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# Biodiversity values of abandoned teak, *Tectona grandis* plantations in southern Western Ghats: Is there a need for management intervention?

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## Abstract

Abandoned plantations could potentially support a large number of native tree species through succession and restore the original tree community. In order to assess the ability of abandoned teak plantations to recover through regeneration, teak stands from 29 to 80 years old were sampled for seedling and sapling density, species richness and the use by large ungulates in the southern Western Ghats using 10 m circular plots. The influence of the forest-plantation edge was also studied. There was regeneration of a species-rich tree community in the understorey of abandoned teak plantations. However, regeneration was arrested, and thereby the large girth-class tree community remained species-poor. There was no significant change in the tree species richness with distance from natural forest, suggesting that the forest-plantation edge had little influence on the penetration of native tree species inside plantations. Asian elephant and Indian gaur dung densities were significantly lower in the plantations than in the forest. Indian gaur and sambar used the younger plantations intensively, and the density of their dung was negatively correlated with age of the plantation. Abandonment of mature teak stands arrested the succession of native trees. We provide evidence that abandoned teak plantations might not serve as suitable habitats for large herbivores during the dry months of the year in the region. The study highlights the need for active management of mature teak plantations inside wildlife reserves, in order to promote succession and improve the habitat for wild flora and fauna in the Western Ghats.

## Zusammenfassung

Aufgegebene Plantagen könnten möglicherweise eine große Anzahl einheimischer Baumarten durch Sukzession erhalten und die ursprüngliche Baumgesellschaft wieder herstellen. Um die Möglichkeit abzuschätzen, dass aufgegebene Teakholzplantagen sich durch Regeneration erholen, wurden Teakbestände im Alter von 29 bis 80 Jahren beprobt und die Keimlings- und Schösslingsdichte, der Artenreichtum und die Nutzung durch große Wiederkäuer in den südlichen Western Ghats auf kreisrunden 10 m-Probeflächen festgestellt. Der Einfluss der Grenzlinie zwischen Wald und Plantage wurde ebenfalls untersucht. Es kam zur Regeneration einer artenreichen Baumgesellschaft im Unterholz der aufgegebenen Teakplantagen. Die Regeneration war jedoch gehemmt, und deshalb war die Gemeinschaft der Bäume mit großen Stammumfängen artenarm. Es gab keinen signifikanten Unterschied im Artenreichtum der Bäume in Abhängigkeit vom Abstand zu natürlichem Wald, so dass vermutet werden kann, dass der Waldrand nur einen geringen Effekt auf das Einwandern der einheimischen Baumarten in die Plantage hat. Die Dungdichten der asiatischen Elefanten und indischen Gaur waren in den Plantagen signifikant geringer als im Wald.

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Indische Gaur und Sambarhirsche nutzten die jungen Plantagen intensiv und die Dungdichte war negativ mit dem Alter der Plantagen korreliert. Die Meidung der alten Bestände stoppte die Sukzession der einheimischen Bäume. Wir liefern Hinweise dafür, dass sich die aufgegebenen Teakplantagen vermutlich nicht als Habitate für die großen Herbivoren in den trockenen Monaten des Jahres in dieser Region eignen. Die Untersuchung hebt hervor, dass es eine Notwendigkeit für ein aktives Management für Teakplantagen innerhalb von Wildreservaten gibt, um die Sukzession zu fördern und das Habitat für die wilde Flora und Fauna in den Western Ghats zur verbessern.


***Keywords:*** Forestry; Tropical forest; Regeneration; Restoration; Biodiversity; Western Ghats

## Introduction

Tropical forests are among the richest ecosystems on earth in terms of species richness (Gentry 1992; Myers 1988). Because of the very high rate of deforestation (5.8 million hectares per year), the severely fragmented tropical evergreen and moist deciduous forests continue to degrade (Mayaux et al. 2005). However, forest remnants alone might not be sufficient in order to conserve the diversity of flora and fauna harbored by the tropical forests (Parrotta, Turnbull, & Jones 1997). Efforts to restore areas that were once clear-felled and converted to plantations for timber production, makes available new areas and habitats for native species to survive. Management of these new habitats could regulate the magnitude and direction of the changes in biological diversity in tropical forests (Brockerhoff, Jactel, Parrotta, Quine, & Sayer 2008; Lugo 1995). Additionally, some native tree species regenerate well under tree plantation in the tropics (Parrotta et al. 1997). However, for the management of abandoned extensive tropical plantations and enhancing their biological diversity, there are yet no clear prescriptions. Conservation biology has been called a "crisis discipline" because of the necessity to make decisions in the face of uncertainties (Burgman, Ferson, & Akcakaya 1993; MacCarthy & Possingham 2007). One way of dealing with this is by using adaptive management strategies by monitoring the outcomes of different management regimes, and allowing conservation outcomes to dictate management practices (MacCarthy & Possingham 2007).

Teak (*Tectona grandis*) occurs naturally in south and south-east Asian countries (Altona 1922; Letorneux 1957). It was introduced to other tropical areas as far as central and South America and central Africa. It was selectively propagated using standardized protocols after clear-felling large tracts of tropical forests (Tewari 1992). In India, forest patches of varying sizes were cleared using extensive mechanical, animal and human work force between 1850s and 1960s in order to plant teak (Tewari 1992). Teak plantations are distributed in peninsular India covering an area of 13,301 $km^2$ (Anonymous 1999). It is the second most extensive monoculture plantation covering 8.7% of the total area under plantation in India. In southern India where teak occurs naturally, raising plantations involved clear-felling after selectively retaining a few tree species of significant timber value, such as *Dalbergia latifolia*, *Terminalia tomentosa* and *Lagerstroemia microcarpa* (Sekar & Ganesan 2003).

After the 1960s, conservation reserves gained priority over production-oriented forestry in India. This led to the gradual dismantling of the teak production machinery and workforce in southern India. In 1972 after the Wildlife (Protection) Act was promulgated, production forestry in conservation reserves, otherwise termed as Protected Areas (PAs) including national parks and wildlife sanctuaries, was minimized. While legally notified national parks prohibited any type of consumptive resource use, wildlife sanctuaries continued to have limited operations and felling of timber. Further, in 1988 the National Forest Policy recommended that all forestry practices be stopped inside PAs in India. Therefore, the forestry operations in teak plantations inside PAs were abandoned with the premise that native forest species would replace teak and the original tree diversity would be restored over time. All forest fellings were totally banned within PAs in 1991. Forest succession in tropical tree plantations can be directed by targeted management activities in order to improve species diversity (Lamb 1998; Lugo 1988a, 1988b; Lugo, Parrotta, & Brown 1993). In order to prescribe management activities in the teak plantations within wildlife reserves, the status of regeneration and habitat use by wildlife in teak plantation needs to be assessed.

The Western Ghats of India has about 1.6% of the world's vascular plant diversity and significant populations of large mammals. Adverse impact on the regeneration of native tree species is expected to play an important role in the long-term conservation prospects of the endemic tree species diversity and the large mammal populations, which depend on the understorey foliage. Teak plantations in the southern Western Ghats had lower butterfly diversity (Kunte, Joglekar, Utkarsh, & Pramod 1999), frog diversity (Saravanakumar 1995), rodent biomass and density (Chandrasekar-Rao & Sunquist 1996) in comparison with adjacent intact forests. A study that covered different habitats in Eastern Ghats in India found that bird species diversity was lowest in teak plantations (Beehler, Raju, & Ali 1987). The dense canopy of teak plantations precluding the development of rich understorey and the resulting simple structure of vegetation was pointed out to be the reasons for this (Beehler et al. 1987; Lamb 1998). On the contrary, abandoned teak plantations in central India had similar species richness compared to secondary forests in the same area (Saha 2001).

In the present study, the status of regeneration and wildlife use of teak plantations in the southern Western Ghats were addressed through the following research questions. (i) How does the age of the plantation affect plant species richness, composition, regeneration and use of plantations by large mammals? (ii) What is the influence of distance from forest–plantation edge on plant species richness and use of plantation edge by large mammals? (iii) How does the age distribution of native tree species differ in plantations and natural forest?

## Methods

### Study area

The Anamalais (latitude N 10°7′–10°33′ and longitude E 76°35′–77° 50′) fall under the Ceylonese sub-region of the Oriental region and in the Western Ghats biogeographic zone (Rodgers & Panwar 1998). It includes two Protected Areas viz., the Indira Gandhi Wildlife Sanctuary (IGWLS) (946 $km^2$) and the Parambikulam Wildlife Sanctuary (PWLS) (285 $km^2$) (Fig. 1). The Parambikulam Wildlife Sanctuary encloses an area between Nelliampathy hills to the west and the Anamalai hills to the east. The natural forest types include (i) West coast tropical wet evergreen forest, (ii) West coast tropical semi-evergreen forests, (iii) Southern Indian tropical moist deciduous forest, (iv) Southern Indian tropical dry deciduous forest, (v) Moist bamboo brakes, and (vi) Reed brakes (Wilson 1964). There is a rainfall gradient from the east to the west. The east facing slopes fall in the rain shadow region and are drier than west facing slopes. The western slope has South Indian tropical wet evergreen and Southern Indian tropical moist deciduous forests. The eastern slope has Moist deciduous, Southern Indian dry deciduous and Thorn forests. There is an altitudinal gradient in moisture and temperature, and therefore there is change in vegetation along the elevational gradient. The Southern Indian tropical moist deciduous forest extends from 200 to 600 m a.m.s.l. Mid-elevation evergreen forests exists from 600 to 1500 m a.m.s.l. and the higher reaches have montane wet evergreen forest. The climate becomes increasingly temperate at altitudes above 2000 m a.m.s.l. where there are ‘shola’ forests (Montane wet evergreen forests) and grasslands.

### Management history of teak plantations

After a trigonometrical survey of the forests in 1820 by Ward and Connor, teak plantations were raised (Sekar & Ganesan 2003). At the beginning of the 19th century, natural teak and other economically important timber species were harvested and teak monocultures were initiated. Extensive teak plantations were raised between 1939 and 1981. Prior to planting teak, either seeds or stumps (early plantations raised from seeds, later ones from one-year-old stumps about 25 cm long.), the area was completely cleared, burned, dibbled and weeded to ensure the successful establishment of teak seedlings. Initial spacing of seedlings was 1.37 m apart in most plantations. During the first year, weeds were cut back throughout the year. Second year’s management included cutting back of all weeds, pruning of double leaders and large persistent side branches, coppicing of damaged plants, cutting of bamboo and uprooting of *Lantana camara*. Miscellaneous tree species interfering with teak were pollarded (cutting back of crown) instead of coppiced. A cleaning and climber cutting was done prior to thinning. Generally, plantations were thinned in 6th, 12th, 18th, 30th and 50th years. Felling cycle was 40 years, with a rotation period of 80 years. Other commercially viable species were encouraged within plantations, and there was no removal of miscellaneous species after the establishment of teak trees (Wilson 1964). The initial target of these management activities was maximizing the timber output while reducing the cost, but this was later abandoned in favor of establishing the Anamalai Wildlife Sanctuary in 1976. Subsequently, this sanctuary was given the status of Anamalai Tiger Reserve. Here, 2822.89 ha are under teak plantation while in the adjoining Parambikulam Tiger Reserve, 8847.62 ha are under teak plantation (Wilson 1964).

### Regeneration and wildlife use inside teak plantations

We selected eight plantations of varying ages to study the effect of plantation age on species richness, composition and forest regeneration. The years of planting were 1927, 1930, 1936, 1940, 1960, 1973 and 1978. Thus, the plantations were 80, 77, 71, 67, 47, 34 and 29 years old at the time of the study. Within each plantation, twenty random circular plots were laid out by selecting ten random directions from the center of the plantation and two random distances along each of the directions. Circular plots were chosen instead of quadrats as they reduced the effect of edge on measurement of species richness and abundance (Krebs 1999). The dimensions of circular nested plots were: (i) 10 m radius for trees (girth at breast height, gbh $\geq$ 20 cm), (ii) 5 m radius for shrubs, climbers and saplings (gbh $\leq$ 19–$\geq$3 cm) & seedlings (gbh < 3 cm) of trees. Within the 10-m radius plots, the tree species and number of individuals of each species were recorded. Using the same method, 20 random plots were laid out in a contiguous moist deciduous forest adjoining the teak plantations. These samples served as control, in order to examine the change in the variables within plantations. The moist deciduous forest was the original vegetation type before the plantations were raised. In the reserve, this vegetation type is restricted only to the middle and low elevation (800–200 m a.s.l.), and there are very few remnant patches that were not cleared for plantations. From the same plots, elephant (*Elephas maximus*) dung was counted within the 10-m radius, while gaur (*Bos gaurus*) dung and sambar (*Cervus unicolor*) pellet groups were

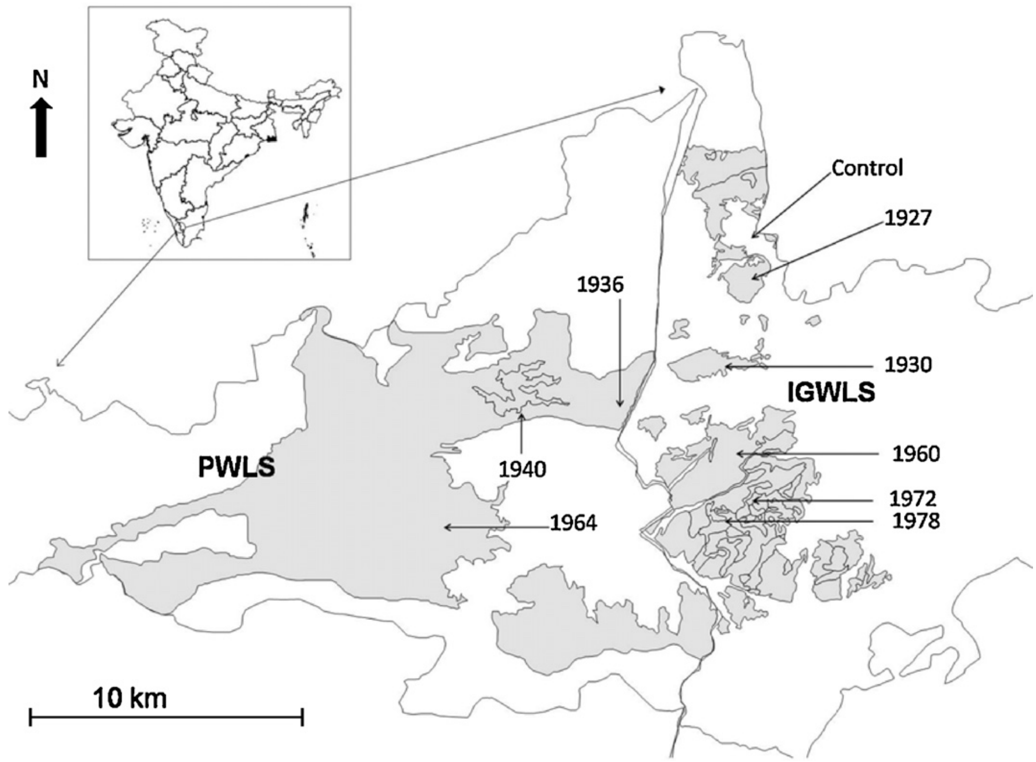


**Fig. 1.** Map showing Parambikulam Wildlife Sanctuary (PWLS) and Indira Gandhi Wildlife Sanctuary (IGWLS) with the overall boundary of teak plantations marked in gray. The approximate locations of sampled plantations are indicated along with the respective plantation years. The surrounding areas in white are dominated by wet evergreen and few scattered patches of moist deciduous forests.

counted within the 5-m radius plots. Based on this, dung or pellet group density per hectare was calculated. In a typical experimental design, each plantation should have a control area adjacent to it. However, the conversion of large expanse of native forests into plantations in the study area severely restricted the choice of control sites for the present study.

In order to study the effect of distance from natural forest-plantation edge on regeneration and wildlife use in plantations, 10 transects were laid out starting at the forest-plantation edge and proceeding to the center of the plantation up to 250 m. Five plots of the above-mentioned dimensions were laid starting at the edge. The distance between the circumferences of successive plots were 10 m, 20 m, 40 m and 80 m. Vegetation data was collected from these plots as mentioned above. Dung and pellet groups were counted in the plots, as described above. The entire study spanned from December 2006 to March 2007.

## Data analysis

The densities of seedlings, saplings, trees, shrubs, climbers, dung and pellet groups were calculated by finding out the number of individuals of each within one square meter. Comparisons for densities were made at one hectare. Species richness estimates were arrived at using the software Estimate S6b1a (Colwell 1997). To account for undetected species, a second order Jackknife extrapolation was used. In all estimations, 10,000 iterations were used. We also computed Simpson's diversity index (D) as $1-\lambda$, where, $\lambda = \sum_{i=1}^{s} p_i^2$ and $p_i$ equals the proportional abundance of species '*i*' in a sample of S species (Krebs 1999). This index was calculated for seedlings, saplings and trees in the plantations and the control. The relative abundances of three common exotic weeds, *L. camara*, *Eupatorium odoratum*, and *Mikania micrantha* were calculated to understand the prevalence of these species in the plantations.

We performed a correspondence analysis (CA) in order to analyze the differences in species composition of trees, saplings and seedlings using Multivariate Statistical Package 3.1 (MVSP). The cells having a value of zero were added with a very small positive value (0.001). Species were not weighted and Kaiser's rule was used to extract the axes. From the resulting CA case scores, the eigen values for the first two axes, for all eight plantations and the control, were plotted on a scatter graph.

A cluster analysis was performed using the modified Morisita's measure to arrive at pair-wise distances between plantations and control. A separate matrix based on pair-wise distances was made using the difference in age of the plantations and the control. Here, the age of the control was assigned as zero. Mantel test was used to correlate the matrices of tree, sapling and seedling species composition, and age of the plantations. The significance of the correlation coefficient was examined by comparing the observed correlation coefficient against the 95% confidence limits of the 10,000 randomly generated correlation coefficients from the same matrices. We used MS Office Excel 2003 with Pop tools add in to perform these analyses.

In order to analyze the trend in regeneration and establishment of other native forest trees in plantations, we compared the girth-class distribution of three of the most common species viz. *L. microcarpa*, *D. latifolia* and *Terminalia paniculata* in plantations and control.

## Results

### Plant species regeneration inside teak plantations

There was variation in the estimated species richness of trees, saplings and seedlings in plantations of different ages (Table 1). Nevertheless, the estimated species richness was not correlated with the age of the plantations ($r = 0.0004$, −0.62, −0.26, 0.63, and 0.13 for trees, saplings, seedlings, shrubs and climbers, respectively). The control site had higher estimated tree species richness than the plantations ($F = 76.61$, $P = 1.57 \times 10^{-15}$; Table 2). Seedling and sapling estimated species richness of the plantations and the control site were not different ($F = 0.33$, $P = 0.56$, and $F = 3.36$, $P = 0.07$, respectively) (Table 2). Estimated shrub and climber species richness were higher in the plantations than in the control ($F = 16.53$, $P = 7.18 \times 10^{-5}$, and $F = 15.43$, $P = 1 \times 10^{-4}$) (Table 2). Observations revealed that most climber species were herbaceous and lianas were represented by few individuals in most plantations (Appendix A). Simpson's diversity index for species richness of climbers, seedlings and saplings were not different in the plantations compared to the control (Table 2). The species diversity of trees was lower in the plantations than in the control (Table 2; Appendix A). The species diversity of shrubs was however, greater in the plantations than in the control (Table 2; Appendix A).

The densities of trees, saplings, seedlings, shrubs and climbers did not show significant relationship with age of the plantation ($r = -0.40$, −0.38, 0.21, 0.32 and −0.25, respectively). The densities of saplings and seedlings were similar in the plantations and the control ($F = 1.42$, $P = 0.23$, and $F = 0.20$, $P = 0.65$), but tree density was significantly higher in the control site ($F = 65.59$, $P = 8.49 \times 10^{-14}$). Shrub density was greater in the control site, while climber density was greater in the plantations ($F = 15.91$, $P = 9.69 \times 10^{-5}$ and $F = 13.76$, $P = 3 \times 10^{-4}$ respectively). As expected, teak was the most abundant tree species within all plantations, with an average density of 128 trees $ha^{-1}$ (SE = 24, $n = 8$; see Appendix A). In contrast, the control site had only 1.50 teak trees $ha^{-1}$. In plantations, the density of teak seedlings was lower (339 per ha, SE = 100, $n = 8$) than seedling density (2735 per ha, SE = 531, $n = 8$). Openings in the plantations often had very high abundance of herbaceous climbers. Exotic weeds such as *E. odoratum*, *Lantana camara* (relative abundance 0.29 and 0.03, respectively) and *M. micrantha* (relative abundance 0.07) were common in the plantations.

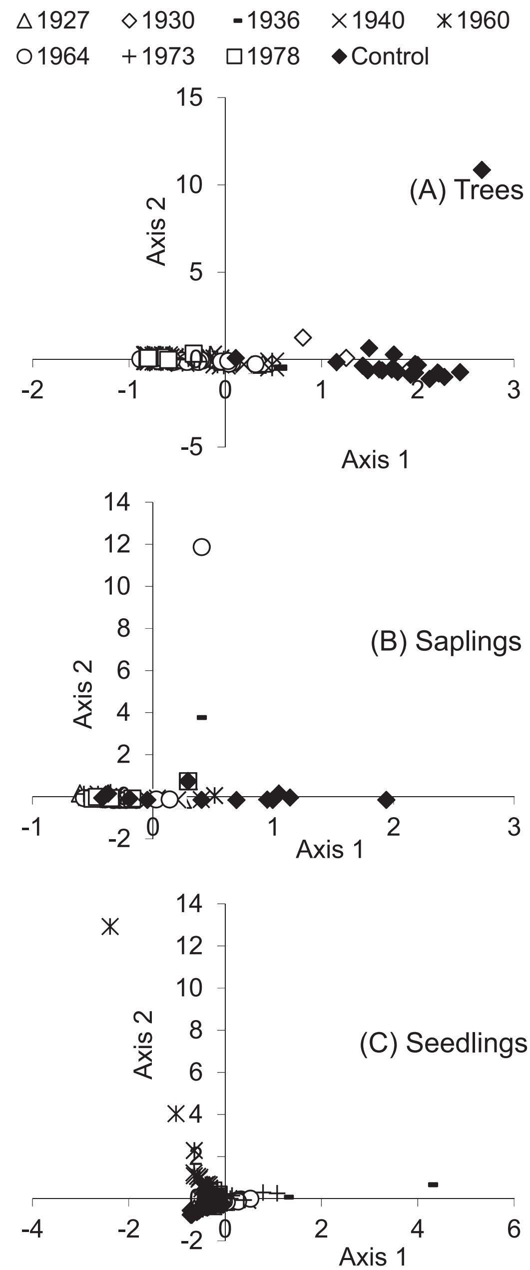


**Fig. 2.** Scatter plot of correspondence analysis case scores of (A) tree, (B) sapling, (C) seedling species in the plantations and the control.

All the plantations were similar to each other in tree, sapling and seedling species composition (Fig. 2A–C). For trees, saplings and seedlings, the first two axes cumulatively explained only 15%, 10% and 12% variation respectively. The control area exhibited heterogeneity in species composition and its tree and sapling community composition

**Table 1.** Second order Jackknife estimates of species richness in teak plantations of varying ages and control forest. *Abbreviation*: Co, Control.

| Age | Estimate of species richness | | | | |
|---|---|---|---|---|---|
| | Trees | Saplings | Seedlings | Shrubs | Climbers |
| 29 | 11.8 ± 1.4 | 16.4 ± 1.56 | 33.3 ± 2.4 | 29.5 ± 1.7 | 26.0 ± 1.7 |
| 34 | 20.2 ± 1.1 | 30.7 ± 2.3 | 60.2 ± 2.7 | 21.7 ± 3.7 | 38.3 ± 1.9 |
| 43 | 40.1 ± 2.1 | 22.8 ± 1.9 | 71.0 ± 2.2 | 29.6 ± 1.9 | 85.6 ± 3.7 |
| 47 | 20.3 ± 2.3 | 20.3 ± 2.2 | 58.0 ± 3.0 | 21.8 ± 1.9 | 32.3 ± 2.8 |
| 67 | 15.2 ± 3.5 | 22.3 ± 2.7 | 40.3 ± 2.5 | 29.3 ± 2.1 | 33.8 ± 1.5 |
| 71 | 20.3 ± 1.4 | 14.1 ± 1.4 | 35.8 ± 1.9 | 26.1 ± 1.5 | 34.1 ± 2.4 |
| 77 | 13.7 ± 1.5 | 8.1 ± 1.3 | 51.1 ± 2.5 | 39.0 ± 1.8 | 37.9 ± 3.6 |
| 80 | 29.8 ± 2.3 | 15.5 ± 1.2 | 47.3 ± 2.2 | 36.5 ± 2.4 | 68.9 ± 3.9 |
| Co | 54.8 ± 3.3 | 22.8 ± 2.1 | 50.2 ± 3.5 | 30.5 ± 1.8 | 32.4 ± 2.6 |

**Table 2.** A comparison of species richness and density in the plantations and in the control (standard sample size of 20 plots). The second order Jackknife estimate was obtained by pooling and randomizing the data from 160 plots in eight different plantations in the Anamalais and selecting the first twenty plots. This was compared with estimate from 20 plots in the control. *D* is Simpson's diversity index.

| | Species richness | | | | | | | Density (n/ha) | |
|---|---|---|---|---|---|---|---|---|---|
| | Control | | | | Plantation | | | Control | Plantation |
| | Area sampled (ha) | Observed | Estimate | *D* | Observed | Estimate | *D* | Estimate | Estimate |
| Trees | 6280 | 32 ± 4 | 55 ± 3 | 0.9 | 18 ± 3 | 33 ± 8 | 0.6 | 457 ± 171 | 228 ± 112 |
| Saplings | 1570 | 15 ± 3 | 23 ± 2 | 0.9 | 12 ± 2 | 23 ± 7 | 0.9 | 280 ± 263 | 206 ± 262 |
| Seedlings | 1570 | 39 ± 2 | 50 ± 4 | 0.9 | 44 ± 4 | 66 ± 10 | 0.9 | 2433 ± 1473 | 2674 ± 2317 |
| Shrubs | 1570 | 21 ± 3 | 31 ± 2 | 0.3 | 31 ± 3 | 42 ± 7 | 0.9 | 24,943 ± 10,787 | 15,681 ± 9665 |
| Climbers | 1570 | 25 ± 2 | 32 ± 3 | 0.9 | 48 ± 4 | 79 ± 13 | 0.9 | 3172 ± 2088 | 7872 ± 5339 |

differed from that of the plantations (Fig. 2A and B; Appendix B). The tree species composition seems to have influenced the seedling community, but not the sapling community (Table 3). The species composition in the three (tree, sapling and seedling) communities showed a significant negative relationship with the age of the plantations (Table 3). In plantations, only about 34% of the total seedling species were represented in sapling community, whereas, at control site, about 45% of the seedling species were represented in the sapling community. Seedling and sapling species richness decreased from the edge to the interior of the plantation up to a distance of about 40 m after which it seemed to remain uniform (Fig. 3). However, tree species richness did not show any clear pattern with increasing distance from the forest-plantation edge (Fig. 3). The girth class distributions of *L. microcarpa*, *D. latifolia* and *T. paniculata* showed a reversal of trend in the plantations in comparison with the control site (Fig. 4A and B). Plantations had greater abundance of seedlings of these species compared to the natural forest.

**Table 3.** Mantel's correlation coefficients of matrices of similarity in the composition of trees saplings, seedlings and plantation age in teak plantations (* indicates correlations significant at $P < 0.05$). See Appendix C for the similarity matrices on which the table is based.

| | Trees | Saplings | Seedlings |
|---|---|---|---|
| Saplings | 0.13 | – | |
| Seedlings | 0.46* | −0.02 | – |
| Age | −0.6* | −0.24* | −0.36* |

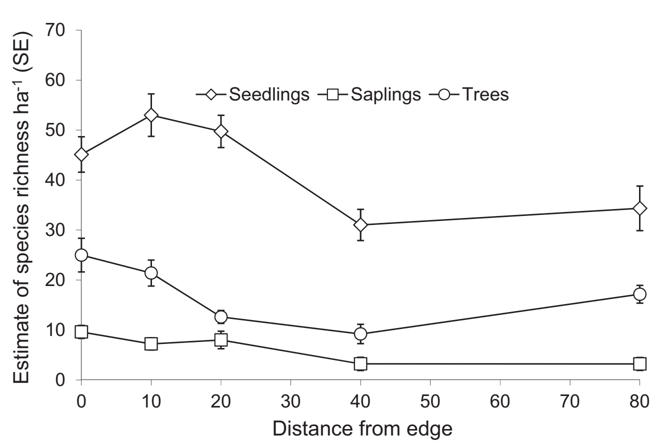


**Fig. 3.** Patterns in species richness of seedlings, saplings and trees inside the plantations with increasing distance (m) from forest-plantation edge.

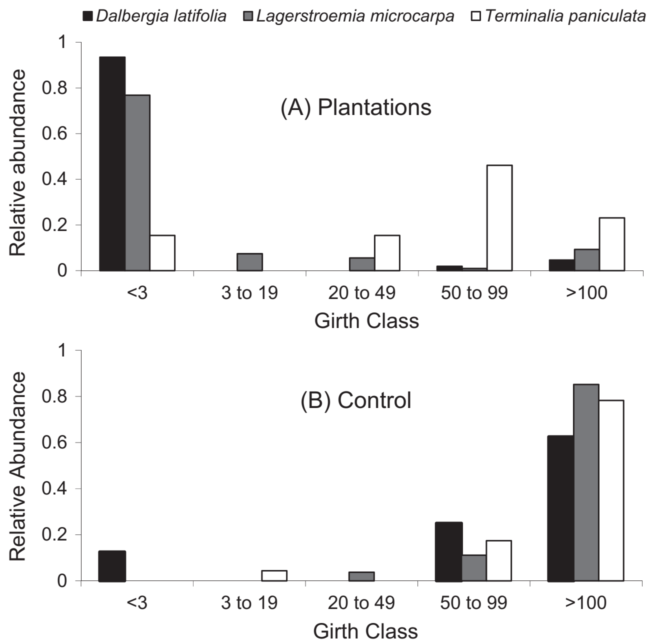


**Fig. 4.** Girth class (cm) distribution of three common tree species in (A) plantation and (B) control site.

## Use by large herbivores

Asian elephant (*E. maximus*) dung densities were similar in the plantations and the control ($F = 3.74$, $P = 0.06$). In the case of sambar (*C. unicolor*), pellet densities were similar in the plantations and the control ($F = 2.68 \times 10^{-4}$, $P = 0.99$). However, gaur (*B. gaurus*) dung densities were significantly lower in the plantations than in the forest ($F = 43.06$, $P = 5.67 \times 10^{-10}$). Elephants did not show any clear-cut pattern in the use of the plantations of different ages. Gaur used the younger plantations intensively, and there was a negative correlation between gaur dung density and age of the plantation (Table 4). Sambar pellet densities also showed a negative correlation with age of the plantation (Table 4). Elephant dung was more abundant near forest–plantation edge and decreased significantly, as the distance from the edge increased (Table 4). Gaur and sambar did not show any significant pattern in use with distance from the forest-plantation edge.

**Table 4.** Wildlife use of plantations and its relationship (Pearson correlation) with plantation age and distance from edge (* indicates correlations significant at $P < 0.05$).

| | Pellet/dung density (n/ha) | | Correlation with | |
|---|---|---|---|---|
| | Forest | Plantation | Age | Distance from edge |
| Elephant | 23.89 | 14.73 | −0.01 | −0.65* |
| Gaur | 58.92 | 21.49 | −0.69* | 0.07 |
| Sambar | 127.39 | 156.03 | −0.72* | 0.04 |

# Discussion

## Vegetation regeneration inside teak plantations

Broadly, teak plantations differed from natural forests in: (i) low tree diversity and density, (ii) high dominance of teak in abandoned plantations, and (iii) poor recruitment of tree species in >20 cm girth class. The few other tree species that were represented in the >20 cm girth class in the plantations were commercially important species such as *L. microcarpa* and *D. latifolia*, which were allowed to grow. Although climber species richness was high in the plantations, most were herbaceous climbers. Lianas were few in number in most plantations. The fact that the plantation with high diversity and density of lianas (43 years old) also had very high species richness of seedlings, saplings and trees may not be a coincidence. Schnitzer, Dalling, and Carson (2000) reported that liana density and diversity increased with increasing density and diversity of pioneer trees. Lianas added to the structural diversity of the habitat and attracted many birds and other frugivorous animals (personal observations), which may have helped in better seed dispersal in this plantation, and at the same time controlled the growth of teak trees. Intensive management of teak plantations was practiced only during the first eight years after a plantation has been raised. Many studies have reported development of complex understorey vegetation in timber plantations within 20 years (Keenan, Lamb, Woldring, Irvine, & Jensen 1997; Oberhauser 1997; Saha 2001). However, so far, no study has reported forest trees replacing a mature monoculture plantation.

The lack of significant relationship between age of plantations and species richness was surprising because there are studies that reported a positive correlation between the two (e.g., Keenan et al. 1997; Lugo et al. 1993; Oberhauser 1997). This might have happened because the plantations we sampled had a mature stand of trees and accumulated the highest number of species that they could possibly hold, which led to a lack of incremental change in species richness. The relationship between age and species richness is expected in the early years after abandonment of a plantation (Lugo 1992). Alternatively, edaphic and microclimatic factors might have obscured the relationship between age and species richness. The plantations were juxtaposed with remnant moist deciduous and degraded evergreen forests, which were the sources for the establishment of a diverse seedling and sapling community. The low abundance of rodents in these plantations as reported by Chandrasekar-Rao and Sunquist (1996) could be directly related to the high seedling diversity and density, as these may be major seed and seedling predators.

Our findings on regeneration in abandoned mature teak plantations suggest that there is no progressive change in the plant community and the succession of natural moist deciduous forest was arrested. An earlier study in central India showed that teak plantation abandoned within 4–5 years of planting resembled a secondary deciduous forest after 18 years (Saha 2001). The mature teak plantations in our study area were managed for 6–57 years. In our study, one plantation that was managed for 6 years, and later abandoned for 25 years had 25 tree species while, the moist-deciduous forest had 55 tree species. This plantation did not possess a plant community similar to that of the moist-deciduous forests. The differences in the findings of the two studies could be due to any of these reasons: (i) the differences in the growth of teak in the two strikingly different climatic zones, (ii) the greater tree species richness in the moist deciduous forests of southern India, than in the dry deciduous forests of central India, and (iii) the greater role played by anthropogenic pressure in the dry deciduous forests of central India, than in the moist deciduous forests of southern India that are within protected areas.

Our study suggests that there was poor natural regeneration of teak in the plantations. The recruitment of native species into the plantations at the seedling and sapling stage seemed healthy regardless of the age of the plantation. The lack of similarity between seedling and sapling communities within plantations was because of the low proportion of seedling species that were also present in the sapling community. The successful establishment of a species at the seedling level did not ensure its survival to the sapling stage. The sapling composition did not show strong correlations with seedling and tree composition, because the plantations closer to evergreen forests had microclimatic conditions that promoted the growth of evergreen species more and the plantations closer to moist deciduous forests had the microclimatic conditions more suitable for the growth of deciduous species. Even though the plantations had similar seedling communities, the sapling communities, which arose from them, resembled the intact forest that was closest to the plantation. The strong negative correlation between the age of the plantations and the similarity in composition of tree species indicated that the plantations of similar ages had similar tree, sapling and seedling species compositions.

We anticipated that during the last twenty-five years of abandonment, different age classes of native tree species would have established themselves in the plantations. However, there was no significant change in tree species (>20 cm gbh) richness, density and composition. Seedling and sapling species richness decreased rapidly with increasing distance from the edge and then remained constant when the center of the plantation was approached. Therefore, native tree species had little success in penetrating and establishing in the plantations. The regeneration in mature teak plantations in the Anamalais was arrested and their abandonment might not significantly alter the tree species richness and composition.

We found further support for our argument, in the girth-class distribution of three dominant tree species in the forests, where there was a reversal of the pattern in the recruitment at different girth classes. The fewer number of seedlings in the plantations than in the control site may be a result of the reduced seed and seedling predation inside the plantations. The abundance of rodents in the plantations in Anamalais was lower than in the natural forests (Chandrasekar-Rao & Sunquist 1996), but the reasons for this are not clear. Rodents serve as seed and seedling predators, and reduction in their numbers in plantations could be responsible for the high seedling density. The reduction in the relative abundance of larger girth classes of these tree species from the plantations could be attributed to selective extractions in the past and poor recruitment in the larger girth classes. Silvicultural practices prescribe teak trees to be spaced in a manner that there would be 90% of the canopy cover during the entire year, except between January and March, when the teak sheds its leaves. We suspect that this practice used in raising the plantations could be an important factor that suppressed the regeneration of light demanding species.

In our study, we had only one control area, which introduces a problem of insufficiently accounting for the diversity in the control site. Therefore, our results on species richness in the control site are an underestimate. This would not affect our inferences because the species richness, composition and age structure of the trees communities in plantations were starkly different from the control site. Future intensive studies on the biodiversity value of plantations will help us propose management strategies for abandoned teak plantations.

### Use by large herbivores

Elephant signs were more abundant towards the edges of plantations, probably because of lack of palatable vegetation within the plantations. Among the large herbivores that used plantations, sambar was the most abundant. Chital, an important prey species for large carnivores, rarely used the teak plantations. The young plantations had higher density and species richness of seedling and sapling community, which has contributed to greater use of these plantations than the old teak plantations.

## Conclusions

In 1971, after meeting extensive local demand for railroad industry India exported 857 cubic meter of teak. In 1991, there was negligible export and 49,893 cubic meters was imported (Anonymous 1999). The cost of not working teak plantations in protected areas for the benefit of wildlife is considerable for developing nations such as India. The anticipated gain of this measure was improvement of the habitat for wild flora and fauna. However, our study in the Anamalais suggests that succession is arrested in mature teak stand, in spite of high density and species richness of many tree species in its understorey. Therefore, the anticipated gain of improved habitats for wild flora and fauna because of the abandonment of plantation forestry practices in the Anamalais is marginal.

Timber plantations might make an important contribution to biodiversity when degraded lands are put to such land use (Carnus et al. 2006), but not when they are established by replacing native forest (Brockerhoff et al. 2008). When native forests are replaced by mature plantations and given that there has been impoverishment of biodiversity, and the management objective is to preserve biodiversity, what are the options for forest managers? Keenan et al. (1997) listed the various management options for timber plantations: (i) the biodiversity values in plantation should be considered transitory and managed until it is harvested; (ii) change the management objective from production forestry to protection of biodiversity; (iii) carefully thin the plantation to recover the cost of establishing the plantation and then protect for biodiversity; (iv) change to polycyclic silvicular system. In the case of the teak plantations in the Western Ghats, the second option has already been taken up and the results have not been satisfactory in restoring native biodiversity. The first and the fourth options are not applicable considering the legal restrictions imposed on the land use practice. The choice of exercising option three remains open for management.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.baae.2012.01.001.

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