forest⁶. Currently, the tree density of the Ainurmarigudi Reserve Forest is decreasing, which is a clear threat to the sustainability of the ecosystem. A further step will be to know whether this trend is prevailing over the whole Bandipur–Mudumalai area. However, it may be necessary to adopt a better fire management policy.

Frequent and uncontrolled fires, as in the present situation, endanger the ecosystem. Total protection is not possible because of the traditions of the local people, nor is it advisable. Even when attempted, it leads to a more closed forest, which is not advantageous for the grazing herbivores. During the course of plant succession, the biomass increases, and when the fires do occur they are generally violent, killing a large number of plants and animals⁴. If there are no fires, weeds may invade and block the succession process, reducing the forage availability²⁸. An intermediate solution could be fire control. Late burning reduces tree population by killing young trees¹⁰, but early burning does not drastically affect the tree community²⁴ and could be applied safely. Setting early fires of lower frequency (once in two or three years) has the advantage of preventing catastrophic fires, stopping the spread of weeds and maintaining the tree cover. As a measure to safeguard the immense floral and faunal wealth of this ecosystem, it is advisable to determine carefully the optimal burning rate and frequency by experimental work.

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Movement of ³²P in sunflower plants inoculated with single and dual inocula of VAM fungi

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Sunflower plants were inoculated with single and dual inocula of *Glomus intraradix* and *Glomus mosseae*. ³²P-labelled phosphate was applied after sufficient infection was obtained in all treatments. Plants inoculated with dual inocula of the two VAM fungi showed significantly higher shoot weight than those inoculated with single inocula and control treatments. Of the ³²P transported to the plants, the percentage of ³²P transported to the shoot was 59.9 in *G. intraradix* + *G. mosseae*, 25.12 in *G. intraradix*, 33.31 in *G. mosseae* and 35.2 in uninoculated control. The present study reveals that the increased growth in plants inoculated with dual inocula compared to those inoculated with single inocula of VAM fungi may be due to the increased transfer of P to the shoot from the root.

It is now well-established that vesicular-arbuscular mycorrhizal (VAM) infection can enhance P uptake by