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Original article

Assessing vegetation changes in the dry deciduous Ainurmarigudi Reserve Forest, South India

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Summary — The dry deciduous forest of Ainurmarigudi belonging to *Anogeissus latifolia – Tectona grandis – Terminalia alata* type, was classified as a reserve forest under the Project Tiger in 1973. Twenty years later, although felling has not been resumed, fires still occur regularly and the density of herbivores has increased considerably. This article attempts to determine the impact of 15 years (1978–1993) of total protection on the evolution of the stand from studies on the floristic and spatial structures, mortality, recruitment and regeneration. The stand is still open and deficient in young individuals (except for the population of *Grewia tiliifolia).* All the species do not evolve in the same manner. *Tectona* grandis and *Dalbergia latifolia* have serious problems of regeneration. In contrast, *Grewia tiliifolia,* whose recruitment is impressive, does not seem to be capable of establishing itself in the adult stage. From the point of view of regeneration, the only species which appears to maintain itself in the forest is *Anogeissus latifolia.* Establishment of the reserve has thus led to the opening up of the stand as well as a fall in its biomass, and also a slight decline in its tree diversity. The increase in the populations of big herbivores probably plays a major role in this evolution.

effect of total protection / forest structure / mortality / regeneration / tropical deciduous forest / elephant pressure / fire / India

Résumé — Impact de la mise en réserve sur la forêt décidue sèche d'Ainurmarigudi, dans la réserve du «*Project Tiger*», Inde. *La forêt décidue sèche d'Ainurmarigudi, à* Anogeissus – Tectona – Terminalia, *a été classée en réserve en 1973, dans le cadre du* Project Tiger. *Vingt ans après, si l'exploitation n'a pas repris, le feu passe régulièrement et les populations de grands herbivores ont considérablement augmenté. Cet article tente de déterminer l'impact de cette mise en réserve totale dans l'évolution du peuplement. L'étude des changements intervenus pendant 15 ans (1978–1993) dans les structures floristiques et spatiales, la mortalité, le recrutement et la régénération permet de dégager les tendances évolutives. Le peuplement est en phase d'ouverture et présente un déficit en jeunes individus (excepté pour la population de* Grewia tiliifolia*). Toutes les essences n'évoluent pas dans le même sens.* Tectona grandis *et* Dalbergia latifolia *montrent de graves problèmes de renouvellement et déclinent.* Grewia tiliifolia, *dont le recrutement est en revanche impressionnant, ne semble pas* *capable de s'installer à l'état adulte. La seule espèce qui paraît se maintenir dans le peuplement est* Anogeissus latifolia. *La mise en réserve, en plus d'une ouverture et d'une diminution de biomasse, est donc à l'origine d'une perte de diversité au niveau arborescent, l'augmentation des populations de grands herbivores jouant vraisemblablement un rôle majeur dans cette évolution.*

effet de la mise en réserve totale / structure de peuplement / mortalité / régénération / forêt tropicale décidue / impacts des éléphants / feu / Inde

INTRODUCTION

In 1978, the French Institute of Pondicherry (India) and the ecology laboratory of the École Normale Supérieure (Paris) undertook a comparative study of the woody formations in the dry tropical zones of Asia and West Africa (Legris *et al*, 1981). They compared the structures of forest stands along a gradient of decreasing rainfall. The Indian transect comprised 8 stations showing the gradual passage from a dry and dense deciduous forest to a low and discontinuous thicket. It was located on the Mysore plateau in the Project Tiger Reserve which was established in 1973, with the aim of saving the tiger, an endangered species. In this transect, particular attention was paid to Ainurmarigudi Forest, which is in the central part of the gradient. Two permanent plots were established for this purpose. Twenty years after the reserve was created and a ban imposed on logging operations, it was expected that the stand would become closed and there would be a regeneration of tree species. However, regular visits to the site showed that this was not the case. It therefore seemed interesting to undertake a fresh survey to analyse the development of the floristic and spatial structures of the forest, and to study dynamic parameters such as mortality, recruitment, regeneration (Gaulier, 1993). These data are compared to those obtained in 1978 (Legris *et al*, 1981) to evaluate the actual impact of its classification as a reserve on the evolution of the stand.

STUDY AREA

The Project Tiger Reserve is located in the southern part of the Mysore plateau (11° 45'N, 76° 30'E), at an elevation of *c* 900 m, 50 km east of the summit of the Western Ghats (fig 1).

Climate

The rainfall regime is of the tropical type with a dry season of 4 months (December to March) alternating with a rainy season, mostly from the summer monsoon (maximum in July). Over the plateau the rainfall diminishes rapidly from west to east moving away from the crest: 2 151 mm in Tovarimala, 1 118 mm in Mulehole and 722 mm in Gundlupet (fig 1). At Gundlupet, the rainfall regime is no longer determined by the monsoon rains, but by convectional rainfall of April and October. The rainfall regime of Ainurmarigudi is well represented by Mulehole station.

The mean temperatures vary from 22.3°C in January to 28°C in April and May. The mean of the minima is 16°C in January and that of the maxima, 37–38°C in April (Legris *et al*, 1981). The relative humidity is maximum during the monsoon months (85–88%) and minimum during the dry season (56–60%).

Soil

The study site is situated on Precambrian rocks, essentially of gneiss associated with

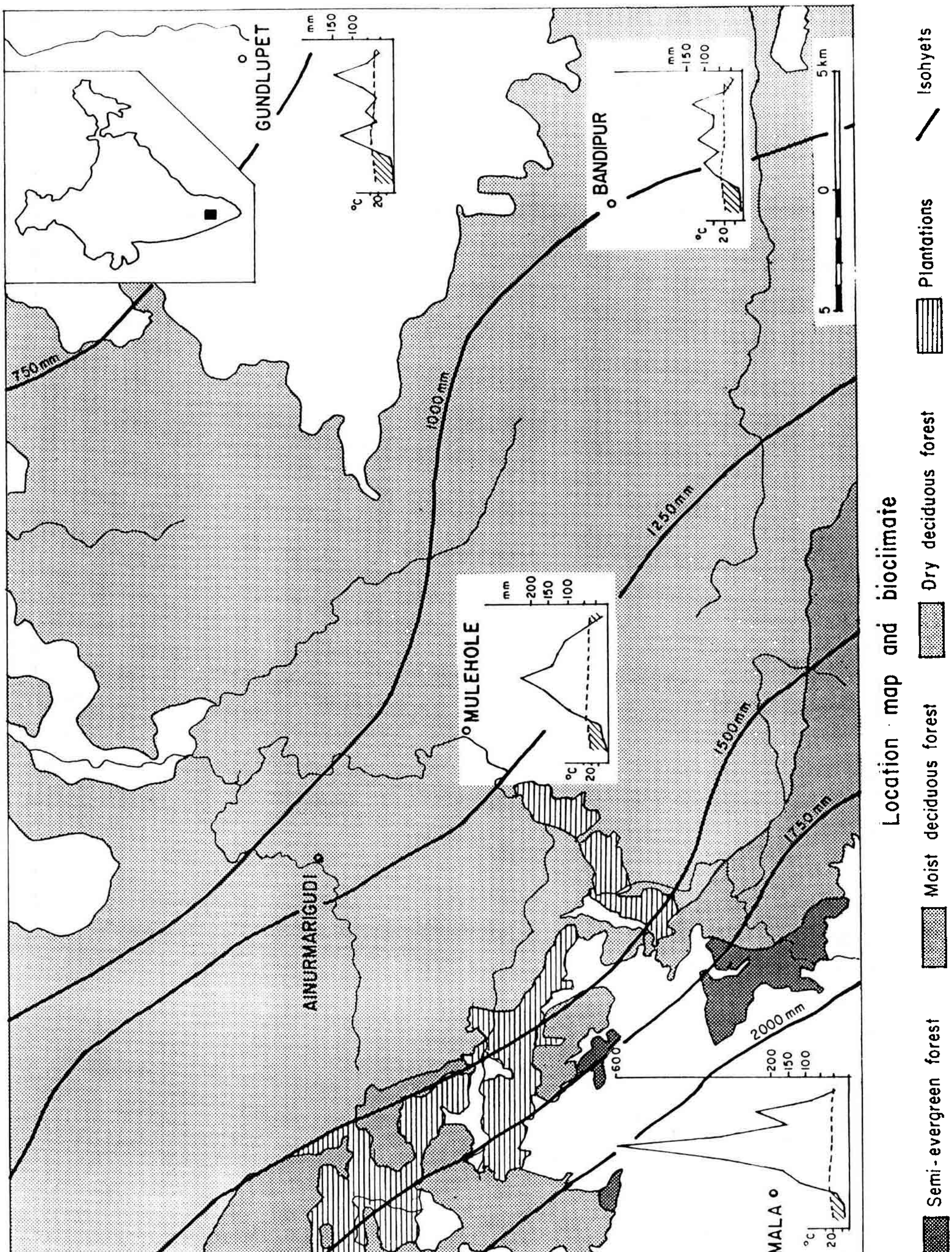

Fig 1. Location and bioclimatic map of the study area.

amphibolites. The soils are classified under "Red soils" and correspond to the Kandic Rhodustalf in *Soil Taxonomy* (Bourgeon, 1989). They are in the transitional zone, between the ferrallitic and fersiallitic soils, which follows the rainfall gradient (Bourgeon, 1992).

Plant formation

The declining rainfall gradient is reflected in the changes in the forest formations. The zonation is as follows (fig 1): evergreen forest generally degraded into semi-evergreen forest generally degraded into semi-evergreen forest (rainfall higher than 2 000 mm), moist deciduous forest (between 1 500 and 2 000 mm) and dry deciduous forest (less than 1 500 mm). Ainurmarigudi Forest (2 624 ha) is situated right in the middle of a dry forest and belongs to the *Anogeissus latifolia – Tectona grandis – Terminalia alata* type (Pascal, 1982, 1986). Deciduous forests, the normal habitat of the tiger, are still quite extensive in this region, justifying their selection for the Project Tiger.

The stand is open. The basal area is about 22 m^2/ha and the height of the canopy varies from 15 to 24 m (fig 2). The ground is covered by a continuous herbaceous layer dominated by cespitose Poaceæ such as *Themeda triandra, Heteropogon contortus, Bothriochloa pertusa, Themeda cymbaria* and *Cymbopogon flexuosus.*

History of the forest

The history of Ainurmarigudi Forest can be traced from the Working Plans of the Forest Department (Srinivasarao 1910–1930; Muthanna 1931–1941; Kadambi 1941–1961).

Prior to 1910, exploitation was on the basis of demand. At times uncontrolled, it often led to an overexploitation of teak wood. Fire protection measures were introduced at the end of the nineteenth century, but without much success. The first Working Plan dates back to 1910. Exploitation depended on forest production and selective felling was practised, the last felling probably having been carried out in 1940. The exploited species were mainly *Tectona grandis* (teak), *Dalbergia latifolia* (rosewood), *Pterocarpus marsupium* and *Terminalia alata.*

In 1973, the forest was declared a reserve under the Project Tiger. Felling has been stopped completely and man's interference in the forest is strictly controlled to the minimum: cattle grazing, collection of fuel wood and house construction have been banned.

One of the major consequences of the establishment of this reserve is the considerable rise in the herbivore populations (deer and elephants) which exert increasing pressure on the plant species. According to Sukumar (1989), this region is "one of the finest elephant habitats in South India". He estimated the elephant population to be between 1 200 and 1 500, one of the highest in India. On the other hand, despite the regulations of forest protection, there is hardly any change in the frequency of fires: ground fires regularly sweep the forest every year or two, and forest fires still occur like the one which severely damaged the forest in 1985.

METHODS

In 1978, a plot for studying the biomass production was established by the French Institute of Pondicherry in order to compare this production with that of similar formations in Africa (Legris *et al,* 1981). The plot contains 2 rectangular subplots of 0.2 ha each (20 x 100 m) close to each other. All the trees of girth of 10 cm or greater in these subplots have been mapped and botanically identified and their girths measured at 1.30

Fig 2. Structural profile of a 30 m x 20 m forest plot in Ainurmarigudi Reserve Forest (from Legris *et al*, 1981). The correspondence between the numbers and the different species is: 1, 2, 3, 15, 21, 23, 28 = *Anogeissus latifolia;* 4, 5, 18 = *Dalbergia latifolia;* 6, 11, 12, 13, 24, 27 = *Tectona grandis;* 7, 8, 10, 14, 19, 20, 22, 25 = *Terminalia alata;* 16, 26, 29 = *Grewia tiliifolia;* 17 = *Haldina cordifolia;* 30 = *Antocephalus chinensis;* 9 = dead tree.

m with a measuring tape. For trees forking below this height, the thicker of the 2 ramifications was taken. The total height of the trees and of the forks were measured either with a graduated pole (for heights < 6 m) or with a Blume-Leiss (for heights > 6 m).

Since 1993, besides these measurements, the height of the fork, as well as observations on the state of the trees (broken trunk, fallen trees, bark injuries), have been noted. Two sets of supplementary data were also recorded: recruitment and regeneration. Recruitment corresponds to trees which had attained a girth of 10 cm between 1978 and 1993. Hence, they have been mapped and measured in the same way as the others. Regeneration studies concern stems of girth of less than 10 cm of only the woody species. Sampling was carried out on six 5 x 5 m quadrats per plot, accounting for a total area of 300 m^2. For each tree species, the number of regenerating plants and their height were noted. In the case of basal branching, only the highest trunk was measured.

The floristic structure is described by different indices:

– Simpson's index:

$$D = 1 - \sum_{i=1}^{S} \left(\frac{ni}{N}^{2} \right)$$

where S = total number of species, N = number of individuals, ni = number of individuals of the species i.

– Shannon's index:

$$H' = -\sum_{i=1}^{s} \left(\frac{ni}{N}\right) \log_2 \left(\frac{ni}{N}\right),$$

and equitability $E = H'/Hmax$, where $Hmax = \log_2 S$ (the number of trees is the same for all the species).

– Importance value index (IVI) calculated according to Cain *et al* (1956) : IVI = $rD + rd + rF$, where rD = relative density, rd = relative dominance in basal area, and rF = relative spatial frequency.

RESULTS

Structure and floristic composition

The floristic composition is given in table I. In the 0.4 ha plot, 12 species (girth ≥ 10 cm) were present in 1978 and 14 in 1993. Thus, 2 new species have appeared during this period: *Polyalthia cerasoides* and *Schrebera swietenioides.*

The IVI reveals the preponderance of 4 species: *Tectona grandis, Grewia tiliifolia, Anogeissus latifolia* and *Dalbergia latifolia.* These species will, therefore, be studied in greater detail. The importance of the first 2 species increased during the period under consideration, while that of the other 2 decreased. Table II shows a diminution in all the indices of floristic diversity (Simpson's and Shannon's) since 1978. Despite the appearance of 2 new species, equitability has fallen by 10% in 15 years, mainly due to the increase in the number of *Grewia.*

Spatial structure

Evolution of density and basal area

The density and basal area of the stand, as a whole, have slightly declined from 1978 to 1993 (table III). *Grewia tiliifolia* is the only one of the main species whose density has increased, but its basal area shows a decline, which is the opposite of that observed for teak. Both the parameters have diminished for *Anogeissus latifolia* and *Dalbergia latifolia.* It must be remembered that the measurements in 1978 were made at the end of the rainy season when the water

Table I. Floristic composition and importance value index (IVI) in 1978 and 1993.

Species	*Family*	*IVI 1978*	*IVI 1993*
Tectona grandis L	Verbenaceæ	74.0	80.4
Grewia tiliifolia Vahl	Tiliaceæ	67.0	82.0
Anogeissus latifolia (Roxb ex DC) Wall	Combretaceæ	62.7	58.9
Dalbergia latifolia Roxb	Faboideæ	36.5	29.0
Terminalia alata Heyne ex Roth	Combretaceæ	19.4	16.0
Terminalia paniculata Roth	Combretaceæ	8.3	5.0
Lagerstrœmia parviflora Roxb	Lythraceæ	6.5	5.6
Eriolæna hookeriana Wight & Arn	Sterculiaceæ	6.4	2.7
Emblica officinalis Gaertner	Euphorbiaceæ	5.6	1.9
Dalbergia paniculata Roxb	Faboideæ	5.3	5.9
Haldina cordifolia (Roxb) Risdale	Rubiaceæ	4.3	5.2
Hymenodyction excelsum (Roxb) Wall	Rubiaceæ	4.1	4.5
Polyalthia cerasoides (Roxb) Bedd	Annonaceæ	–	1.4
Schrebera swietenioides Roxb	Oleacae	–	1.4

Table II. Diversity indices in 1978 and 1993.

Diversity index	*1978*	*1993*
Simpson's index	0.79	0.73
Shannon's index	2.72	2.47
Equitability (Shannon)	75.7%	64.9%

capacity of the trunks is maximal, and hence of maximal girth, while those of 1993 were recorded in the dry season when tree girth is minimal. The net variations in the basal area are, therefore, underestimated.

Girth distribution

The girth distribution of all the trees in the 10 cm classes is given in figure 3. A comparison of the distribution patterns of 1978 and 1993 shows a statistically significant evolution (chi-square test) in the 3 girth classes less than 40 cm. In 1978, the number of trees in these 3 classes decreased regularly. In 1993, the 10–20 cm class was very well represented, while the 20–30 and 30–40 cm classes showed a clear deficit.

Girth distribution was calculated only for the 4 most important species, the number of trees of the other species being too small for their distribution to be significant.

A statistically significant evolution is not discernible (test of the number of pairs) in the girth distribution of *Tectona grandis* (fig 4). In 1978, as in 1993, there was not a single young tree of girth less than 50 cm.

Anogeissus latifolia shows changes in the lower girth classes. in 1978, young trees were quite numerous except in the 10–20 cm class. In 1993, the 20–30 and 30–40 cm classes show a decline.

The distribution patterns of *Grewia tiliifolia* in 1978, as in 1993, are L-shaped, straightening towards young individuals, with very few trees of medium and large girths (> 70 cm). As for the whole stand, the only statistically significant change is that

Table III. Density (number of trees/ha) and basal area (m^2/ha) in 1978 and 1993.

	Density		*Basal area*	
	1978	*1993*	*1978*	*1993*
Stand	***550***	***510***	***22.7***	***21.4***
Tectona grandis	82.5	77.5	9.4	9.9
Anogeissus latifolia	97.5	82.5	6.0	5.1
Dalbergia latifolia	62.5	40	2.4	2.0
Grewia tiliifolia	200	235	2.0	1.7
Terminalia alata	37.5	25	0.8	0.7
Hymenodictyon excelsum	2.5	2.5	0.6	0.7
Dalbergia paniculata	7.5	7.5	0.5	0.6
Emblica officinalis	7.5	2.5	0.4	0.1
Lagerstrœmia parviflora	12.5	10	0.2	0.2
Terminalia paniculata	20	10	0.1	0.1
Haldina cordifolia	7.5	7.5	0.1	0.3
Eriolæna hookeriana	12.5	5.	0.03	0.01
Polyalthia cerasoides	–	2.5	–	0.02
Schrebera swietenioides	–	2.5	–	0.03

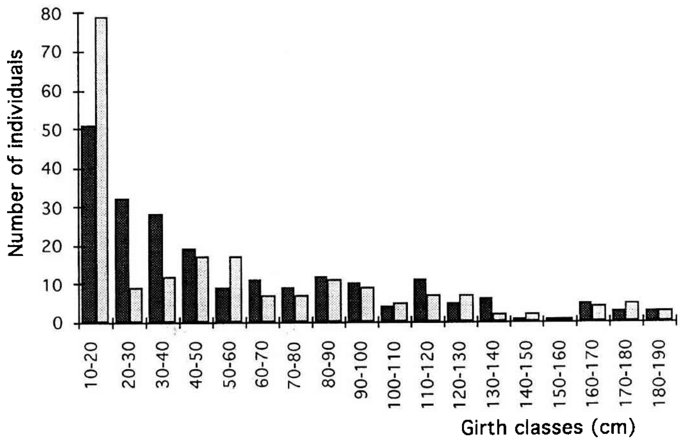

Fig 3. Girth distribution of stand in 1978 ■ and 1993 ▨.

in girth classes less than 40 cm. If in these girth classes the distribution decreased regularly in 1978, a considerable increase in the number of trees in the 10–20 cm class is noticed in 1993, while the number in the 20–30 and 30–40 cm classes has fallen sharply.

The number of *Dalbergia lalifolia* trees is not sufficient to draw statistically valid conclusions on the evolution of the distribution. Nevertheless, a grouping of individuals in the girth classes between 60 and 100 cm can be observed.

Girth-height relationships

The girth-height relationships are given in figure 5. Almost all the trees constituting the higher structural ensembles (*sensu* Oldeman, 1974) belong to 5 species only. The next lower structural ensemble is mostly composed of other species. The main species of the set of the future are *Grewia* and *Anogeissus* (along and to the left of the line H = 100 D).

One way of evaluating the conditions under which a tree has grown is to observe the height of the fork. A closed milieu, where competition for light would be strong, will induce a late forking. Inversely, free growth will be expressed by a precocious, and hence low, forking. Figure 6 shows the ratio between the height of the fork (Hf) and the total height of the tree (Ht) for the 2 most common species of the higher structural ensemble. The 2 distributions are similar: in both the species, trees with high (Hf/Ht > 0.5) and low (Hf/Ht < 0.3) forking are observed, with a mode for forks at moderate height. In the case of teak, all the trees are already old and exceed 60 cm in girth and 10 m in height (fig 7). The variations in the growth conditions are, therefore, old and it is difficult to trace their history. Although intermediate levels of forking are observed in all the height and girth classes, girths of individuals with high forking (> 0.5) are smaller than those with low forking.

Mortality

The mortality rate of the stand is high between 1978 and 1993: 44.5% (98 trees), corresponding to 3.2% per year, which means nearly half the individuals present in 1978, have disappeared. Figure 8a shows that among the young trees, practically all the individuals of 20–30 cm girth and almost half of those belonging to 10–20 cm and

30–40 cm classes (49 and 53.3%, respectively) present in 1978 have disappeared.

Five species account for 80% of the total mortality: *Grewia tiliifolia* (64%), *Dalbergia latifolia* and *Anogeissus latifolia* (5% each) and the 2 *Terminalia* species (5%).

The mortality rate can be validly assessed only for species with a sufficiently large population (fig 8b). In the case of *Grewia tillifolia,* 79% of the individuals (89% of them are young trees) and 66% of the basal area have disappeared during the period under consideration. In *Dalbergia,* mortality mainly affects the 10–40 cm class, while in the case of *Anogeissus* all the classes are affected, as also seen in the similar mortality rates of individuals and basal area. In fact, it is the only important species whose mortality rate is higher in basal area than in individuals.

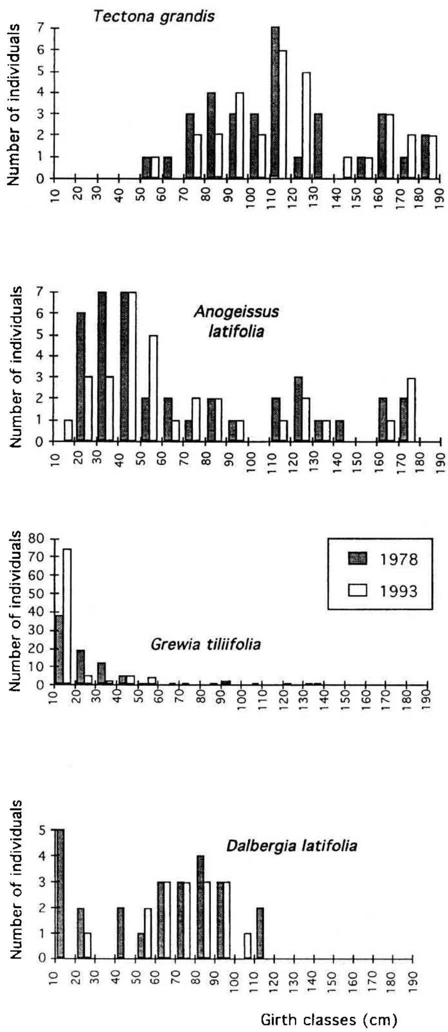

Fig 4. Girth distribution of *Tectona grandis, Anogeissus latifolia, Grewia tiliifolia* and *Dalbergia latifolia* in 1978 and 1993.

Recruitment

In the 2 plots, 38% of the trees in 1993 have attained a girth of 10 cm or greater between 1978 and 1993. Except for 4 trees, all are *Grewia tiliifolia* and of these, all but 3 were of the 10–20 cm class in 1993. Because of the high mortality and considerable recruitment, 79% of the *Grewia* present in 1993 are from recruitment. However, only 45% of these trees can be considered as healthy (not broken or bent, no bark injuries), and only 15% are healthy and unforked. Consequently, although recruitment in *Grewia tiliifolia* population is quite high, only a restricted number of individuals grow into vigorous, healthy trees with a good conformation, and hence will be maintained in the future stand.

Regeneration

The total regeneration (individuals of tree species with girth < 10 cm) exceeds 10 000 stems per ha (table IV).

It is interesting to compare the regeneration density of the different species with their population density (individuals of girth > 10 cm). Species whose relative regeneration density is higher than 2% are given in figure 9. The 2 distributions are significantly different (chi-square test).

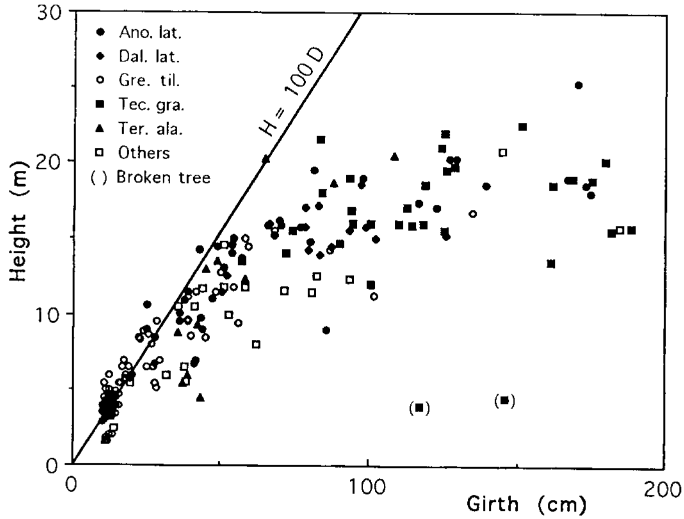

Fig 5. Girth-height relationships.

Tectona grandis, with a high relative density in the stand, has very low natural regeneration. Conversely, the relative densities of *Anogeissus latifolia,* and specially of *Dalbergia latifolia,* are much higher for regeneration than for the stand. The regeneration of *Grewia tiliifolia* is poor when compared to its relative density in the stand.

Table IV. Average total regeneration and mean regeneration (per ha).

Species	*No of stems/ha (G < 10 cm)*
All the species together	**10 667 ± 35**
Anogeissus latifolia (Roxb ex DC) Wall	3 333 ± 13
Dalbergia latifolia Roxb	2 167 ± 33
Grewia tiliifolia Vahl	1 567 ± 12
Dalbergia paniculata Roxb	633 ± 5
Terminalia sp	633 ± 5
Hymenodyction excelsum (Roxb) Wall	533 ± 6
Emblica officinalis Gaertner	500 ± 4
Tectona grandis L	400 ± 3
Diospyros montana Roxb	233 ± 12
Pterocarpus marsupium Roxb	200 ± 12
Cassia fistula L	100 ± 10
Albizia marginata Merr	67 ± 9
Unidentified species	67 ± 8
Garuga pinnata Roxb	67 ± 8
Lagerstrœmia parviflora Roxb	67 ± 8
Bridelia crenulata Roxb	33 ± 7
Diospyros melanoxylon Roxb	33 ± 7
Holarrhaena antidysenterica Wall	33 ± 7

Values are given with their confidence interval, calculated by Student's law.

Lastly, the regeneration of 3 species, *viz, Dalbergia paniculata, Emblica officinalis* and *Hymenodictyon excelsum,* which are poorly represented in the stand, is not negligible.

Figure 10 shows the distribution of the regeneration of the main species in 4 height classes (< 0.5 m, 0.5–1 m, 1–2 m, > 2 m). Two groups of species can be distinguished based on these distributions (test of number of pairs): *Tectona grandis* and *Grewia tiliifolia* where the major part of the regeneration is above 1 m, and *Anogeissus latifolia* and *Dalbergia latifolia* where the major part of the regeneration is below 1 m.

Regeneration of *Dalbergia lalifolia,* which is abundant, hardly exceeds 1 m. The same tendency, although less pronounced, is seen

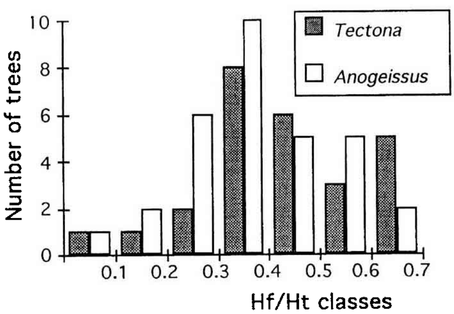

Fig 6. Distribution of the ratio between the fork height (Hf) and the total height (Ht) for *Tectona grandis* and *Anogeissus latifolia.*

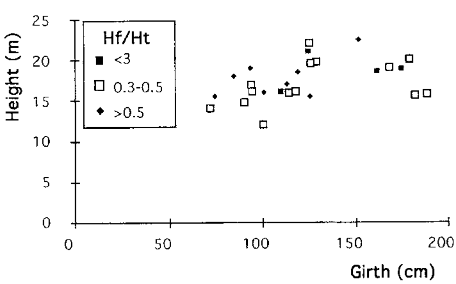

Fig 7. Relationships between H fork/H total ratio and height/girth ratio for *Tectona grandis.*

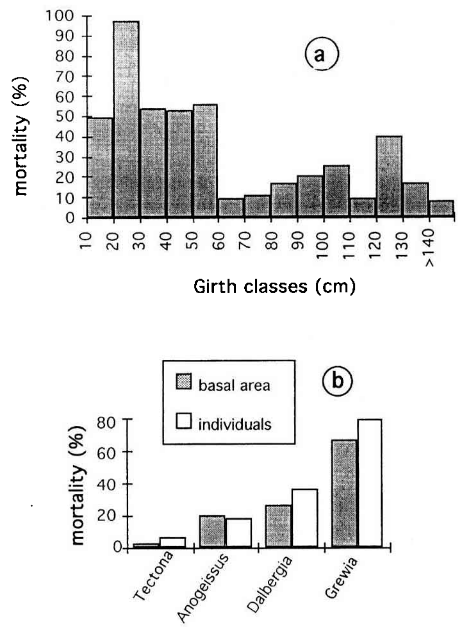

Fig 8. Rate of mortality between 1978 and 1993. (a) Girth classes of 10 cm; (b) rate of mortality (basal area and individuals) for *Tectona grandis, Anogeissus latifolia, Dalbergia latifolia* and *Grewia tiliifolia.*

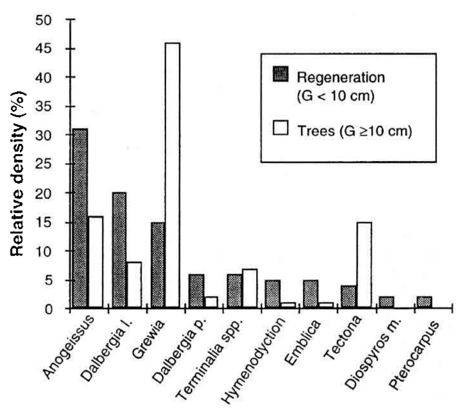

Fig 9. Relative densities in the regeneration (girth < 10 cm) and in the stand (girth ≥ 10 cm) for the species whose relative density in the regeneration is higher than 2%.

in *Anogeissus latifolia* where the regeneration rarely surpasses 2 m. Besides poor regeneration, *Tectona grandis* shows a deficit in plants exceeding 2 m. In the case of *Grewia tiliifolia,* the deficit seems to be in the smaller height classes, which could be due to its vegetative mode of reproduction.

Table V recapitulates the results concerning the evolution of the structure, dynamics and regeneration of the stand and of the 4 main species.

DISCUSSION

The vegetation map (Pascal, 1982) shows clearly that the natural deciduous forests tend to disappear when not managed by the Forest Department. Even then, repeated fellings have more or less degraded the stands. It was expected that classifying them as a reserve, which implies prohibition of logging and a relative control on human interference, would lead to the restoration of the forest structure.

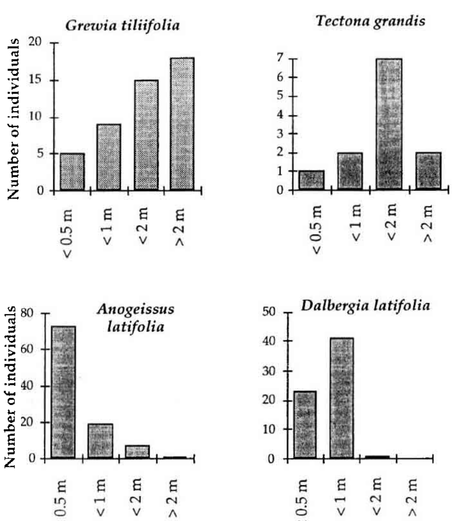

Fig 10. Height distribution in regeneration for *Grewia tillifolia, Tectona grandis, Anogeissus latifolia* and *Dalbergia latifolia.*

Despite 15 years of protection, the density of the stand, taken as a whole, has diminished as has the basal area, but to a lesser extent. The general tendency is thus towards opening of the stand. Although the mortality and recruitment rates are high, it is always the same 4 species which dominate the floristic composition (*Tectona grandis, Grewia tiliifolia, Anogeissus latifolia* and *Dalbergia latifolia*). Tree species diversity has decreased slightly due to the increased importance of the first 2 species.

Changes are almost exclusively in the smaller girth classes. In spite of a high mortality rate, the class of very small trees (10–20 cm girth) showed a considerable increase thanks to heavy recruitment. On the contrary, despite recruitment, the 20–30 cm and 30–40 cm classes have become markedly poorer because of the death of almost all the trees of the 20–30 cm class present in 1978, and of half of those belonging to the 30–40 cm class.

It is certainly the combined action of the forest fire of 1985 and the increasing pressure of the big herbivores which have led to the deficit in these 2 classes. Besides the species they consume, elephants break, uproot and push down the young trees which are in their way (Sukumar, 1989). The impact of megaherbivores on the opening of the stand and its fragmentation is well known (Schüle, 1992). Saplings were not saved either, but the openings created in the stand would have favoured the growth of survivors, which explains the rise in the number of trees of the first class.

The changes in the species populations will be analysed only for the 4 most important species (in terms of IVI) which are responsible for practically the whole evolution of the stand.

(i) The population of *Tectona grandis* has hardly changed. Even in 1993 there was no young tree and only a few old trees were observed. Mortality is low, as well as regeneration which seems to be mainly through

Table V. Main dynamics results for the stand and the 4 main species: *Tectona grandis*, *Dalbergia latifolia*, *Anogeissus latifolia* and *Grewia tiliifolia*.

		Stand	*Tectona grandis*	*Dalbergia latifolia*	*Anogeissus latifolia*	*Grewia tiliifolia*
Evolution of the floristic structure	Floristic diversity IVI	↘	↗	↘	↘	↗
Evolution of the spatial structure	Density	↘	↘	↘	↘	↗
	Basal area	↘	↗	↘	↘	↘
	Girth distribution 1978	Deficit in youngs	No girth < 50 cm	Girths between 60–100 cm	Deficit in 10–20 cm class	Deficit G > 60 cm
	1993	Like 1978 ↗ 10–20 ↘ 20–40	Like 1978	Like 1978 almost no girth < 50 cm	Deficit in 10–40 cm class	Like 1978 ↗ 10–20 ↘ 20–40
Population dynamics	Mortality	Very high 45%	Low	Medium mostly youngs	Moderate all girth classes	Very high (80%) 90% of youngs
	Recruitment	High (38% of 1993 trees)	Nil	Nil	Almost nil	Very high (79%) but damaged
Regeneration	Quantity	10 000 stems/ha	Poor	Good	Good	Medium
	Quality	Floristic differences stand/reg		Deficit in height > 1 m	Deficit in height > 2 m	Deficit in height < 1 m
	Mode		Vegetative	Seeds	Seeds	Vegetative

vegetative shoots (Planchais, 1993). The *Tectona* population is thus ageing and presents a serious problem of regeneration.

It is difficult to explain this phenomenon because the conditions seem ideal for the extension of this species. In fact, this species resists fire very well at the adult stage and opening of the stand favours its regeneration (Troop, 1921; Kadambi, 1972). Trees of the stand are fertile. Planchais (1993) has demonstrated that most of the seeds on the ground are fertile and that fire does not seem to have an adverse effect on them and could, under certain conditions, remove their dormancy.

The structure of the teak population shows a trace (in the height of the fork) of earlier modifications in the stand opening, as a result of overexploitation prior to 1910 and selective felling afterwards which continued up to the 1940s. Furthermore, felling has removed the sturdiest trees. However, it is difficult, in light of our knowledge, to understand why regeneration through sexual reproduction is not observed here, as well as in the other parts of India.

(ii) The *Dalbergia latifolia* population is low and therefore one should be cautious in interpretating it. Nevertheless, the concentration of trees in the 60–100 cm girth class, already quite clear in 1978, has increased in 1993: there is hardly any tree of girth of less than 50 cm left; hence, recruitment is absent in the lower classes. Regeneration, which seems to be mostly through seeds, is profuse but the plants do not exceed 1 m (Planchais, 1993). Environmental conditions do not seem to be favourable for *Dalbergia latifolia* as there is no big tree (this species is capable of exceeding a girth of 250 cm). Moreover, the population experiences a serious problem of regeneration.

Exploitation has probably led to the disappearance of the big trees. Despite the cessation of felling since the early 1940s, big trees are still not encountered. This may be because the opening of the stand is too big for this species which is often described as not being favourable to too much light (Troop, 1921).

(iii) The *Anogeissus latifolia* population has evolved very little between 1978 and 1993, the principal differences being observed in the 3 smallest girth classes. The deficit in young trees has become more pronounced: from a deficit mostly in the 10–20 cm class, it now touches all of the 3 classes. Recruitment is nonexistent. Regeneration, which seems to be through seeds, is profuse but shows difficulty in exceeding 2 m. However, this problem of renewal is not as serious as in the species mentioned earlier as the number of young trees is quite high. It may be only temporary because although this species always produces a lot of seeds, they are fertile only during certain years (Troop, 1921; Champion, 1934; Planchais, 1993). The regeneration of *Anogeissus latifolia* could take place in waves corresponding to the years of prolific production of fertile seeds. The present period in Ainurmarigudi could be just after one of these production phases (there is a good regeneration up to a height of 2 m). The poor regeneration above 2 m, as well as in young individuals, could correspond to an earlier phase when the seeds produced were not fertile. A more detailed study covering a longer period would be necessary to confirm or refute this hypothesis.

(iv) The *Grewia tiliifolia* population has changed the most in these 15 years. This species has a fast turnover, high mortality rate especially among young individuals, and high rate of recruitment. This renewal is only in the low girth classes: augmentation in the 10–20 cm class and reduction in the next 2 classes. Given the high mortality in the 10–20 cm class and the increase in the number of trees in it, recruitment has been profuse. However, the poor state of the young trees must be noted. Regeneration, which is mostly vegetative (Planchais, 1993), is fairly abundant. The problem seems to be more with respect to the young reaching the adult stage, as young trees in poor condition find it difficult to get firmly established.

As for the stand taken as a whole, forest fires and increasing herbivore pressure have caused the disappearance of young trees. *Grewia tiliifolia* is a very appetising plant for elephants and a major part of its mortality can be attributed to them. Elephants are also responsible for the poor condition of the young trees which have a lot of bark injuries and also forks at a height of 1.5–2 m, which are characteristic of the damage caused by these animals (Sukumar, 1989).

On the other hand, opening of the stand has greatly benefited this species as a very high recruitment of young trees is observed.

CONCLUSION

The sampling pattern having been established for other purposes, its size is not suitable to generalise the results with respect to the whole area of the Project Tiger Reserve. The period of study should also be longer to better evaluate the consequences of protection on the evolution of the stand. However, our repeated and systematic surveys reveal the same tendencies throughout this region. In a 50 ha plot in Mudumalai, Sukumar *et al* (1992) also observed the opening of the stand, with a deficit in individuals of small girth and a mortality of 14% in the first 2 years. Mortality is mainly attributed to the damage caused by elephants and, to a lesser extent, to fire. The Mudumalai Reserve, which is near the Ainurmarigudi Forest, has similar climatic conditions with, however, a slightly higher rainfall, which explains the different floristic composition and probably the evolution of *Grewia tiliifolia* and *Anogeissus latifolia* populations which are deficient in young plants here.

We can thus conclude that cessation of felling and relative protection of the forest do not seem to have led to a closing of the stand, nor to an increase in its density, height or tree diversity. In fact, the opposite tendencies are observed. The teak population continues to age and that of *Dalbergia latifolia* remains in disequilibrium. These 2 species thus seem to be in jeopardy in the long term. *Grewia tiliifolia,* which has a great capacity for recruitment, does not seem to be able to establish itself in the adult state. Only *Anogeissus latifolia* seems to benefit from the prevailing conditions and, if this evolution continues, will ultimately dominate the stand. In fact, throughout this region forest patches composed of nearly pure stands of *Anogeissus* can be observed. The opening of the stand and diminution in its biomass, together with the ongoing processes, thus lead to a reduction in the tree species diversity.

Establishing a reserve has had very little effect on the fire regime, including forest fires. It has, on the other hand, greatly increased the herbivore population, particularly elephants, which have caused considerable damage to the stand and its regeneration.

Similar evolutionary processes have been described in other regions established as reserves: for example, in the Aberdare National Park (Schmitt, 1992) and in the Simba Hills National Reserve (Schmidt, 1992) in Kenya. However, in these 2 reserves anthropic pressure is still evident, which is not the case in Ainurmarigudi except for fire. Hence, certain general features can be distinguished in the evolution of stands in reserve forests where the impact of big herbivores is quite pronounced. The success of managing the reserve would thus depend on the objective pursued. If it is reconstitution of the tree cover, the herbivore population should be controlled. On the other hand, the result is more satisfying for the Project Tiger which aims at increasing the carnivore population *via* herbivores (particularly the Cervidae) and maintaining a not very dense cover which is better suited for tigers. However, a new problem arises with a thick bushy undergrowth growing in response to the increasingly high density of the herbivores. Annual fires do not seem capable of containing it. This, in time, could threaten the grass cover necessary for herbivores and modify the present dynamics of the ecosystem.

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REFERENCES

Bourgeon G (1989) *Explanatory booklet on the reconnaissance soil map of forest area. Western Karnataka and Goa.* Institut français de Pondichéry. Trav sec sci et tech, hs n° 20, 96 p

Bourgeon G (1992) *Les sols rouges de l'Inde péninsulaire méridionale. Pédogenèse fersiallitique sur socle cristallin en milieu tropical.* Institut français de Pondichéry. Publications du département d'écologie N° 31, 271 p

Cain SA, Castro de O, Pires JM, Silva NT da (1956) Application of some phytosociological techniques to Brazilian rain forest. *Am J Bot* 43, 911-941

Champion HG (1934) Seed crop and fertility of *Anogeissus lalifolia. Indian Forester* 60, 150-153

Gaulier A (1993) Évolution de la forêt sèche d'Ainurmarigudi, rôles joués par la mise en réserve, les grands herbivores et le feu. ENGREF, Formation des ingénieurs forestiers, Nancy, France, 15-115

Kadambi K (1943) *Working Plant for the Ghat Forest of Mysore, 1941–1961.* Karnataka Forest Department

Kadambi K (1972) Sylviculture and management of teak. *School of forestry, State University, Texas,* USA, Bulletin 24

Legris P, Devineau JL, Pascal JP, Deshayes M, Menaut JC, Janel P (1981) Étude comparative de formations ligneuses en zone tropicale sèche d'Asie et d'Afrique occidentale. DGRST-7970023, 113 p

Muthanna MA (1931) *A working plan for the state forests Metikuppe, Kakankote, Begur, Ainurmarigudi & Katwal in the Heggaddevankote, Kakankote, Begur and Ainurmarigudi Forest Ranges of Mysore Forest Division, 1931–1941.* Forest Department of Karnataka

Oldeman RAA (1974) *L'architecture de la forêt guyanaise.* Mémoires ORSTOM n° 73, 204 p

Pascal JP (1982) *Forest map of South India–Mercara-Mysore.* Institut Français de Pondichéry. Trav sec sci et tech hs, n° 18

Pascal JP (1986) *Explanatory booklet on the forest map of South India. Sheets: Belgaum-Dharwar-Panaji, Shimoga, Mercara–Mysore.* Institut Français de Pondichéry, Trav sec sci et tech, hs, n° 18, 88 p

Planchais I (1993) Évolution de la forêt sèche d'Ainurmarigudi. Étude de l'effet du feu sur la germination des essences dominantes. ENGREF, Formation des ingénieurs forestiers, Nancy, France, 117-196

Schmdit R (1992) Degradation of a forest in the Shimba Hills National Reserve, Kenya, as initiated by man and maintained by wildlife. *In: Tropical forests in transition* (JG Goldammer, ed), Birhhäuser, Basel/Switzerland, 85-104

Schmitt K (1992) Anthropo-zoogenic impact on the structure and regeneration of a submontane forest in Kenya. *In: Tropical forests in transition* (JG Goldammer, ed), Brihhäuser, Basel/Switzerland, 105-126

Schüle W (1992) Vegetation, megaherbivores, man and climate in the quaternary and the genesis of closed forests. *In: Tropical forests in transition* (JG Goldammer, ed), Birhhäuser, Basel/Switzerland, 45-76

Srinivasarao H (1910) *Working plan 1910–1930 Heggaddevankote sub-division, Mysore District.* Forest Department of Karnataka

Sukumar R (1989) *The Asian elephant. Ecology and management.* Cambridge University Press, Cambridge, UK, 255 p

Sukumar R, Dattaraja HS, Suresh HS, Radhakrishnan J, Vasudeva R, Nirmala S, Joshi NV (1992) Long-term monitoring system of vegetation in a tropical deciduous forest in Mudumalai, Southern India. *Curr Sci* 62, 608-616

Troop RS (1921) *The sylviculture of Indian trees.* 3 vols. Oxford University Press, Oxford, UK, 1195 p