# Changes in Four Rainforest Plots of the Western Ghats, India, 1939–93

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*A major question of concern to forest ecologists in India is how well the forests have withstood the impact of human activities, and if they will be able to recover their stand characteristics, including number and size of trees, biomass and species composition, once they are protected from further disturbance. To examine the process of forest disturbance and possible recovery, four research plots in the evergreen forests of the Western Ghats of Karnataka State were analysed for stand characteristics and species composition starting in 1939 when they were remote and had minimal human impact. In these plots, all trees were identified and measured for diameter at breast height. The original trees continued to be censused at approximately five-year intervals. New recruits were first censused in 1984, and their size in the past was estimated from average growth rates. The plots were not treated differently from the surrounding forest, so they serve as a sample of the status of the surrounding forest. These forests then experienced increasing levels of human activity in the form of clearing for roads and power lines, fires, grazing by cattle, collection of forest products and low-level selective logging in the 1970s and 1980s, during which time forest censuses continued. At all four forests, there was a steady decline over time in the number of trees, with sharper declines associated with periods of logging and clearing. At the point of greatest decline following logging, only about 70 per cent of the original numbers of trees were present; however, the number of new trees increased after logging stopped in 1988, compensating to some degree for the loss of the original trees. Above-ground biomass also declined over time, with only about 70 per cent of the original*

**Acknowledgements:** We thank the Karnataka Forest Department for permission to use the historical data and for assistance with the field work. S.S. Rané provided valuable help in the field. Boston University provided facilities for the analysis and writing. Funding was provided by the US Man and the Biosphere Program. Useful comments on the manuscript were provided by Kamaljit Bawa, Cam Webb, and Nick Brokaw.

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***Conservation and Society*, 1, 1 (2003)**
SAGE Publications New Delhi/Thousand Oaks/London

*biomass present after selective logging and other disturbances, but recovering to 73 per cent to 85 per cent by 1993. Mortality and estimated recruitment rates in these forests was low prior to 1970, but then increased as the pace of human activity increased. Species composition has remained relatively stable over the census period, with most of the original species still present. Additional species became established on the plots, many of which were common pioneer species, resulting in an overall increase in the total number of species at each plot. There have been substantial effects of human activity on these forests, with the intensity of this impact increasing in the 1970s and 1980s. With the cessation of logging, these forests are beginning the process of succession to their original stand characteristics. However, the presence of roads, power lines and substantial nearby human populations will probably prevent a full recovery.*

## Introduction

In recent decades rain forests worldwide have been affected by human activity on an unprecedented scale. The tropical evergreen forests extending along the crest of the Western Ghats, an extensive mountain range that skirts India's south-western coast, are no exception (Aldhous 1993; Pascal 1988). Human activities in rainforests have important local and regional implications, both long and short term. The forests of the Western Ghats, for example, are rich in wildlife and endemic species (Gadgil and Guha 1992) and contain wild ancestors of important crop plants such as black pepper (*Piper nigra*), mango (*Mangifera indica*) and jackfruit (*Artocarpus heterophylla*). Such species may play a significant part in the daily livelihoods of local people, but the species are threatened by activities such as encroaching agriculture, cattle grazing, hydroelectric projects, roads and other development activities that fragment the forest (Gadgil 1989). There is continuing pressure to use the land and there is ongoing loss of forest area (Jha et al. 2000). Many areas, though still forested, have also been affected by selective logging (Karnataka Forest Department 1993). On a regional level, deforestation in India has led to shortages of natural resources, disruption of watersheds, including erosion, flooding, and water shortages, and a decline in wildlife (Gadgil and Guha 1992; Subhash 1987). Such losses have profound effects on the people of India, either directly by limiting the availability of forest resources used in their daily lives, or indirectly by increasing levels of pollution, disease, siltation of waterways and other side effects of ecological damage. Moreover, there are global impacts to be considered as well, a valid consideration because the damage and degradation described above are common to rainforests worldwide. The Western Ghats rainforests, like other rainforests, have a historical role as part of a large carbon sink that reduces the effects of global atmospheric carbon dioxide elevation (Brown et al. 1996; Ravindranath and Sukumar 1996; Richards and Flint 1994). Thus, these forests are significant locally, regionally and globally.



Most of India's forests have been affected by human activity at some time in the past, but overall forest disturbance increased in both area and intensity in the nineteenth century and early twentieth century under British rule (Gadgil and Guha 1992), accelerating after World War II as human populations, economic development and road construction expanded. Construction of hydroelectric projects in the Ghats (to take advantage of the high rainfall and steep terrain) began in the 1950s, and other infrastructure improvements, such as clearing for power transmission lines, have had significant effects. As the human population in the area has grown, collection of firewood, poles (used mainly for small-scale construction and farm work), timber and non-timber products, such as bamboo canes, wild pepper, fruit, medicinal plants and leaves, has steadily increased.

Despite the importance of the forests of the Western Ghats, information on their original condition is mostly descriptive rather than quantitative (Champion and Seth 1968; Chandrashekara and Ramakrishnan 1994; Pascal and Pelissier 1996; Pascal et al. 1998; Sukumar et al. 1998). The original stand structure of forests in the Western Ghats is poorly known, and the effects of human activities, including logging and fragmentation, have not been adequately quantified. This lack of quantitative information makes it difficult to accurately gauge the damage done by selective logging and fragmentation; such long-term data would provide the best basis for understanding what constitutes recovery from disturbance. Such efforts could also inform recent programmes to open forests to the removal of dead trees, by estimating the potential for wood production and wood damage. In rainforests elsewhere, selectively logged rainforests have shown the potential to retain the full diversity of tree species, and thus the potential for recovery even though the relative importance of individual species may change (Cannon et al. 1998; Verssimo et al. 1995). If this proves to be a general case, then selectively logged forests could represent an important reservoir of species diversity.

Tropical forest research plots with decades-long histories are rare. Often stand structure by itself has been used to infer stand dynamics. Much of our knowledge of the stand dynamics of tropical forests comes from the few plots where enumerations were done at intervals of one or more years (Burslem et al 1998; Crow 1980; Sheil 1998; also see Dallmeier and Comiskey 1998). Most such plots have been followed for only one or two decades, making it difficult to examine the process of disturbance and recovery. Only a long-term study with regular enumerations, such as the plots used for our research, can provide an actual record of stand dynamics, and the extent to which forests are responding to and recovering from disturbances of all scales. These disturbances include rare, large-scale natural events such as hurricanes and fires, significant human-caused disturbances such as episodes of logging, and less obvious, recurrent sources of small-scale disturbance, both natural and man-made. The study reported here is an example of such a long-term monitoring effort. The problem with many such studies, including our own, is that the plot sizes are often small, the measurements are irregular and new recruits are often not censused in a consistent manner.

Our study of stand dynamics in Karnataka State in the Western Ghats at about 14 degrees North Latitude had five objectives: (*i*) to describe the original condition of the rainforests with respect to stand structure, biomass and rates of growth, mortality and recruitment; (*ii*) to determine the effects of documented disturbances of various types and durations on these parameters; (*iii*) to document the recovery of these forests (including stand structure and regeneration) after a period of selective logging; (*iv*) to examine the effects of disturbance on species composition; and (*v*) to use the above information to examine the potential of forests of the Western Ghats to return to their original condition.

## THE RESEARCH PLOTS

The four research plots in this study, all named for the particular mountain or place where they are located (Devimane, Katlekan, Kodkani, Malemane), were first established in 1939 in remote primary evergreen rainforest areas with low human populations (see Figure 1). Katlekan forest may have been protected in the past as a sacred forest, prior to coming under Forest Department control (Chandran 1996). The study plots are part of a series of research plots created by the Forest Department of what is now the state of Karnataka, India. The plots used in this study were chosen for long-term analysis because more complete records of these four were available than for any of the other plots that still exist (Rai and Proctor 1986). Information on the history of the plots comes from the site descriptions made in 1939, and reports contained in field books. Additional information came from interviews conducted in 1984 and 1993 with former Range Forest Officer, S.S. Rané. Rané worked in the area of the plots for 40 years until his retirement in 1989, and is very familiar with these research plots, having conducted some of the enumerations. The interviews, combined with the Forest Department field books, provided detailed information on the disturbance history of the plots.

The original purpose of the plots was to help teach research methods and to determine the growth rates of trees. When the plots were established there was no record of logging in these areas, and large animals were known from the area. Following establishment, the research plots were not protected from the disturbances affecting the surrounding forests. As a result, they no longer accurately reflect primary forest conditions; rather these plots represent typical forest conditions in the present-day Western Ghats. Parts of three of the plots (Devimane, Katlekan, Malemane) were logged in the mid to late 1970s and early 1980s. Logging was selective, meaning a maximum of ten trees greater than 2 m girth, or 63.6 cm diameter at breast height (dbh; bh = 1.37m) per ha were removed for timber. Trees harvested were mainly species in the genera *Elaeocarpus, Dipterocarpus, Holigarna, Myristica, Nothopegia, Hopea* and *Calophyllum*. Logging was not mechanised, but was done using hand labour and draft animals, resulting in less damage than the mechanised logging done elsewhere in the world. Logging in the evergreen forests of India was banned in 1986 (Gadgil and Guha 1992),



**Figure 1**
***Map of Karnataka Showing the Field Sites***

**Note:** The location of Karnataka on the Indian subcontinent is shown in the inset. On the main section of the map, the Western Ghats are shown as well as the location of the research plots, indicated by a box, an arrow and a double asterisk. The locations of the research plots relative to each other and their distances from each other are shown in the inset marked with a double asterisk.

and there have been massive reforestation projects in many types of forests, though not in the immediate area of the plots (Karnataka Forest Department 1993). Nevertheless, the study plots are still crossed by abandoned logging roads, and local roads that were cart tracks in 1939 are now paved roads carrying trucks and cars. Thus, any recovery observed in these plots should also be representative of a general trend in the area (Chaturvedi 1994; Forest Survey of India 1993). The forests will probably never return to their original conditions due to the continuing presence of roads, power lines, cattle and an increasing human population. People still enter the forests to collect fallen limbs as firewood and medicinal plants under the supervision of the Forest Department, and this too has an impact on the forest.

## Methods

### *Site Description*

This study includes a total area of 9.12 ha divided among the four plots, all in primary southern tropical wet evergreen forest (Champion and Seth 1968; Pascal 1988). The four plots are all within 28 km. of each other, and three are within 12 km. As such they could be considered as 4 plots within one large forest type. A detailed description of each plot and the disturbances that have affected them are contained in Table 1. This area experiences monsoon rains from May to October.

**Table 1**
***Descriptions of the Four Research Plots***

| | *Katlekan* | *Malemane* | *Devimane* | *Kodkani* |
|---|---|---|---|---|
| Latitude | 14° 16' N | 14° 17' N | 14° 17' N | 14° 15' N |
| Longitude | 74° 42' E | 74° 44' E | 74° 42' E | 74° 50' E |
| Elevation (m) | 579 | 143 | 274 | 610 |
| Area (ha) | 1.09 | 2.7 | 2.7 | 2.6 |
| Number of trees in 1939 | 362 | 1,149 | 1,312 | 1,052 |
| Trees per ha | 332 | 426 | 486 | 405 |
| Number of species | 89 | 111 | 92 | 114 |
| Annual Rainfall (mm) | 5,000 | 5,000 | 3,800 | 3,810 |
| Terrain | Gradual | Sloped | Steep | Very steep |
| Logging | 1974–75 | 1979 | 1982–84 | No |
| Roads | Paved 1956 | Paved 1974 | Paved 1956 | Paved 1956 |
| Powerlines | No | No | Clearing 1970–75 | Clearing 1954 and 1970 |
| Fires | No | Occasional after 1954 | 1970–73 | Frequent after 1974 |

Two of the plots, Katlekan and Malemane, are on gradual slopes with heavy rainfall (5,000 mm per year). Road construction occurred on both plots followed by selective logging, though Katlekan was exposed to these activities earlier than Malemane. Devimane and Kodkani are on much steeper slopes (with Kodkani



having slopes of up to 55 to 65 degrees over certain sections of the plot) and both have somewhat less rainfall (3,800 mm per year) than the other plots; both these sites were affected by both roads and power line construction which removed approximately 20 per cent of the original forest cover. Areas cleared for power lines eventually came back with tree cover. Devimane was also affected by selective logging. Kodkani, though not logged, was heavily impacted by power lines, which also removed about 20 per cent of the forest cover; this site repeatedly experienced ground fires from the late 1950s to the present. Of all the plots, Katlekan is the least disturbed, and Kodkani the most heavily disturbed. Information on plot history is not quantitative and is sketchy as few contemporaneous records were kept, with disturbance often inferred from current observations of the plots and interviews with Forest Department officials.

### *Field Methods*

The plots were originally laid out in 1939 by establishing a central survey line and measuring 10.05 m to each side of the line. Thus, the plots are 20.1 m wide (1 chain) and vary from 623 to 1,347 m in length. Posts were set every 20.1 m (1 chain) and undergrowth was cleared for about 0.5 m on each side of the central line. At the time of the original survey, all trees within the boundaries of the plots that were over 10 cm dbh were recorded. Locations of trees were recorded as distance along the central line and offset to the left or right of the line in 20.32 cm units (8 inch links). Trees were identified to species in order to find the mean growth rates of different species. Stamped number plates were nailed to each tree 15 cm above the point of measurement, generally around 1.37 m dbh, which was marked with a painted plus (+) symbol. When necessary, paint marks were placed above tree buttresses.

On each tree, a pair of diameters (taken in inches with calipers) was taken at right angles to each other; for very large trees with diameters too great for the calipers to measure, girths were taken. Diameter measurements were repeated by the Forest Department on the original resident trees approximately every five years until 1975. Censuses at Katlekan, Kodkani and Malemane were repeated in 1977.

In 1984, recruit trees that had reached 10 cm dbh were recorded, mapped and measured for the first time on all four plots. In 1993, a complete enumeration was performed for all trees > 10 cm dbh, including the original resident trees marked in 1939, the recruits first censused in 1984, and recruits that had reached 10 cm dbh between 1984 and 1993.

### *Data Analysis*

Trees were assigned to 10 cm dbh classes for analyses. The relatively few trees over 60 cm dbh were combined into one class of large trees. Conveniently, 2 m girth was the minimum size for a tree to be logged, so most of the trees cut during logging were in the largest dbh class. Tree diameters were used to calculate above-ground biomass using a relationship developed by Rai and Proctor (1986) for these forests, based on harvested trees.

Annual growth rate was calculated for each census period in which a tree was present and for the recorded lifetime of each tree. Growth rates of recruits from 1984 to 1993 were used to backdate the recruits and estimate both the year in which they first reached 10 cm dbh and their probable size at each enumeration from then until 1984. We recognise that growth rates are highly variable among individuals and that stand-level growth rates can change over time; however, this method gives an insight into how the forest might have looked over time, even though it may be only an approximation. For recruits first recorded in 1993, and those recorded in 1984 that had died by 1993, mean growth rates of recruits of the same species on the same plot were used to estimate the past year in which they had reached 10 cm dbh. Where no other individuals of the same species were present, recruits of the same genus were used to estimate mean growth rate; where that was impossible, mean growth rate for all recruits on that plot was used (see Pomeroy 1996 for further details).

Mortality of individuals on each plot was calculated for each diameter class and for entire plots at each time interval using the methods of Hall (1991) and Pomeroy (1996). Mortality rates include trees that were cut during logging and clearing operations because, although notes were kept of which areas were logged, there are no records of exactly which trees were cut in a given area and which ones died from other causes. These calculations of recruitment and mortality are certainly underestimates because new recruits were only first censused in 1984; trees could have reached 10 cm dbh during an earlier census period, but then have died prior to 1984. It is quite likely that many new trees grew up on the plots in the years following disturbances, especially logging, fire and clearing for power lines, but then died prior to the 1984 census. The reader should be aware of this limitation in our data set.

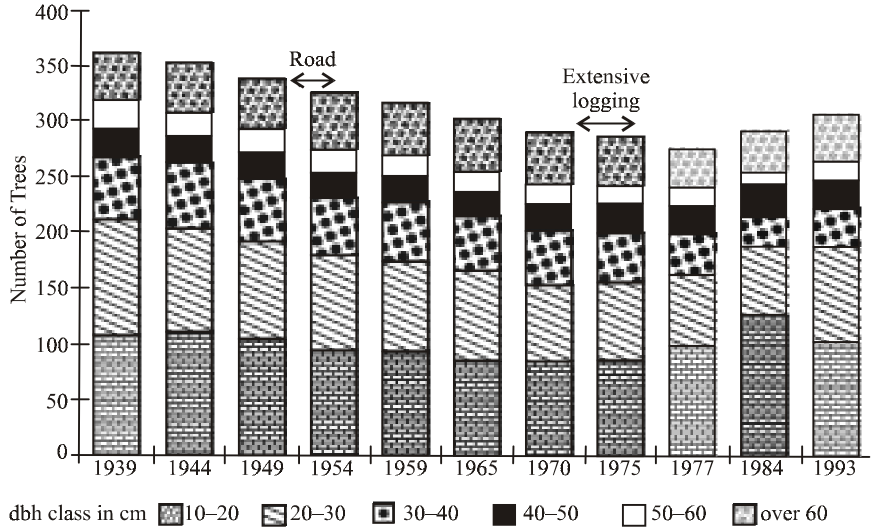
## Results

### *Density and Stand Structure*

Each forest had a distinctive initial density and size-class distribution; the main differences are between Katlekan and the other three forests. The relatively flat forest at Katlekan has a relatively low initial density of trees, around 330 trees per ha (see Figure 2). In contrast to the other forests, Katlekan shows a higher percentage of large trees (greater than 50 cm dbh) at around 20 per cent, in contrast with Devimane (5–6 per cent), Kodkani (7–11 per cent) and Malemane (8–10 per cent). Katlekan has a lower proportion of small trees (10–30 cm dbh) of around 60 per cent, in contrast to much higher proportions at Kodkani (65–70 per cent), Malemane (70–75 per cent) and Devimane (75–80 per cent). These three forests in turn have a higher initial density of trees, in the range of 400 to 480 trees per ha.



**Figure 2**
***Katlekan: Number of Trees in Each DBH Class***



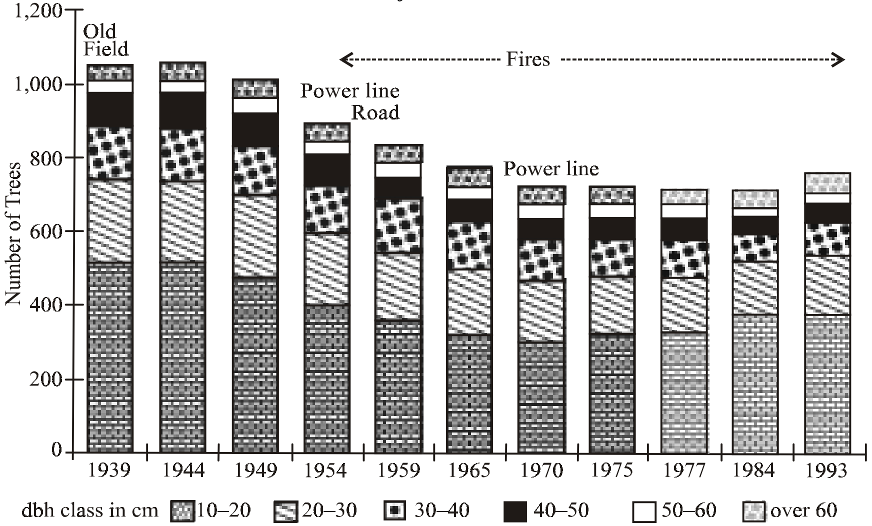

**Notes:** Katlekan—a forest with abundant rainfall on a gradual slope.
Change in the number and size distribution of trees from 1939 to 1993. Each shaded section represents a size-class of trees, with the lowest representing trees in the 10–20 cm dbh range and the highest section representing those trees greater than 60 cm. New recruits are estimated for 1944 to 1977.

At all four plots the density of trees has declined (see Figures 2, 3, 4 and 5), with sharper declines during periods associated with logging and clearing for power lines. The low point occurs in the period 1977 to 1984, when tree density is only 70 per cent of the original density. By 1993, there has been some recovery at all plots, with the recovery most pronounced at Katlekan. Even with the decline in the density of trees, the proportion of trees in each size class remained roughly the same in each forest.

### *Frequencies of Residents and Recruits*

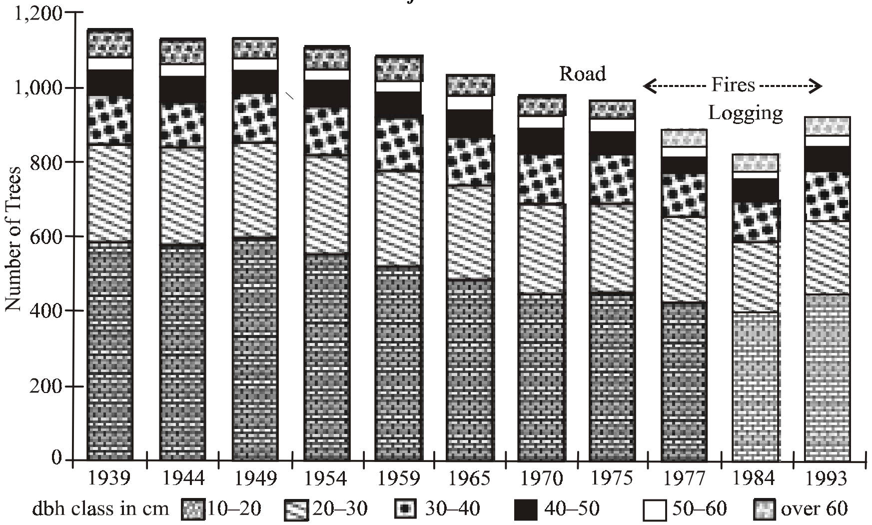
New recruits (trees not originally on the plots in 1939) are estimated to be present in all four plots starting with the second census period; Figure 6 shows original trees and new recruits from Devimane only. It must be emphasised that the estimates for new recruits are dependant on the assumptions of the analysis, in which trees have been growing at a predicted average rate in the past. The number of recruits is estimated to be 25 per cent of the number of trees present in 1977. Because the pattern is very similar in all four plots, only Devimane is shown. The steady increase in the number of new recruits at all four sites may indicate continual opportunities for recruitment, or alternatively the method of determining past size may have led to this gradual pattern of recruitment. Despite this increase in

**Figure 3**
***Kodkani: Number of Trees in Each DBH Class***




**Notes:** Kodkani—a forest on very steep slopes, affected by monsoons and considerably fragmented. Change in the number and size distribution of trees from 1939 to 1993. Each shaded section represents a size-class of trees, with the lowest representing trees in the 10–20 cm dbh range and the highest section representing those trees greater than 60 cm. New recruits are estimated for 1944 to 1977.

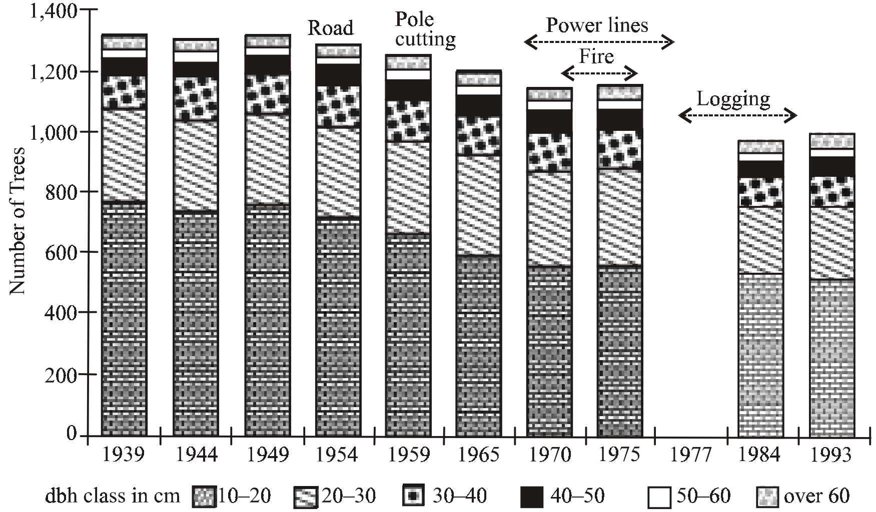
**Figure 4**
***Malemane: Number of Trees in Each DBH Class***




**Notes:** Malemane—a forest with abundant rainfall on a gradual slope.
Change in the number and size distribution of trees from 1939 to 1993. Each shaded section represents a size-class of trees, with the lowest representing trees in the 10–20 cm dbh range and the highest section representing those trees greater than 60 cm. New recruits are estimated for 1944 to 1977.

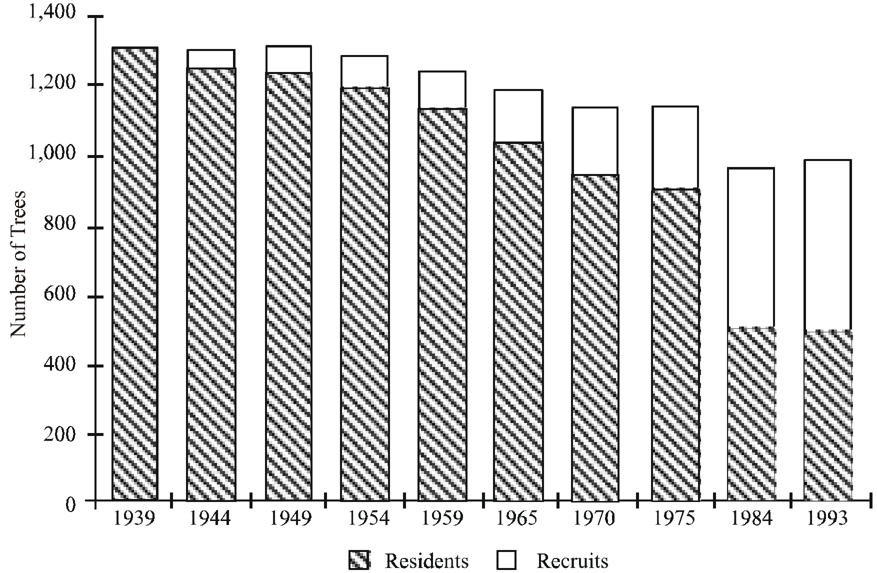


**Figure 5**
***Devimane: Number of Trees in Each DBH Class***




**Notes:** Devimane—a forest on steep slopes with nearby human population.
Change in the number and size distribution of trees from 1939 to 1993. Each shaded section represents a size-class of trees, with the lowest representing trees in the 10–20 cm dbh range and the highest section representing those trees greater than 60 cm. New recruits are estimated for 1944 to 1977.

**Figure 6**
***Devimane: Number of Residents and Recruits***




**Note:** Number of original trees (in 1939) and estimated new recruits at Devimane.

the estimated number of recruits, the total number of trees declined as the number of original resident trees dying was greater than the estimated number of new recruits growing in the plot. In 1984, when recruits are censused for the first time, at all four sites recruits account for about half of all trees, as shown in Figure 6 for Devimane. This increase in the number of recruits balances to some extent the sharp decline in the number of original resident trees between 1975 and 1984. The further increase in the number of recruits by 1993 was responsible for a slight increase in the number of trees present in these forests.

The new recruits were almost always small (less than 20 cm dbh) when they were first recorded. Even by 1993, more than 96 per cent of the recruits were still in the 10–30 cm size-class, indicating the long time period required for small trees to become large trees.

### *Above-ground Biomass and Basal Area*

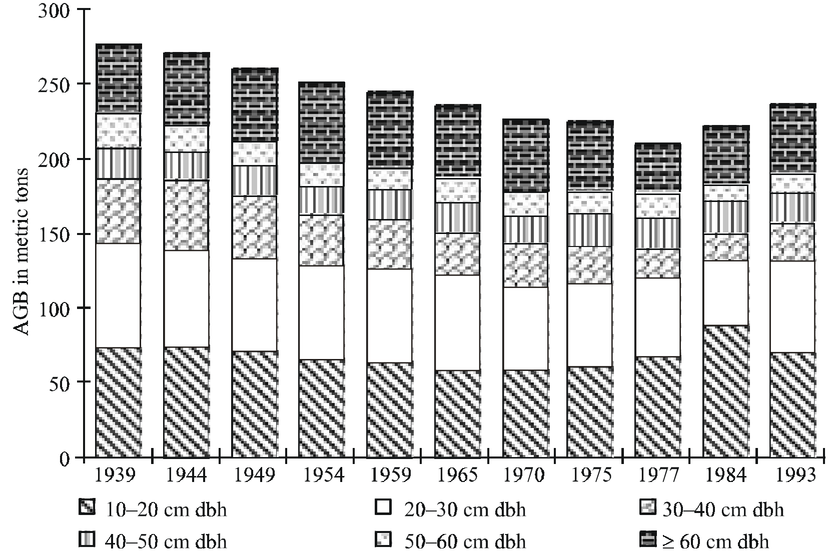
The above-ground biomass (AGB) and basal area (BA) of the forest are determined by the number and size distribution of the trees. Large trees contribute disproportionately to AGB and BA, as shown in Figures 7 and 8 for two sites. The AGB also includes the estimated contribution of new recruits. In the early censuses, these new, small recruits represent only a small percentage of total AGB. Even by 1993, the new recruits only represent 7 per cent to 15 per cent of AGB, depending on the site. At the four forests, AGB was in the range of 275 to 375 metric tons per ha, with Katlekan being the lowest and Devimane the highest. These values are paralleled by changes in BA. The AGB declined steadily from 1939 to 1970 and then dropped to around 70 per cent of the original levels due to logging during the period 1970 to 1984. The loss in AGB occurred in all size-classes. The loss was particularly sharp at Malemane following logging. At Kodkani, where there was continuous disturbance but no logging, a steady loss in AGB was evident, reaching a low point of 68 per cent of the 1939 AGB in 1984. By 1993, AGB had begun to recover at all four sites, reaching 73 to 85 per cent of original levels. The recovery was most dramatic at Katlekan with the forest recovering from 75 per cent of the original AGB in 1977 to 85 per cent AGB by 1993.

### *Mortality and Recruitment*

Each forest had distinctive patterns of mortality and recruitment reflecting the differing factors affecting each forest. At all four forests prior to 1970, mortality rates were generally greater than estimated recruitment rates (see Figures 9 and 10). Mortality rates were predominantly below 2 per cent and estimated recruitment rates were mainly lower than 1 per cent. During the 1970s and 1980s, when recruits were counted for the first time, mortality and recruitment rates began to increase dramatically. As stated earlier, mortality and recruitment rates might have been much higher in the past if there were numerous unrecorded recruits which died before the 1984 census. Mean mortality rates for all four forests rose above 4 per

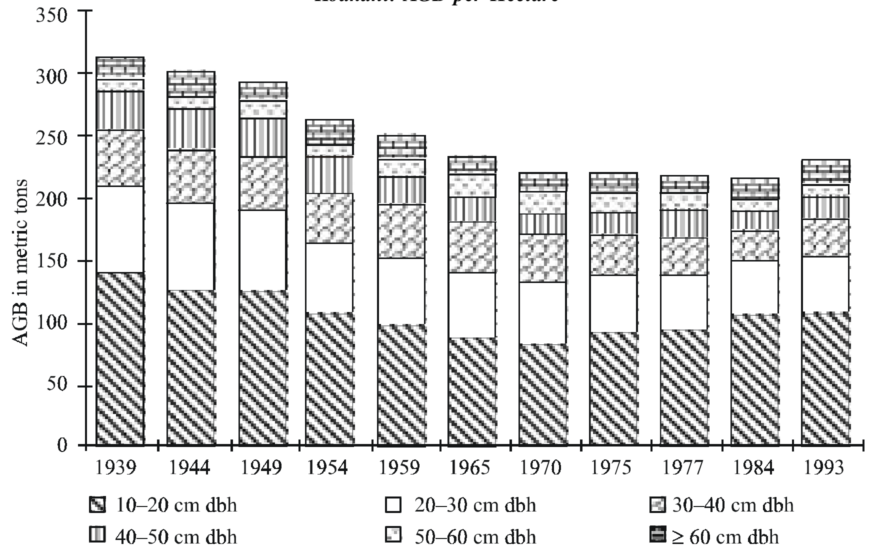


**Figure 7**
***Katlekan: AGB per Hectare***



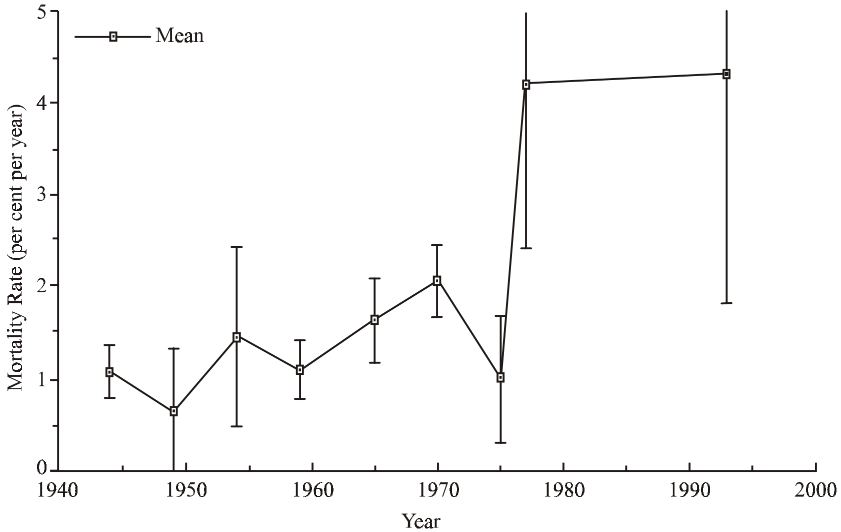

**Note:** Above-ground biomass (in metric tons) per ha for Katlekan. The contribution of each size-class to total biomass is given, with the smallest trees at the bottom of each bar and the largest tree at the top. New recruits are estimated for 1944 to 1977.

**Figure 8**
***Kodkani: AGB per Hectare***



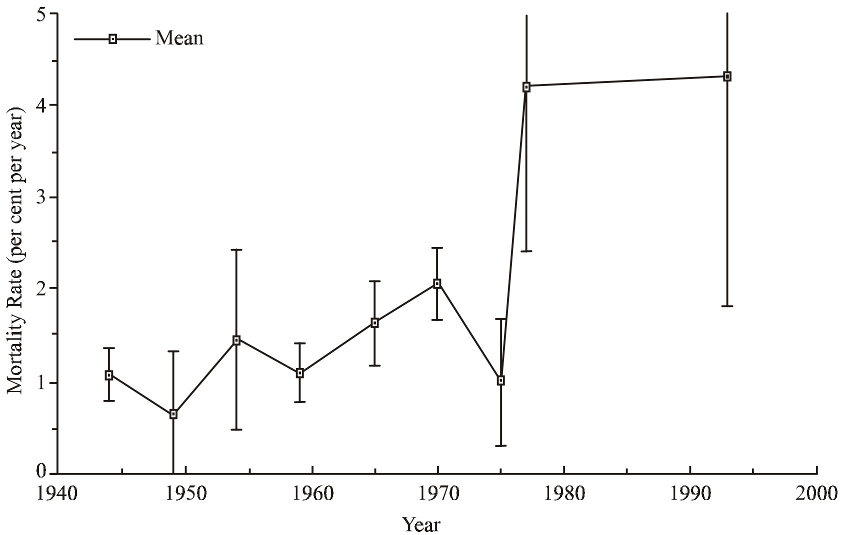

**Note:** Above-ground biomass (in metric tons) per ha for Kodkani. The contribution of each size-class to total biomass is given, with the smallest trees at the bottom of each bar and the largest trees at the top. New recruits are estimated for 1944 to 1977.

**Figure 9**
***Mean Mortality Rate of Trees for all Four Plots with 95 per cet Confidence Intervals***




**Note:** Mean mortality rates at the end of each interval for the four forests, shown as a percentage per year over time, with 95 per cent confidence levels.

**Figure 10**
***Mean Recruitment Rate of Trees for all Four Plots with 95 per cent Confidence Intervals***




**Note:** Mean mortality rates at the end of each interval for the four forests, shown as a percentage per year over time, with 95 per cent confidence levels.



cent, reaching 8 per cent at Katlekan in 1993 and 6 per cent at Malemane in 1977 during periods of logging. The mean estimated recruitment rates also increased dramatically to around 4 per cent in 1977 (see Figure 10), approximately balancing mortality.

The mortality and recruitment of trees have a definite spatial pattern. Loss of trees and canopy cover is most pronounced in areas where a power line right-of-way was established and maintained, or was established and then abandoned. Fire spreading from these rights-of-way killed many trees in the adjacent forests. Some death of trees also occurred along the roadways. New recruits were distributed throughout the plots but were concentrated along the power lines and adjacent forest that had been burned.

### *Species Composition*

A total of 209 taxa were identified on the four plots, with 26 species found on all four plots in either 1939 or 1993 (see Table 2). Each plot had around 100 species, with Katlekan having the fewest (eighty-nine species) and Kodkani the most (114 species). In order to compare plots for similarity of species composition, each species was assigned a species importance value by adding its relative frequency on the plot to its relative above ground biomass, and dividing by 2 so that the total adds up to 100. The most important species at all plots were *Knema attenuata*, *Dimocarpus longan* and *Diospyros oocarpa*. Other species found at all plots and important at certain plots include *Hopea ponga*, *Olea dioica* and *Aglaia roxburghiana*. *Macaranga peltata* was not common at any of the plots in 1939, but had become a common species at Kodkani and Malemane by 1993.

To determine which pairs of plots are most similar, the species importance values are examined using correlation analyses between successive pairs of plots. All of the correlations are highly significant due in part to the large sample sizes (see Table 3). The two plots most similar in species importance value are Malemane and Devimane. Of the six pair-wise comparisons between plots, five increased in similarity based on their correlation values from 1939 to 1993 indicating that the plots are becoming more similar to each other. This is largely due to the increasing abundance of widespread pioneer species, such as *Macaranga peltata* and *Callicarpa lanata*, on all plots.

Growth rates over time were analysed for thirty-three species which had at least twenty of the original individuals present at each census period. Regression analysis demonstrated that of the thirty-three species, six species showed a significant increase in growth rate over time: *Hopea ponga*, *Garcinia gummigutta*, *Sageria laurifolia, Myristica malabarica*, *Dipterocarpus indicus* and *Diospyros oocarpa*. The remaining twenty-seven species did not show any changes in growth rate over time, and no species showed a declining rate of growth.

Each plot was also analysed using a pioneer index, based on observations of tree species, information available from Forest Department staff and published

**Table 2**
***Species Common to all Four Plots in 1939 and 1993***

| Species | Importance Value 1939 | | | | Importance Value 1993 | | | |
|---|---|---|---|---|---|---|---|---|
| | Plot 1 | Plot 2 | Plot 3 | Plot 4 | Plot 1 | Plot 2 | Plot 3 | Plot 4 |
| *Dimocarpus longan* | 4.7 | 15.2 | 5.3 | 4.1 | 3.8 | 10.6 | 6.4 | 2.8 |
| *Knema attenuata* | 17.5 | 1.4 | 4.3 | 7.7 | 18.9 | 2.2 | 4.2 | 9.6 |
| *Holigarna arnottiana* | 0.5 | 2.2 | 0.3 | 0.6 | 0.3 | 0.7 | 0.6 | 1.3 |
| *Hopea ponga* | 5.7 | 10.4 | 0.5 | 13.9 | 8.5 | 8.3 | 0.5 | 14.0 |
| *Olea dioica* | 5.2 | 7.1 | 12.5 | 2.3 | 3.5 | 5.6 | 8.2 | 2.0 |
| *Diospyros candolleana* | 2.0 | 1.3 | 5.6 | 2.5 | 1.3 | 2.5 | 4.6 | 2.6 |
| *Garcinia gummi-gutta* | 4.1 | 1.4 | 3.8 | 1.0 | 5.9 | 1.3 | 2.2 | 1.2 |
| *Aglaia roxburghiana* | 2.6 | 0.8 | 11.4 | 1.9 | 2.9 | 1.2 | 10.4 | 1.8 |
| *Garcinia morella* | 2.0 | 0.2 | 0.9 | 0.1 | 2.2 | 0.9 | 1.4 | 0.2 |
| *Syzygium gardnerii* | 0.3 | 4.9 | 0.1 | 3.7 | 0.9 | 4.9 | 0.1 | 1.7 |
| *Diospyros paniculata* | 0.4 | 1.0 | 0.8 | 0.2 | 0.5 | 1.2 | 0.2 | 0.5 |
| *Ficus nervosa* | 0.5 | 0.8 | 0.4 | 0.4 | 0.7 | 0.1 | 0.3 | 0.5 |
| *Aglaia anamalayana* | 0.2 | 0.2 | 5.7 | 2.7 | 0.2 | 0.9 | 6.3 | 4.0 |
| *Nothopegia dalzelli* | 1.2 | 1.6 | 0.9 | 5.7 | | | | |
| *Persea macrantha* | 0.2 | 2.8 | 1.1 | 0.2 | | | | |
| *Mallotus phillipenensis* | 1.4 | 0.8 | 1.1 | 0.2 | | | | |
| *Strombosia ceylanica* | 0.1 | 1.6 | 0.9 | 0.4 | | | | |
| *Cinnamomum zeylanicum* | | | | | 0.4 | 1.2 | 1.6 | 0.7 |
| *Diospyros oocarpa* | | | | | 4.8 | 0.9 | 0.1 | 14.4 |
| *Diospyros* species | | | | | 5.9 | 1.3 | 2.2 | 1.2 |
| *Mangifera indica* | | | | | 0.1 | 0.3 | 0.6 | 0.2 |
| *Nothopegia* species | | | | | 0.5 | 0.6 | 0.4 | 3.5 |
| *Myristica magnifica* | | | | | 1.4 | 3.5 | 0.5 | 0.6 |
| *Macaranga peltata* | | | | | 1.1 | 0.9 | 4.7 | 7.7 |
| *Holigarna* species | | | | | 0.9 | 0.3 | 0.1 | 0.1 |
| *Callicarpa lanata* | | | | | 0.1 | 2.5 | 0.5 | 0.5 |

**Note:** Values are only shown when the species is present at all four plots.

**Table 3**
***Correlations of Species Importance Values (IV) between Plots for 1939 and 1993***

| | Devimane | Katlekan | Kodkani | Malemane |
|---|---|---|---|---|
| Devimane | | 0.30<br>$p < 0.000$ | 0.45<br>$p < 0.000$ | 0.61<br>$p < 0.000$ |
| Katlekan | 0.35<br>$p < 0.000$ | | 0.32<br>$p < 0.000$ | 0.35<br>$p < 0.000$ |
| Kodkani | 0.39<br>$p < 0.000$ | 0.37<br>$p < 0.000$ | | 0.20<br>$p < 0.004$ |
| Malemane | 0.68<br>$p < 0.000$ | 0.37<br>$p < 0.000$ | 0.31<br>$p < 0.000$ | |

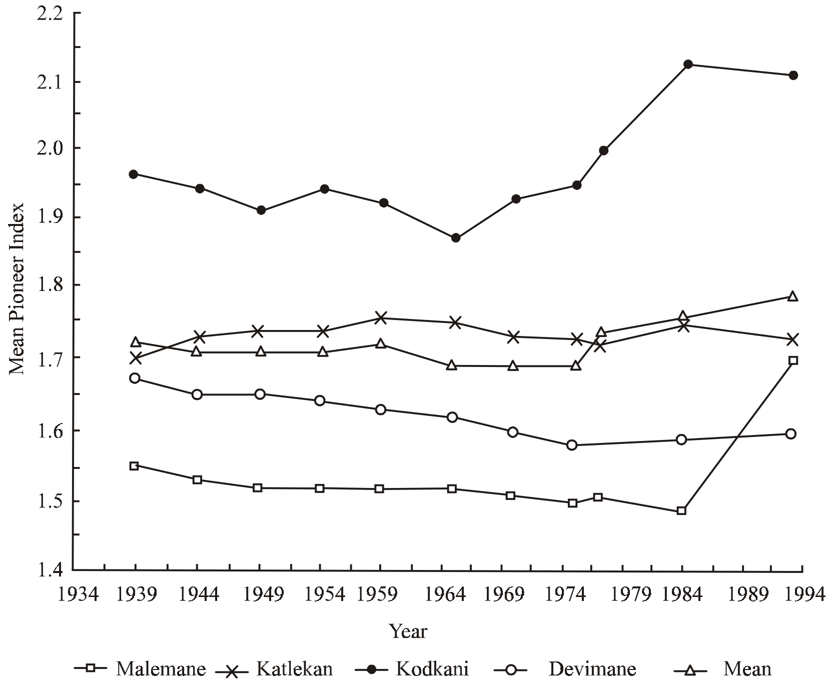
**Note:** Values for 1939 are shown above the diagonal, and values below the diagonal are from 1993.

descriptions (Pascal 1988; Pascal and Pelissier 1996). Each species was assigned a pioneer index value from 1 to 4 with 1 being closed forest species, 2 being species that need a small opening or stream, or that is more characteristic of semi-



evergreen or deciduous forest, 3 being species which respond to openings, often found in semi-evergreen or deciduous forests and 4 being pioneer species, often found in open areas or forest margins. Whitmore (1989) gives further details on the use of the pioneer index. The pioneer index for each plot was calculated by multiplying the number of stems of each species by its pioneer index and dividing by the number of stems of all species in the plot. For the four plots, Kodkani had the highest pioneer index and Malemane had the lowest (see Figure 11). An increase in the pioneer index was evident for Malemane in 1994 and Kodkani in 1984, indicating the increasing importance of pioneer species in the plots.

**Figure 11**
***Changes in Mean Pioneer Index Over Time***




**Note:** The mean pioneer index for each plot and the mean for the four plots together are shown for each census over the entire 54 year plot history. Increases in the mean pioneer index of Kodkani are shown following the clearing and fires of the 1970s. The steep increase at Malemane follows logging in 1977.

$$\text{Mean Pioneer Index} = \frac{(XXX)\,(XXXX)}{(XXXX)}$$

At all four plots, new species arrived and existing species went locally extinct. Virtually all of the species that went locally extinct had less than ten individuals in 1939. Across the four plots, a total of seventeen rare species went locally extinct, while seventy rare species persisted over the entire period. At all four plots, new species were recorded over time; at each plot the number of new species exceeded the number of old species which went extinct. The result was that each plot had more species present in 1993 than in 1939. Many of the new species were pioneer or semi-pioneer species that were present in more than one or all four plots.

## Discussion

These four forests of the Western Ghats have been strongly affected by human activities, in the form of logging, roads, power line rights-of-way, fires, cattle grazing and gathering of forest products. As a result, the number of trees and the above-ground biomass declined gradually during the 1940s, 1950s and 1960s. The fact that the proportion of trees in each size-class remains approximately the same over decades in which the number of trees was declining by 30 per cent suggests that trees were being removed or destroyed in all size-classes; there is no evidence that large trees were being disproportionately removed or that there was an abundance of small trees being recruited following the cessation of logging. With the onset of selective logging in the 1970s and 1980s, the number of trees, biomass and basal area declined even further, but the forests have recovered to some extent after logging ended.

Within this general pattern each forest exhibited certain unique patterns:

**Katlekan** contains the most gradual slopes and is particularly moist. Perhaps as a result of these more stable growing conditions, the forest has a higher percentage of large trees and fewer small trees. In addition, there is no record of fire at this site, and substantial numbers of small trees grew up in the years following logging.

Although **Malemane** is similar to Katlekan in terms of being gradual in slope and moist, it has a substantial number of small trees. Forest decline began in the 1950s, but accelerated with road construction, logging and fires. Many of the new trees are pioneers associated with disturbance, such as *Macaranga peltata*. By 1993, the forest was showing signs of recovery.

**Devimane** has the largest neighbouring human population and showed a continuous decline in number of trees, probably related to removal of poles by villagers. Logging was also later and apparently more severe at this site.

**Kodkani** is a steep site, broken up by an old field, two power lines and a road, and is drier than the other three sites. Even though this area was not logged, frequent fires, cattle grazing and collection of forest products make this the most fragmented and disturbed of the four sites. This site shows a gradual and substantial decline in the number of trees and biomass over time, particularly associated with the road and power lines. There is a corresponding increase in the number of pioneer species and the overall pioneer index. The forest only began to show signs of recovery in 1993.



This study has documented the significant long-term effects of human activity on these forests. From an ecosystem perspective, the most significant effect may be the loss of basal area and above-ground biomass. Basal area is a standard index of the amount of wood in forests, whereas AGB is a measure of the organic matter in the forest as well as the stored carbon. In calculations of the global carbon budget, two key measurements are the amount of forest remaining and the rate of deforestation (Dale et al. 1994; Flint and Richards 1994). This study shows that these apparently intact forests may have already lost 30 per cent of their AGB due to selective logging and other human impacts. On the positive side, once logging has stopped, and the area is protected from human impact, these forests have the potential to recover a substantial proportion of their lost AGB within one decade of the cessation of logging and perhaps recover even more in the coming decades. Tree seedlings and saplings are present in these forests, and in some places even abundant, providing the starting point for the next generation of trees. Full recovery of AGB and other ecosystem characteristics will probably never occur due to ongoing human activities in the area associated with roads, power lines, cattle grazing, gathering of forest products and fire. Areas now occupied by roads and power lines will never return to forests, making full recovery an impossibility. These forests will need to be monitored carefully in the future to ensure that this partial recovery continues.

### *Disturbance*

Logging in these forests was relatively light until the demand for plywood logs developed in the 1970s (Gadgil and Guha 1992). Many of India's main hardwood species, such as *Tectona grandis* and *Dalbergia* species, are not evergreen forest species; however, the evergreen forests do contain many good plywood species, such as species of *Calophyllum*.

Because the Western Ghats are a mountainous area with high rainfall, these areas have been a favoured site for hydroelectric projects. As the populations of towns on both sides of the Ghats have grown, demand for electricity has increased. The forest has become increasingly fragmented by clearing for transmission lines from the hydroelectric plants in the Ghats as well as by clearing for the reservoirs, dams and hydroelectric plants themselves. Two of these plots, Devimane and Kodkani, have been disturbed by this clearing. Perhaps as much as 20 per cent of the initial loss of biomass and number of trees could be accounted for by the clearing for roads and transmission lines. All dbh classes were affected by these large disturbances. Transmission lines also make convenient paths for people and cattle to enter the forest, and disturbances along the transmission lines often continue after the original clearing in the form of fires, grazing, firewood gathering and maintenance of the power lines. We observed all of these disturbances in these study plots during the 1993 study season, with Kodkani being the most affected.

### *The Future of these Forests*

Our results demonstrate that at least partial recovery in stem density and above-ground biomass is possible in areas that were selectively logged and have had no further disturbance. In the absence of further disturbance, a substantial recovery of these stand characteristics can be expected after several decades in those areas, with respect to stem count and above-ground biomass. In addition, most of the original tree species are still present, as has been found in selectively logged tropical forests elsewhere (Cannon et al. 1998). However, disturbances will not cease, as the human population in the area continues to grow and development continues. Areas such as Kodkani continue to experience disturbances. Further, recent Forest Department programmes to open up forests for the removal of dead trees may expose the forests to a new round of disturbance. If living trees are also harvested or just damaged at the same time, the impacts to the forests could be considerable.

In the past, traditional logging was selective and was done with buffalo and hand labour, not with heavy equipment. The logging roads were smaller than they would have been had heavy equipment been used and consequently skidding damage was lighter. Additionally, cutting may have been lighter than the maximum allowed as not all species were equally desirable and some of the desirable species were not present in large numbers. The minimum dbh cut (60 cm) was far above the average dbh of trees on the research plots, which never exceeded 28 cm. At least 95 per cent of the trees on these plots were too small to be cut in a logging operation, unless they were in the way of logging roads or were knocked down inadvertently. Consequently, recovery from traditional selective logging by these forests does not imply that recovery will be similar in forests where heavy machinery has been used on steep slopes, logging roads large enough for logging trucks have been built or large numbers of species are harvested. Neither does it imply that these forests can withstand further harvesting of timber. The length of the cutting cycles that would be required in order to allow the forests of this area to recover completely probably preclude any large commercial benefits from repeated timber harvest. Additionally, logging contributes to fragmentation of these forests by opening up new routes ever deeper into these forests for people and livestock.

A larger problem than selective logging by itself is the disturbance caused by fragmentation. The evergreen forests of the Western Ghats are becoming a mosaic of forest in various stages of growth. Patches of primary forest remain among areas of selectively logged forest, and clearings for electric lines, roads, hydro-electric projects and agriculture have become common as the human population in the Western Ghats increases and modernises. Many of the new trees recorded in the plots are widespread pioneer species, as seen also in the increasing pioneer index at each plot. Clearing on steep terrain is followed by severe erosion and poor establishment of closed forest species in large clearings, as has been found in tropical forests elsewhere (Uhl 1987). Additionally, clearings are frequently taken over for grazing and agriculture, and fires spread from clearings into the forest. In such cases, the regeneration process in clearings and adjacent forests is often much slower than regeneration after selective logging alone. Without protection from continuing disturbance, large clearings may never return to evergreen forest. The roadside clearings at Kodkani are bordered by short-lived, fast-growing pioneer species and dense brush and climbers. At Kodkani, there are two large clearings on steep slopes; one clearing is accessible from a road and the other is not. The clearing that is inaccessible from the road shows no signs of grazing and contains many very large saplings, while the clearing near the road has no growth on its slopes and shows definite signs of grazing; cattle were observed grazing there in 1993.

In these forests it is clearly direct human impact causing the changes in forest structure and species composition, rather than the more subtle effects of global climate change and carbon dioxide levels over which many scientists have expressed concern (Phillips 1998; Phillips and Gentry 1994). High levels of human disturbances affecting rates of mortality and recruitment have been noted in other Asian forests (Pascal et al. 1998; Primack and Lee 1991; Sukumar et al. 1998). The forests described here have substantially greater rates of mortality and recruitment than undisturbed forests elsewhere in the Western Ghats (Ganesan et al. 2001; Sukumar et al. 1998). Similarly, many tree species in these plots have increased growth rates over time, apparently in response to higher light levels and reduced competition following logging.

## Conclusion

Although logging of these evergreen rainforests was stopped in 1988, the continuing high mortality and recruitment rates as well as ongoing human activities in the area, show that cessation of logging clearly is not enough to ensure the continued health of the forests. The current regrowth in these forests is encouraging, but will not lead to a full recovery, particularly if the forests are opened for the removal of dead trees. Future development needs to be planned so as to minimise impact on these forests. Clearing and creation of routes into the forest, even just for the removal of dead trees, encourage ongoing land uses such as increased foot traffic, fires, firewood collection and especially grazing of livestock, all of which prevent regeneration. Such disturbance favours light-demanding pioneer species over the traditional forest species. This problem is likely to increase as the human population of the area grows. Areas with low natural regeneration that continue to be disturbed, will need to be replanted and actively managed to allow them to return to their original condition, as described by Rai (1981). Future use of forest resources should be planned with the goal of decreasing the level of disturbance, protecting seedlings and saplings and allowing for long recovery periods. Extensive reforestation programmes that are currently underway in Karnataka should continue, as should monitoring of the research plots to assess ongoing forest recovery.

The future availability of resources from reforested areas may be the best incentive for the continued existence of the remaining natural forests of the Western Ghats.

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