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Impact of human extraction on tropical humid forests in the Western Ghats in Uttara Kannada, South India

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Summary

1. Thirty strip transects of 2400 m^2 each, in the evergreen forest tract of the district of Uttara Kannada in South India, were clustered into two groups with high and low levels of disturbance on the basis of the density of perennial flowering plants and the fraction of deciduous species.
2. The set of 20 transects corresponding to low disturbance localities harboured 48 ± 6 (mean ± SD) species and 694 ± 135 individuals per transect, while the other 10 transects affected by high levels of disturbance supported 36 ± 12 species and 379 ± 135 individuals.
3. Eighty-four of the total of 200 species (operational taxonomic units) were exclusive to sites of low disturbance, and 28 to those of high disturbance; 88 species were shared by sites of high and low disturbance. This number of shared species was significantly less than expected on the basis of chance alone.
4. The differences in species richness, as well as those in species turnover (0·73 ± 0·07 for high and 0·65 ± 0·01 for low disturbance sites) were significant at the 1% level, but were as expected given the lower plant densities at sites of high disturbance.
5. Lack of coppicing ability in conjunction with their use in the plywood/matchwood industry has led to the disappearance of several evergreen species such as *Syzigium gardneri* and *Myristica malabarica* at sites with high levels of disturbance.
6. With villagers concentrating on harvests of trees in the height class of 4–8 m as poles, and commercial interests mostly extracting trees > 16 m in height, there was a reduction of around 45% across all height classes between sites of low and high levels of disturbance.

Key-words: biodiversity, hot spot, human cultural disturbance, plywood industry, species turnover.

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Introduction

Tropical humid forests are amongst the most diverse, most productive and most threatened of biological communities. Indeed 14 of the 18 biodiversity hot spots identified by Myers (1988, 1990) represent this biome. Two of these, the Eastern Himalayas and the Western Ghats, occur in India. The Western Ghats constitute a hill chain of length 1600 km and, along with the narrow coastal strip, form a region with an average width of 105 km, and receiving annual rainfall in the range of 2000 to 6000 mm, largely concentrated in the monsoon months of June to October. This region can potentially support 64 750 km^2 of evergreen forests and 103 000 km^2 of deciduous forest.

On the basis of satellite imagery and vegetation maps available in the mid 1980s, Gadgil & Meher-Homji (1986) estimated that the evergreen forest cover had been reduced to 22 000 km^2. The Ministry of Environment and Forests (1989, 1992), of the Government of India, estimated a 20% reduction in forest cover from the Western Ghats states of Kerala, Tamil Nadu, Karnataka, Goa and Maharashtra between 1972 and 1982, and a lower rate of 4·32% between 1982 and 1990. This was subsequently brought under check, leading to an actual increase of 0·01% between 1991 and 1993 (Ministry of Environment and Forests 1993).

While the process of loss of forest cover in the Western Ghats has thus been contained, pressures leading to erosion of forest biomass and local extinctions of species continue (Pascal 1988; Gadgil & Subash Chandran 1989b; Nadkarni, Pasha & Prabhakar 1989). The present investigation attempts to document these changes on the basis of a set of 30 strip transects sampled in the single most extensive remaining tract of the Western Ghats evergreen forest, in the district of Uttara Kannada (13°55′–15°32′N and 74°05′–75°05′E). Geologically, this is a region of transition between the northern Deccan traps and the southern Archaen crystalline shield, with a very narrow coastal strip and low broad hills rising to no more than 1000 m before merging with the Peninsular Plateau at an altitude of 600 m. Champion & Seth (1968) characterized the vegetation of this tract as west coast evergreen/semi-evergreen forest. Pascal (1982, 1984) has published maps (at 1 : 250 000) of the vegetation of the district, which is characterized as belonging to the *Memecylon–Syzigium–Actinodaphne* and *Persea–Diospyros–Holigarna* series of tropical wet evergreen forest. The vegetation is distributed in five broad zones governed by the rainfall gradient, and remains most intact in the northern and southern evergreen zones (Fig. 1). Even here the vegetation is an intricate mosaic of different stages of degradation. There has been little extraction from the more inaccessible slopes in these two zones, although many of these areas might have been under shifting cultivation prior to 1865 (Gadgil & Subash Chandran 1989b). This tract thus provides an excellent setting for comparing forests under varying degrees of human impact.

These forests have been and are still subject to a variety of human impacts, including commercial logging, extraction of fuelwood and fencing poles, lopping of leaves, cattle grazing and dry-season fires. Little quantitative information is available on any of these activities, so that it is not possible to grade different localities along a well-defined scale of disturbance. It is, however, reasonable to assume that increasing levels of disturbance are accompanied by a reduction in forest biomass, an opening of the forest canopy and a reduction in soil moisture. These environmental changes favour deciduous species at the cost of shade-tolerant and moisture-loving evergreen species (Puri *et al.* 1983; Pasal 1988). The extent of reduction in forest biomass and increase in the fraction of deciduous species may then serve as useful measures of increasing levels of disturbance for the evergreen forest tracts in the Western Ghats. We discuss below the changes in forest composition in terms of species richness, species turnover, attributes of constituent species and the structure of the vegetation along such a gradient.

Materials and methods

The study was based on 30 transects of 600 × 4 m, i.e. 2400 m^2, selected in order represent all levels of degradation of the evergreen forest vegetation in the Uttara Kannada district, as indicated on Pascal's (1982, 1984) vegetation maps at a scale of 1 : 250 000 (Table 1). Along the transects we sampled all flowering plants excluding grasses, epiphytes, seedlings at cotyledon stage and shorter herbaceous plants. Herbaceous plants over 1 m in height belonging to the families Zinziberaceae and Marantaceae were included. The plants were assigned to seven height classes, namely 0–1, 1–2, 2–4, 4–8, 8–16, 16–32 and >32 m (Daniels 1989; Daniels, Joshi & Gadgil 1992). In all 200 species were involved; of these 121 could be identified to species level, 35 only to genus level, and nine only to family level, with the help of Saldanha's collec-

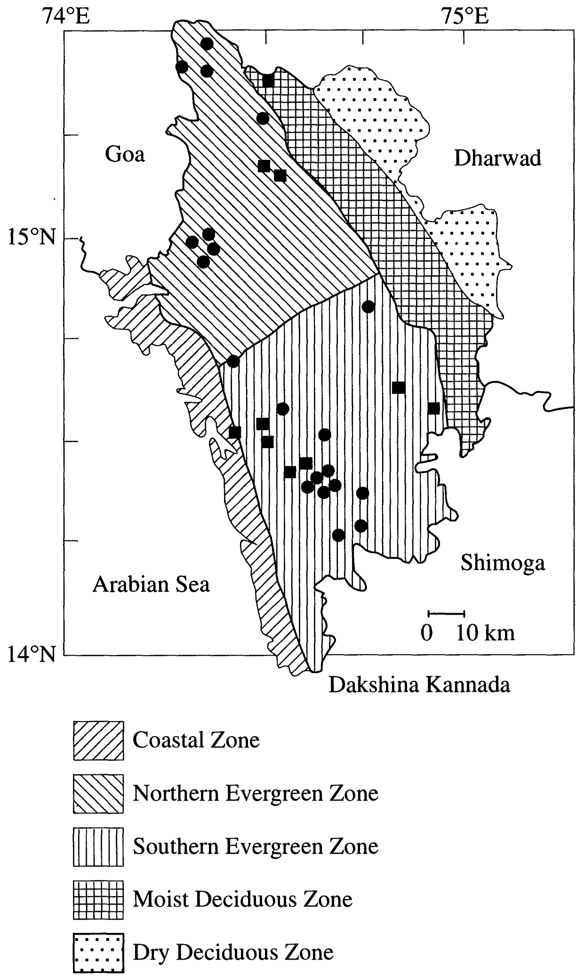

Fig. 1. Vegetation zones in Uttara Kannada with locations of sites with low (●) and high (■) levels of disturbance.

tions lodged at the Indian Institute of Science (Saldanha & Nicholson 1978; Saldanha 1983). The remaining 35 were considered to be operational taxonomic units (OTUs) with the rank of species.

The 165 securely identified OTUs were then characterized in terms of evergreen or deciduous habit, incidence of spines, thorns or latex, sun-loving or shade-loving habit, and pioneer, climax or relict species status (Pascal 1988). Our own field observations were used to assess the coppicing abilities of various species and their involvement in a variety of human usages. Records of the Forest Department provided additional information on commercial uses, especially in the plywood and matchwood industry (Gadgil & Subash Chandran 1989a).

The composition of the 30 sampled plant communities was then plotted in the space defined by two indicators of disturbance, namely plant density and fraction of individuals of deciduous species (Fig. 2). The 30 points seem to constitute two distinct clusters in this space. As Fig. 1 indicates, sites assigned to the two clusters were geographically interspersed and did not represent distinct bioclimatic zones. Rather, they probably correspond to categories of low and high levels of disturbance. It is therefore of interest to assess whether these were significantly distinctive in their species composition. The frequency distribution

Table 1. Details of the 30 sample localities

Number, latitude and longitude	Locality	Altitudinal range (m)	Date of sampling	Vegetation series*	Incidence of trails	Incidence of induced fire	Incidence of grazing
Low disturbance							
1 14°15′N–74°38′E	Mastimane	60–200	4-4-87	PDH	–	–	–
2 14°36′N–74°33′E	Yan	~140	29-4-87	PDH	+	–	Seasonal
3 14°31′N–74°38′E	Bandal Ghat	80–480	16-3-88	PDH	–	+	No
4 14°02′N–74°45′E	Unchalli Falls	180–220	20-3-87	PDH	–	–	No
5 14°22′N–74°38′E	Doddamane Ghat	50–180	17-3-87	PDH	–	–	No
6 15°23′N–74°21′E	Castle Rock	550–570	21-1-88	MSA	+	–	No
7 15°30′N–74°18′E	Meda	580–620	24-1-88	MSA	+	–	No
8 14°55′N–74°21′E	Anshi Ghat	350–360	9-2-88	PDH	–	–	Seasonal
9 15°N–74°24′E	Anshi (Vakkihalla)	380–440	10-2-88	PDH	–	–	No
10 15°N–74°18′E	Anshi (Bharadi)	510–580	11-2-88	MSA	–	–	No
11 15°N–74°22′E	Talapa (Nujji)	570–580	23-2-88	MSA	–	–	No
12 14°22′N–74°37′E	Methini Ghat	400–410	1-4-86	PDH	+	–	Perennial
13 14°24′N–74°38′E	Aghanashini	30–80	20-3-86	PDH	+	+	No
14 14°15′N–74°45′E	Malemane Ghat	520–560	3-5-86	PDH	+	–	No
15 14°44′N–74°24′E	Makigadde	~40	21-3-88	PDH	+	+	No
16 14°49′N–74°45′E	Manchikere	480–530	18-3-88	MSA	–	–	No
17 14°22′N–74°38′E	Huladevagodlu (Bridge)	110–180	13-3-87	PDH	–	–	No
18 14°23′N–74°38′E	Huladevagodlu	50–160	27-2-87	PDH	–	–	No
19 15°17′N–74°30′E	Jagalbet	610–660	5-1-88	MSA	–	–	Seasonal
20 15°25′N–74°16′E	IB Customs (Karambal) Kaskowadar	~620	23-1-88	MSA	–	–	Seasonal
High disturbance							
1 14°24′N–74°37′E	Badal	80–220	31-3-87	PDH	–	+	No
2 14°24′N–74°36′E	Basalli (Santeguli)	60–100	26-3-87	PDH	–	–	No
3 14°31′N–74°24′E	Nagur Cross	~30	24-4-87	PDH	+	–	Perrenial
4 14°30′N–74°30′E	Anegundi-Belangi	~20	5-5-87	PDH	+	+	Seasonal
5 14°31′N–74°30′E	Sandoli	~20	7-5-87	PDH	+	+	Perrenial
6 14°39′N–74°50′E	Targod	540–570	20-5-87	PDH	+	–	No
7 15°11′N–74°31′E	Patoli	520–500	4-2-88	MSA	+	–	No
8 14°34′N–74°56′E	Bidralli	~520	18-2-88	PDH	+	–	Seasonal
9 15°22′N–74°30′E	Jagalbet (Bori)	590–600	6-1-88	MSA	–	–	Seasonal
10 15°11′N–74°30′E	Joida	540–560	8-1-88	MSA	–	–	No

* MSA, '*Memecylon–Syzigium–Actinodaphne*' series of tropical wet evergreen forest. PDH, '*Persea–Diospyros–Holigarna*' series of tropical wet evergreen forest.

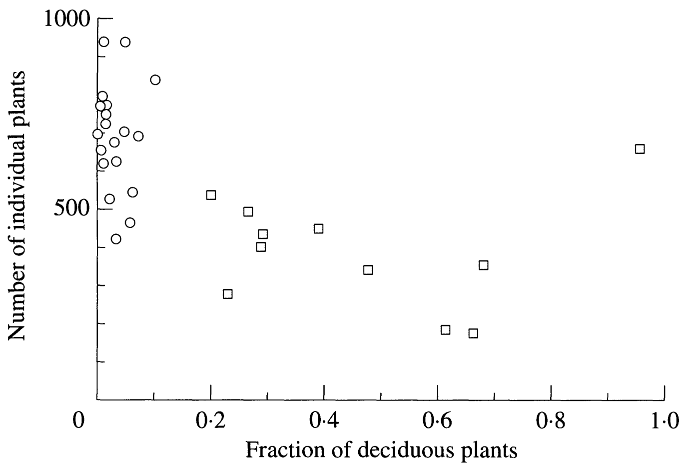

Fig. 2. Distribution of low (○) and high disturbance (□) transects according to the fraction of individuals of deciduous species (x-axis) and the total number of individual plants (y-axis) in each transect.

of numbers of individuals per species, recorded in the different sample plots, does not readily conform to standard distributions; nor are the numbers of plots or individuals belonging to the two categories equal. We therefore resorted to Monte Carlo simulations to test the null hypothesis that all species were distributed amongst the two categories without any bias. We performed three kinds of simulations.

1 Distributing the 30 sample sites at random amongst two groups of 20 and 10 each.

2 Distributing the 30 sample sites at random amongst two groups such that each group harboured a number of individual plants as close as possible to that which belonged to each of these two categories, namely 13 886 individuals for low and 3790 for high levels of disturbance.

3 Assigning the individuals belonging to 200 species to the two categories of low and high disturbance with a probability of 13 886/17 676 and 3790/17 676, respectively.

The simulations provide a distribution for the number of species exclusive to the two categories, as well as for the number of shared species, under the null model. These could be compared with the observed values for a statistical validation of our categorization.

Results and discussion

Table 2 compares the results of the simulations on the basis of these three different assumptions with the actual observations on the number of species exclusive to and number of species shared between the two categories of high and low disturbance. Evidently sites belonging to the two categories harboured a significantly distinctive set of species. As Table 3 shows, the sites belonging to the categories also differed significantly from the expected direction in three measures of disturbance, namely occurrence of trails, pressure of grazing and incidence of fire. None of these differences was initially used to delineate the two categories, and this suggests that we were justified in the conclusion that our 30 sample sites could be divided into two groups of high and low levels of human-induced differences that have favoured the occurrence of distinctive sets of species.

Table 2. Observed number exclusive to, as well as shared between, sites of low and high disturbance. The expected numbers were obtained, under the null hypothesis of no difference between the two groups, from 1000 Monte Carlo simulations using the models: (1) dividing the populations of 30 sites as observed randomly amongst two groups of 20 and 10; (2) assigning populations at different sites at random amongst two groups such that the total numbers in the two groups were as close as possible to 13 886 and 3790; (3) assigning individual plants randomly to two groups of sites with 13 886 and 3790 individuals, respectively. The probability *P* is that of obtaining a value as high as the observed for the number of exclusive species, and as low as the observed for the number of shared species

	Observed	Expected			
			1	2	3
Exclusive to sites of low disturbance	84	μ	54·2	75·5	41·5
		σ	7·8	9·7	4·0
		Max	79·0	103·0	57·0
		Min	32·0	49·0	30·0
		P	<0·001	0·219	<0·001
Exclusive to sites of high disturbance	28	μ	20·7	12·4	5·6
		σ	5·9	4·7	2·1
		Max	38·0	27·0	13·0
		Min	4·0	1·0	0·0
		P	0·099	<0·001	<0·001
Shared between the two sites	88	μ	125·2	112·1	152·8
		σ	4·5	7·1	3·4
		Max	137·0	131·0	163·0
		Min	109·0	83·0	141·0
		P	<0·001	0·003	<0·001

Table 3. Number of transects where different agents of disturbance were present

Agent of disturbance	Low disturbance (20 transects)	High disturbance (10 transects)
Grazing	5 (25%)	5 (50%)
Fire	3 (15%)	3 (30%)
Trails	7 (35%)	6 (60%)

The differences in percentages were significant ($P < 0{\cdot}05$) in all cases.

SPECIES RICHNESS

It was thus appropriate for us to look for differences between these two sets of sites in variables other than the plant density and fraction of deciduous species that were used in deriving the groupings. Species richness, or α-diversity, and species turnover, or β-diversity, were two such parameters of interest.

One expects two kinds of processes to affect the number of species found on a transect in relation to disturbance. A reduction in plant density would be accompanied by a reduction in the total number of species per unit area, simply because of the decrease in the total number of individuals being sampled. At the same time, opening up of the canopy may lead to a reduction in resource competition, permitting invasion by a large number of species. Indeed, it has been documented that under certain conditions intermediate levels of disturbance lead to an increase in α-diversty (Connell 1978; Pickett & White 1985; Fuentes & Jaksie 1988).

The 20 evergreen transects harboured between 35 and 62 species, with a mean of 48·8 and a standard deviation (SD) of 5·6. The numbers were lower at the 10 disturbed sites, with a range of 18–55, a mean of 35·7 and with a standard deviation of 11·9. This difference is statistically significant at $P = 1\%$ (*t*-test, Mann-Whitney *U*-test). A total of 172 OTUs made up the 13 886 individuals on the 20 evergreen transects; in contrast, only 116 OTUs occurred amongst the 3790 individuals on the 10 disturbed transects. Simulations of sampling 3790 individuals from the total pool of 13 886 individuals of 172 species for the low-disturbance sites provide an estimated mean number of 111 OTUs, with a standard deviation of 6·5. This is slightly lower, but not significantly so, than the 116 species/OTUs amongst the many individuals on the highly disturbed sites . This suggests that the lower number of species on the highly disturbed transects may simply be a consequence of a decrease in density, and may thus be unrelated to any changes in the packing of species within the community. Values of the exponential of the Shannon-Weaver index $H = -\sum_i P_i \ln P_i$, where P_i is the fraction of the i^{th} species) were also not significantly different for the low as opposed to highly disturbed sites, being 18·4 ± 6·1 for the former and 15·2 ± 7·8 for the latter. In the case of these 10 sites then, an increased level of disturbance was not accompanied by significantly increased levels of α-diversity.

SPECIES TURNOVER

A variety of human disturbances has created a vegetation mosaic in Uttara Kannada. It is possible that in such a landscape a wide range of species may have opportunistically colonized the disturbed patches, with the identity of colonizers differing greatly from patch to patch. This could imply a greater level of species turnover, or β-diversity, for the disturbed patches, even though individual disturbed patches had a lower level of α-diversity.

By defining β-diversity as the fraction of unshared species between any pair of patches, the highly disturbed sites showed a value of 0·73 ± 0·07 (mean ± SD), as opposed to a value of 0·65 ± 0·1 for the low disturbance sites. This difference is significant at the $P = 1\%$ (*t*-test, Mann-Whitney *U*-test). However, since the highly disturbed sites had fewer individuals, randomly constituting any pair of such sites from a common pool is expected to give a greater fraction of unshared species. Correcting for this effect, the fraction of unshared species in low disturbance sites is expected to be 0·70 ± 0·09, which is not significantly different from that of disturbed sites. Thus disturbance did not enhance this component of diversity either.

SPECIES ATTRIBUTES

Of the 165 securely identified taxa, 138 occurred on low disturbance sites with 60 being exclusive to them, while 105 occurred on high disturbance sites with 27 being restricted to them. Seventy-eight taxa were shared by high and low disturbance sites. By definition, low disturbance sites had a higher fraction of evergreen species. Species characterized by Pascal (1988) as climax species similarly comprised a higher fraction of the flora on low disturbance sites, while those characterized as pioneers as well as heliophile formed a significantly greater fraction of those restricted to highly disturbed sites (Table 4). Pascal (1988) terms as relicts those evergreen species which persist under disturbance; our data support this contention. No relict species were exclusive to low disturbance sites, but a much greater fraction occurred amongst species shared between low and high disturbance sites than among species restricted to highly disturbed sites alone.

In addition, it is of interest to investigate whether human harvesting more directly favours species with attributes that either (i) hinder harvesting, as with thorns, spines or poisonous latex, or (ii) enhance the species' ability to withstand harvesting, for instance by coppicing. As expected, thorny or latex-bearing plants as well as plants able to be coppiced (Table 4) were significantly less frequent amongst species restricted to low disturbance sites (χ^2 test, $P < 0.05$).

Table 4. Number of species with various attributes occurring in low disturbance (L) and high disturbance (H) sites

	Sites					
Attribute	All	L	H	Only L	Only H	L and H
Climax	48	48	0	48	0	0
Deciduous	33	23	31	2	10	21
Evergreen	121	107	65	56	14	51
Coppicing possible	136	110	95	41	26	69
Human demand	54	44	35	19	10	25
Heliophilic	23	16	17	6	7	10
Pioneer	29	22	28	1	7	21
Relict	48	43	48	0	5	43
Thorny	16	11	13	3	5	8
Used for plywood	36	30	23	13	6	17
Used for plywood and possibly coppicing	27	21	21	6	6	15
Used for plywood but not coppicing	9	9	2	7	0	2
Coppicing possible, but no plywood use	109	89	74	35	20	54
Total	165	138	105	60	27	78

Finally, plant species differed greatly in the variety of uses to which they were put. These included local subsistence uses such as fuel, small timber or leaf manure, and commercial uses as in the matchwood and plywood industries. The forests of Uttara Kannada have been under the pressure of subsistence use for centuries; in the last 50 years they have come under the pressure of considerable commercial use as well. We therefore scored the species in terms of subsistence use and use in the matchwood and plywood industry. Low and high disturbance sites did not differ significantly in terms of the fraction of species of subsistence or commercial use. However, there was a significant trend when use in the matchwood/plywood industry and coppicing potential were considered in conjuction. Low disturbance sites supported a significantly larger fraction of species (χ^2 test, $P < 0.05$) demanded by the plywood industry but incapable of being coppiced (Table 4). In other words such species were particularly liable to disappear under high levels of disturbance.

BIOMASS DEPLETION

By definition, sites with high levels of disturbance had lower plant densities. But it is of interest to provide a quantitative assessment of the extent of the lowering of biomass levels. The data to hand are restricted to the number of plants of different taxa in each of the seven height classes. This is inadequate for an estimation of absolute levels of biomass, but could be used for an estimation of relative change. Table 5 provides an estimate of the number of plants per 2400 m^2 in each of the seven height classes. While the two sets of sites bore significantly different total numbers of individual plants, there was no significant

Table 5. Number of individuals in each of the seven height classes in transects of 2400 m^2. The numbers are means of 20 transects for the low and of 10 transects for the high disturbance sites

Height class (m)	Disturbance Low	High	*t*-test	*U*-test
0–1	149	129	*	NS
1–2	138	70	NS	*
2–4	168	59	**	NS
4–8	93	45	NS	NS
8–16	103	61	NS	**
16–32	41	21	NS	NS
Above 32	2	0·2	NS	NS

* Significant at 5%.
** Significant at 1%.
NS, not significant ($P > 0{\cdot}05$).

change in the fraction of plants in the various size classes. This reflects the fact that there have been manifold demands on these forests: while industry requires the larger trees, farmers take out the small trees for fencing poles. If all the plants are taken into account, the density is reduced from 2893 per hectare in sites of low to 1579 in sites of high disturbance, a decline of 45%. The decline is more marked in the height categories of 2–4 m, favoured as poles by villagers, and over 8 m, favoured as timber by commercial interests.

BIODIVERSITY LOSSES

There have been a few estimates of biodiversity losses on the Western Ghats (Nair & Daniel 1986). Specifically for Uttara Kannada, five bird species characteristic of forest tracts, namely, *Zoothera dauma*, *Psittacula eupatoria*, *Picus myrmecophonens*, *Treron bicincta* and *Aethopyga siparaja* have apparently disappeared over the last century (Daniels, Joshi & Gadgil 1990). There is also evidence of one plant species having similarly disappeared from this region: a grass *Hubbardia heptaneuron* Bor, recorded only from the spray zone of the Sharavathy river's Jog falls just across the border of Uttara Kannada, has apparently become extinct following the impoundment of the river upstream of the waterfalls. Our data further show that as many as 84 out of 172 OTUs occurring in the low disturbance transects have disappeared locally under high levels of disturbance. This suggests that a number of species characteristic of evergreen forests may be in danger of gradual elimination with increasing disturbance. Notable amongst these are 10 taxa that occurred in seven or more of the 20 low disturbance transects (see Appendix), but were absent from all 10 of the highly disturbed transects. These included two species characteristic of interior evergreen forests, namely *Syzygium gardneri* and *Myristica malabarica*. Both have been exploited by the plywood industry but not by villagers. *M.malabarica* is particularly valued for its fruit, which is collected and marketed by villagers who do not cut the tree. *Holigarna grahamii* is also exploited by the industry, but is left untouched by the local people because of its poisonous latex. Three other evergreen species characteristic of low disturbance transects but absent from highly disturbed ones have been used both by industry and by the villagers as small timber. These are *Calophyllum polyanthum*, *Dysoxylon malabaricum* and *Polyalthia fragrans*. The woody gymnospermous climber *Gnetum ula* and many species of the angiospermous vine genus *Piper* similarly characterized low-disturbance tracts, but have disappeared from all highly disturbed transects. These climbers have been subject to regular 'climber-cutting' as part of silvicultural practices prescribed by the Forest Department. Three other widespread evergreen species that disappear under disturbance, *Dichapetalum gelanioides*, *Elaeocarpus* sp. and *Neolitsea zeylanica* have not been in industrial demand and seem to have been affected primarily by village-level utilization and changes in the microclimate that accompanies opening of the canopy.

A much smaller number of species absent from low-disturbance sites, namely 28, colonized highly disturbed tracts. Notable amongst these were seven species that were common under high levels of disturbance, occurring in four out of 10 transects. These included *Albizia odoratissima, Cassia fistula, Dalbergia latifolia* (rosewood), *Lannea coromandelica, Schleichera oleosa, Tectona grandis* (teak) and *Xeromphis uliginosa*. Two of these, rosewood and teak, have been highly valued as timber species. All these seven species have a widespread distribution over the Indian subcontinent and in south-east Asia, and are thus of much lower conservation value compared with the evergreen species with more restricted geographical ranges. It would therefore appear that the high levels of disturbance which are now endemic over much of the Western Ghats may be responsible for considerable levels of biomass loss, as well as for local extinctions of several evergreen tree species of high conservation value.

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References

Champion, H.G. & Seth, S.K. (1968) *A Revised Survey of Forest Types of India*. Manager of Publications, New Delhi.
Connell, J.H. (1978) Diversity in tropical rain forests and coral reefs. *Science*, **199**, 1302–1310.
Daniels, R.J.R. (1989) *A conservation strategy for the birds of the Uttara Kannada district*. PhD dissertation, Indian Institute of Science, Bangalore, India.
Daniels, R.J.R., Joshi, N.V. & Gadgil, M. (1990) Changes in the bird

fauna of Uttara Kannada, India, in relation to changes in landuse over the past century. *Biological Conservation*, **52**, 37–48.
Daniels, R.J.R., Joshi, N.V. & Gadgil, M. (1992) On the relationship between bird and woody plant species diversity in the Uttara Kannada district of south India. *Proceedings of the National Academy of Sciences USA*, **89**, 5311–5315.
Fuentes, E.R. & Jaksie, F.M. (1988) The hump-backed species diversity curve: why has it not been found among land animals? *Oikos*, **53**, 139–143.
Gadgil, M. & Meher-Homji, V.M. (1986) Role of protected areas in conservation. *Conservation for Productive Agriculture* (eds V.L. Chopra & T.N. Khoshoo), pp. 143–159. Indian Council of Agricultural Research, New Delhi, India.
Gadgil, M. & Subash Chandran, M.D. (1989a) *Environmental Impact of Forest Based Industries on the Evergreen Forests of Uttara Kannada District; a Case Study.* Department of Ecology and Environment, Government of Karnataka, Bangalore.
Gadgil, M. & Subash Chandran, M.D. (1989b) On the history of Uttara Kannada forests. *Changing Tropical Forests* (eds J. Dargavel, K. Dixon & N. Sempel), pp. 47–58. Australian National University, Canberra.
Ministry of Environment and Forests (1989) *The State of Forest Report–1989*. Forest Survey of India, Government of India, Dehra Dun.
Ministry of Environment and Forests (1992) *The State of Forest Report–1992*. Forest Survey of India, Government of India, Dehra Dun.
Ministry of Environment and Forests (1993) *The State of Forest Report–1993*. Forest Survey of India, Government of India, Dehra Dun.
Myers, N. (1988) Threatened biotas: 'hot spots' in tropical forests. *The Environmentalist*, **8**, 187–208.
Myers, N. (1990) The biodiversity challenge: expanded hot spots analysis. *The Environmentalist*, **10**, 243–256.
Nair, N.C. & Daniel, P. (1986) The floristic diversity of the Western Ghats and its conservation: a review. *Proceedings of the Indian Academy of Sciences (Animal Sciences/Plant Sciences)*, November, **95**, 127–163.
Nadkarni, M.V., Pasha, S.A. & Prabhakar, L.S. (1989) *The Political Economy of Forest Use and Management*. Sage Publications, New Delhi.
Pascal, J.P. (1982) *Vegetation Maps of South India.* Karnataka Forest Department and French Institute, Pondicherry.
Pascal, J.P. (1984) *Vegetation Maps of South India.* Karnataka Forest Department and French Institute, Pondicherry.
Pascal, J.P. (1988) *Wet Evergreen Forests of the Western Ghats of India: Ecology, Structure, Floristic Composition and Succession.* Institut Francais de Pondichery, Pondicherry.
Pickett, S.T.A. & White, P.S. (eds) (1985) *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, New York.
Puri, G.S., Meher-Homji, V.M., Gupta, R.K. & Puri, S. (1983) *Forest Ecology Vol. I Phytogeography and Forest Conservation.* Oxford IBH, New Delhi.
Saldanha, C.J. (1983) *Flora of Karnataka, India. Magnoliaceae to Fabaceae.* Oxford IBH, New Delhi.
Saldanha, C.J. & Nicholson, D.H. (1978) *Flora of Hassan District, Karnataka, India.* Amerind Publishing Co., New Delhi.

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Appendix

A list of species found in at least four of the transects is shown below together with their attributes*. The columns headed L and H indicate the number of transects in the localities with low and high levels of disturbance where the species was present; IL and IH denote the total number of individuals of the species recorded in low- and high-disturbance localities.

Species name	Attributes*	L	H	IL	IH
Exclusive to low disturbance sites					
1 *Arenga wightii* Griff.	C . E	6	0	239	0
2 *Calophyllum polyanthum* Wall ex Choisey	C . E . G . . . . . . W	12	0	142	0
3 *Carallia brachiata* (Lour.)	. . EF . H . . . . . W	5	0	8	0
4 *Dichapetalum gelanioides* (Roxb.) Engl.	C . EF	13	0	743	0
5 *Dysoxylon malabaricum* Bedd.	C . EFG . . . . . . W	13	0	342	0
6 *Dracaena terniflora* Roxb.	C . EF	5	0	23	0
7 *Elaeocarpus* sp.	C . EF . . . . W	13	0	264	0
8 *Ficus nervosa* Heyne ex Roth	C . EFG . . . . . . W	6	0	7	0
9 *Gnetum ula* Brong.	. . EF . . . L	9	0	42	0
10 *Holigarna grahamii* (Wight) Kurz	C . EFG . . . . . . W	12	0	169	0
11 *Litsea* sp.	C . EF	4	0	16	0
12 *Mammea suriga* (Buch. Ham ex Roxb.) Kost	C . EF	4	0	7	0
13 *Murraya paniculata* (L.) Jack.	C . EF	4	0	12	0
14 *Myristica dactyloides* Gaertn.	C . E . . . . W	5	0	21	0
15 *Myristica malabarica* Lam.	C . E . . . . W	15	0	278	0
16 *Neolitsea zeylanica* (Nees) Merr.	C . EF	8	0	84	0
17 *Ochlandra* sp.	C . EFG	4	0	155	0
18 *Piper* spp.	C . EF	13	0	559	0
19 *Polyalthia fragrans* (Dalz.) Bedd.	C . EFG . . . . . . W	7	0	128	0

* The attribute codes are: C, climax; E, evergreen; G, human demand (non-plywood); I, introduced (plantations, etc.); P, pioneer; T, thorny/toxic; D, deciduous; F, able to be coppiced; H, heliophilic; L, liana; R, relict; W, used by the plywood industry.

Appendix *Continued*

Species name	Attributes*	L	H	IL	IH
20 *Reinwardtiodendron anaimalaiense* (Bedd.) Mabb.	C . E	4	0	96	0
21 *Strombosia ceylanica* Gardn.	C . EFG	8	0	159	0
22 *Symplocos racemosa* Roxb.	C . E	4	0	44	0
23 *Syzigium gardneri* Thwaites	C . E . G . . . . . . W	12	0	298	0
Common to both high- and low-disturbance sites					
1 *Actinodaphne malabarica* Balakr.	. . EF . . . . . R . .	15	3	69	8
2 *Alstonia scholaris* (L.) R.Br.	. . EFG . . . . R . W	1	5	1	6
3 *Alseodaphne semecarpifolia* Nees	. . EFG . . . . R . W	1	5	6	19
4 *Ancistrocladus heyneanus* Wall ex Grab.	. . . F . . . L . R . .	10	1	130	1
5 Annonaceae -I	. . E . . . . . . R . .	5	3	8	12
6 *Aporosa lindleyana* Blume.	. . EFGH	11	5	139	258
7 *Artocarpus hirsutus* Lam.	. . EFG . . . . R . W	5	1	7	1
8 *Bauhinia racemosa* Lam.	. D . F . . . . P . . W	1	3	1	4
9 *Buchanania lanzen* Sprengel	. D . FG . . . P . . .	1	3	1	5
10 *Calycopteris floribunda* Lam.	. . . F . . . L . R . .	6	10	13	160
11 *Callicarpa tomentosa* (L.) Murr.	. . EF . H	10	6	38	12
12 *Calamus* sp.	. . . F . . . . . RT .	15	1	1013	1
13 *Careya arborea* Roxb.	. D . F . . . . P . . .	7	9	17	78
14 *Caryota urens* L.	. . E . . . . . . R . .	9	2	21	2
15 *Cinnamomum* sp.	. . EFG . . . . R . W	19	3	289	5
16 *Dillenia pentagyna* Roxb.	. D . F . . . . P . . W	5	8	8	36
17 *Dimocarpus longan* Lour.	. . EF . . . . . R . .	12	1	186	7
18 *Diospyros buxifolia* (Blume) Hiern	. . EFG . . . . R . W	3	1	92	18
19 *Diospyros* sp.	. . EF . . . . . R . .	20	3	546	13
20 *Emblica officinalis* Gaertn.	. D . F . . . . P . . .	2	6	2	54
21 *Ervatamia heyneana* (Wall) Cooke	. D . F . . . . P . . .	9	8	31	138
22 *Syzigium* sp.	. . E . G . . . . R . W	18	1	169	1
23 *Syzigium cumini* (L.) Skeels	. . EF . . . . . R . W	2	3	5	11
24 Euphorbiaceae-I	. . E . . . . . . R . .	5	1	36	3
25 *Ficus* sp.-I	. . EF . . . . . R . .	2	2	9	2
26 *Ficus* sp.-II	. . EF . . . . . R . .	5	4	7	5
27 *Flacourtia montana* Grah.	. . . F . . . . . RT .	8	2	50	46
28 *Garcinia indica* (Dup.-Thou) Choisy	. . E . G . . . . R . .	4	1	5	2
29 *Garcinia* sp.	. . EFG . . . . R . .	13	2	159	3
30 *Gmelina arborea* Roxb.	. D . FG . . . P . . W	2	4	12	14
31 *Grewia tiliifolia* Vahl.	. D . FG . . . P . . .	6	5	9	56
32 *Holigarna arnottiana* Hook.f.	. . EF . . . . . R . W	8	2	36	2
33 *Hopea ponga* (Dennst.) Mabb.	. . EFG . . . . R . .	12	4	658	39
34 *Hydnocarpus pentandra* (Buch-Ham.) Oken	. . EF . . . . . R . .	4	2	8	4
35 *Ixora brachiata* Roxb.	. . EFG . . . . R . .	12	4	147	69
36 *Ixora* sp.	. . EF . . . . . R . .	3	2	51	23
37 *Knema attenuata* (Hook.f. & Thomson) Warb	. . EF . . . . . R . W	16	1	670	19
38 *Lagerstroemia microcarpa* Wight	. D . FG . . . P . . W	8	8	35	77
39 *Leea indica* (Burm.f) Merr.	. . EF . . . . . R . .	20	6	473	118
40 *Macaranga peltata* (Roxb.) Muell. Arg.	. . EF . H	13	9	134	53
41 *Mallotus philippensis* (Lam.) Muell. Arg.	. . EF . H	7	4	36	17
42 *Mangifera indica* L.	. . EFG . . . . R . W	13	2	27	2
43 *Maytenus rothiana* (Walp.) Raman	. . EF . . . . . R . .	10	3	97	9
44 *Melia dubia* Cav.	. . EFGH	3	1	3	1
45 *Memecylon* sp.	. . EFG . . . . R . .	10	2	1339	21
46 *Mimusops elengi* L.	. . EF . . . . . R . W	3	1	3	2
47 *Moullava spicata* (Dalz.) Nicols	. . EF . . . . . . T .	4	4	14	12
48 *Murraya koenigi* (L.) Sprengel	. . E . . H	2	3	28	146
49 *Nothopodytes nimmoniona* (Grah.) Mabb.	. . EF . . . . . R . .	15	3	108	9
50 *Nothopegia* sp.	. . EF . . . . . R . .	14	1	163	4

* The attribute codes are: C, climax; E, evergreen; G, human demand (non-plywood); I, introduced (plantations, etc.); P, pioneer; T, thorny/toxic; D, deciduous; F, able to be coppiced; H, heliophilic; L, liana; R, relict; W, used by the plywood industry.

Appendix *Continued*

Species name	Attributes*	L	H	IL	IH
51 *Olea dioica* Roxb.	. . EFGH	19	3	369	32
52 *Oxytenanthera* sp.	. . EFGH	2	6	14	693
53 *Persea macrantha* (Nees) Kosterm.	. . EFG . . . . R . W	10	1	78	7
54 *Psychotria dalzelli* Hook.f.	. . EF . . . . . R . .	15	4	321	8
55 *Pterospermum* sp.	. D . F . . . . P . . .	11	3	133	25
56 *Xeromphis spinosa* (Thunb). Keay	. . EF . . . . . . T .	9	6	46	41
57 Rutaceae -I	. . EF . . . . . R . .	10	4	119	143
58 Sapindaceae -I	. . EF . . . . . R . .	2	3	110	15
59 *Sterculia guttata* Roxb. ex DC.	. D . F . . . . P . . .	3	2	9	8
60 *Stereospermum personatum* (Hask.) Chatt.	. D . F . . . . P . . W	3	5	3	13
61 *Strychnos nux-vomica* L.	. . EF . . . . . . TW	1	5	1	19
62 *Terminalia bellarica* (Gaertn.) Roxb.	. D . FG . . . P . . W	6	4	12	5
63 *Terminalia paniculata* (Roxb.) Rath	. D . FG . . . P . . W	13	10	72	262
64 *Terminalia alata* Heyne ex Roth.	. D . FG . . . P . . W	4	4	22	31
65 *Vitex altisima* L.f.	. D . F . . . . P . . .	6	3	17	4
66 *Xantolis tomentosa* (Roxb.) Raf.	. . EF . . . . . . T .	1	3	2	5
67 *Xylia xylocarpa* (Roxb.) Taub.	. D . F . . . . P . . .	1	9	29	210
68 *Zyziphus* sp.	. . . F . H . . . . T .	2	8	2	28
Exclusive to highly disturbed sites					
1 *Albizia odoratissima* (L.f.) Benth.	. D . F . . . . P . . .	0	4	0	6
2 *Cassia fistula* L.	. D . FG . . . P . . .	0	5	0	8
3 *Dalbergia latifolia* Roxb.	. D . FG . . . P . . W	0	5	0	7
4 *Lannea coromandelica* (Houtt.) Merr.	. D . FG . . . . . . W	0	5	0	9
5 *Schleichera oleosa* (Lour.) Oken	. D . FG . . . P . . .	0	6	0	64
6 *Tectona grandis* L.f.	. . . F . . I . . . . W	0	5	0	69
7 *Xeromphis uliginosa* (Retz.) Maheshwary, J.	. . EF . . . . . . T .	0	4	0	20

* The attribute codes are: C, climax; E, evergreen; G, human demand (non-plywood); I, introduced (plantations, etc.); P, pioneer; T, thorny/toxic; D, deciduous; F, able to be coppiced; H, heliophilic; L, liana; R, relict; W, used by the plywood industry.