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Evaluating the potential role of *Eucalyptus* plantations in the regeneration of native trees in southern Western Ghats, India

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Abstract: The potential role of *Eucalyptus* plantations in recovering the native tree species regeneration was evaluated in south-western Ghats by comparing 25 year-old (25-EP) and 40 year-old *Eucalyptus* plantations (40-EP) and cleared evergreen forests (CF). Forty non-contiguous quadrats of 10 x 10 m size, totaling 0.4 ha each were randomly established in the 25-EP, 40-EP and the CF to enumerate all the native tree species in adult stage (≥ 10 cm dbh size) and sapling stage (≥ 1 < 10 cm dbh size). Sub-quadrats of 1 x 1 m size at the four corners of 10 x 10 m quadrat were sampled for tree seedlings. The CF had maximum number of native tree species at three states of regeneration (adult, sapling and seedling). Among the *Eucalyptus* plantations, 25-EP had adult species richness little lower than 40-EP, while the tree sapling and seedling diversity in 25-EP were higher than 40-EP. Of the 45 endemic tree species, the CF harbored more endemics (42%) than 25-EP (38%) and 40-EP (39%). Majority of the endemics were climax species (64%) which were dispersed by birds (40%) or mammals (29%). Unlike earlier belief, the *Eucalyptus* plantations in the study area seemed to play a significant role in promoting regeneration of the native tree species and facilitated natural forest succession.

Resumen: Se evaluó el papel potencial de las plantaciones de *Eucalyptus* en la recuperación de la regeneración de especies arbóreas nativas en el sur de los Gates Occidentales, por medio de la comparación de plantaciones de *Eucalyptus* de 25 (25-EP) y de 40 (40-EP) años de edad, y en bosques perennifolios talados (CF). Se establecieron al azar 40 cuadros no contiguos con un tamaño de 10 × 10 m, haciendo un total de 0.4 ha, en las 25-EP, las 40-EP y el CF, donde se enumeraron todas las especies de árboles nativos en estado adulto (≥ 10 cm dap) y juvenil (≥ 1 < 10 cm dap). Las plántulas fueron muestreadas en subcuadros de 1 × 1 m colocados en las cuatro esquinas de los cuadros de 10 × 10 m. El CF tuvo el mayor número de especies arbóreas nativas en los estadios de regeneración (adulto, juvenil y plántula). Entre las plantaciones de *Eucalyptus*, las 25-EP tuvieron una riqueza de especies de adultos un poco menor que las 40-EP, mientras que la diversidad de plántulas y juveniles de árboles en las 25-EP fue mayor que en las 40-EP. De las 45 especies arbóreas endémicas, el CF albergó más endémicas (42%) que las 25-EP (38%) y las 40-EP (39%). La mayoría de los especies endémicas fueron especies clímax (64%) dispersadas por aves (40%) o mamíferos (29%). A diferencia de lo que se pensaba anteriormente, las plantaciones de *Eucalyptus* en el área de estudio parecen tener un papel significativo en la promoción de la regeneración de las especies arbóreas nativas y la facilitación de la sucesión natural del bosque.

Resumo: O papel potencial das plantações de Eucalyptus na recuperação da regeneração de espécies arbóreas nativas foi avaliado no sudoeste dos Ghates comparando plantações de Eucalyptus de 25 anos (25-EP) e de 40 anos (40-EP) e florestas sempreverdes abatidas (CF). Quarenta quadrados não contíguos de 10 x 10 m de lado, totalizando 0,4 ha cada, foram

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estabelecidos casualmente nas 25-EP, 40-EP e nas CF para enumerar todas as espécies nativas arbóreas no estádio adulto (≥ 10 cm de dbh) e no estágio de nascedio (≥ 1 < 10 cm de dbh). Sub-quadrados de 1 x 1 m de lado, nos quatro cantos dos quadrados das parcelas de 10 x 10 m, foram amostrados para as plântulas. As CF apresentavam o número máximo de espécies arbóreas nos três estados de regeneração (adulto, plantio e nascedio). Entre as plantações de Eucalyptus, 25-EP apresentavam uma riqueza específica de espécies adultas ligeiramente mais baixa do que nas 40-EP, enquanto a diversidade de árvores no estádio de plantio e nascedio nas EP-25 era maior do que nas 40-EP. Das 45 espécies arbóreas endémicas, as CF abrigavam mais endemismos (42%) do que 25-EP (38%) e 39% nas 40-EP. A maioria dos endemismos era de espécies clímax (64%) as quais eram dispersos por aves (40%) ou mamíferos (29%). Contrariamente às crenças anteriores, as plantações de *Eucalyptus* na área de estudo pareceu jogar um papel significativo na promoção da regeneração das espécies arbóreas nativas e de facilitar a sucessão florestal natural.

Key words: Cleared evergreen forests, dispersal guilds, endemism, *Eucalyptus* plantations, native trees, regeneration, succession guilds, Western Ghats.

Introduction

It is great concern that the majority of primary wet evergreen forests in the tropics are degraded extensively due to commercial logging for timber and conversion into agricultural lands for shifting cultivation (Whitmore 1997), and consequently they are experiencing severe biodiversity losses, and reverting back to mature state at slower rate with low resiliency (Murphy & Lugo 1986). Such ecological crises in the tropical forests underscore the need for halting all the anthropogenic interventions inside the forests, and restoring the primary forest vegetation in the degraded patches. Tree plantations with fast growing exotics or/and natives are considered as useful long-term management tool for restoring such degraded forests, and also for providing the alternate sources for wood, pulp and fuel that reduce the supply from natural forests (Brown *et al*. 1997; Guariguata *et al*. 1995; Keenan *et al*. 1997; Lamb 1998; Lugo 1997; Parrotta 1992; Parrotta *et al.* 1997). Many studies have confirmed that tree plantations can promote the recovery of natural forests by means of facilitating the regeneration of native pioneer and early successional species under their canopy, and upon which, can catalyze the arrested forest succession (Bone *et al*. 1997; Carnevale & Montagnini 2002; Chapman & Chapman 1996; da Silva Junior *et al.* 1995; Geldenhuys 1997; Haggar *et al*. 1997; Loumeto & Huttel 1997; Lugo 1992; Mathur & Soni 1983; Parrotta *et al.* 1997; Pohjonen & Pukkala 1990; Senbeta & Teketay 2001; Senbeta *et al*. 2002).

In India, *Eucalyptus* plantation was preferred over indigenous trees primarily for the reason of short-term tangible benefits (timber, fuel, fodder, oil and ash), fast growth rate, more productivity per unit area and least post-plantation care (Chaturvedi 1983; Sangha & Jalota 2005). To evaluate the potential role of tree plantations in native species recovery, apart from floristic richness and density (Eshetu 2001; Lemenih *et al.* 2004; Mathur & Soni 1983; Senbeta & Teketay 2001), the functional parameters including succession stage of the plants (Duncan & Chapman 2003; Guariguata *et al*. 1995; Parrotta 1992), presence of wild life (Raman & Sukumar 2002; Wunderle 1997) and plantation age (Loumeto & Huttel 1997; Oberhauser 1997; Senbeta *et al*. 2002), were also considered.

In the Agasthyamalai region of southern Western Ghats of India, Kalakad-Mundanthurai Tiger Reserve (KMTR) (8°25' - 8°53' N latitude and 77°10' - 77°35' E longitude) was established in 1988, merging the Kalakad Wildlife Sanctuary, Mundanthurai Wildlife Sanctuary and later adding the Upper Kodayar and Boothapandi Reserve Forests. It presently covers a total area of ~ 900 km². In Western Ghats, the KMTR and the adjoining ranges in the Agasthyamalai region harbor large undisturbed contiguous tracts of mid-elevation wet evergreen forests (over 400 km^2) (Johnsingh 2001). It is one of the major centres of higher plant diversity and endemism (WCMC 1992), and a haven for close to 2000 plant species out of 3500 in the Western Ghats (Henry *et al.* 1984). More information on floristic diversity, pattern and distribution are found elsewhere (Ganesh *et al.* 1996; Parthasarathy 1999; Parthasarathy & Karthikeyan 1997; Sundarapandian & Swamy 1997).

Over the last century, the extensive mid-elevation wet evergreen forests in KMTR have taken various levels of landscape conversion for the establishment of plantations of tea, coffee, cardamom and *Eucalyptus*, encroachments and reservoirs (Nair 1991). Annual rate of deforestation in the Agasthyamalai region was estimated to be 0.33% during the time interval between 1920 and 1990 with a five-fold increase in forest loss from the periods 1920-1960 to 1960-1990 (Ramesh *et al.* 1997a). Between 1960s and 70s, many good wet evergreen forest patches in the private lands have been clear-felled for the expansion of *Eucalyptus* plantations. The cleared forest patches are always bordered by undisturbed primary wet evergreen forests on either all sides or at least one side. *Eucalyptus* spp. was planted primarily to use the wood logs as fuel source in the tea curing industry. Many such plantations were not allowed to cut, and left abandoned upon legal tussle between private tea estate management and Forest department regarding land ownership in the later years. Some clear-felled forests were abandoned and left undisturbed without any plantations for natural regeneration. Ganesan & Davidar (2003) studied the effects of logging on tree diversity and regeneration in the KMTR region of southern Western Ghats. There have not been any previous studies on native tree species regeneration under *Eucalyptus* plantations in the southern Western Ghats.

This paper attempts to evaluate the potential role of *Eucalyptus* plantations in facilitating the native tree species regeneration, comparing 25 year-old *Eucalyptus* plantations (25-EP) and 40 year-old *Eucalyptus* plantations (40-EP) with cleared evergreen forests (CF) for (1) native tree diversity and density in three regeneration stages *viz.* adult, sapling and seedling and their distribution across succession and dispersal guilds; (2) nature of occurrence of native trees and their distribution across succession and dispersal guilds; (3) endemic native trees in three regeneration stages; (4) relationship between tree saplings and seedling diversity and density and adult tree diversity and density; (5) relationship between diversity and density of tree sapling and seedling and standing *Eucalyptus* density. The outcome of the study will help India's Forest department in silvicultural management of the protected areas.

Materials and methods

Study area

This study was carried out in and around Nalmukku and Kakachi area (77°24' E; 8°32' N) of KMTR at an altitude between 1250 m and 1550 m (Fig. 1). The study sites are covered by contiguous tracts of mid-elevation wet evergreen forests, which are identified as *Cullenia exarillata-Aglaia bourdillonii-Palaquium elipticum* type on the basis of dominance (Ganesh *et al.* 1996). The average annual precipitation recorded at Nalmukku tea estate was between 150 cm and 340 cm with minimum of 20 cm rainfall per month. The mean maximum and minimum temperatures are 24°C and 16°C respectively with two dry seasons between southwest (June-August) and northeast monsoons (October-December).

Field data collection

Sampling plots were established in the 25 year-old (25-EP) and the 40 year-old *Eucalyptus* plantations (40-EP) and the cleared evergreen forests (CF). Forty non-contiguous quadrats of 10 x 10 m size, located at least 50 m apart, totaling the area of 0.4 ha each in 25-EP and 40-EP and CF were randomly established to study the vegetation. The field data collection was made between October 2004 and April 2005. All trees equal or greater than 1 cm diameter at breast height (dbh; 1.3 m height from ground level) in the 10 x 10 m quadrats were enumerated. Each stem girth was taken separately and summed for basal area calculation in case of multi-stemmed trees. Trees of ≥ 10 cm dbh size were considered as adults and less than 10 cm as tree saplings. To enumerate the seedlings of native trees, sub-quadrats of 1 x 1 m size at the four corners of 10 x 10 m quadrat were sampled. All plants were identified and confirmed to species in the field, but in doubtful cases

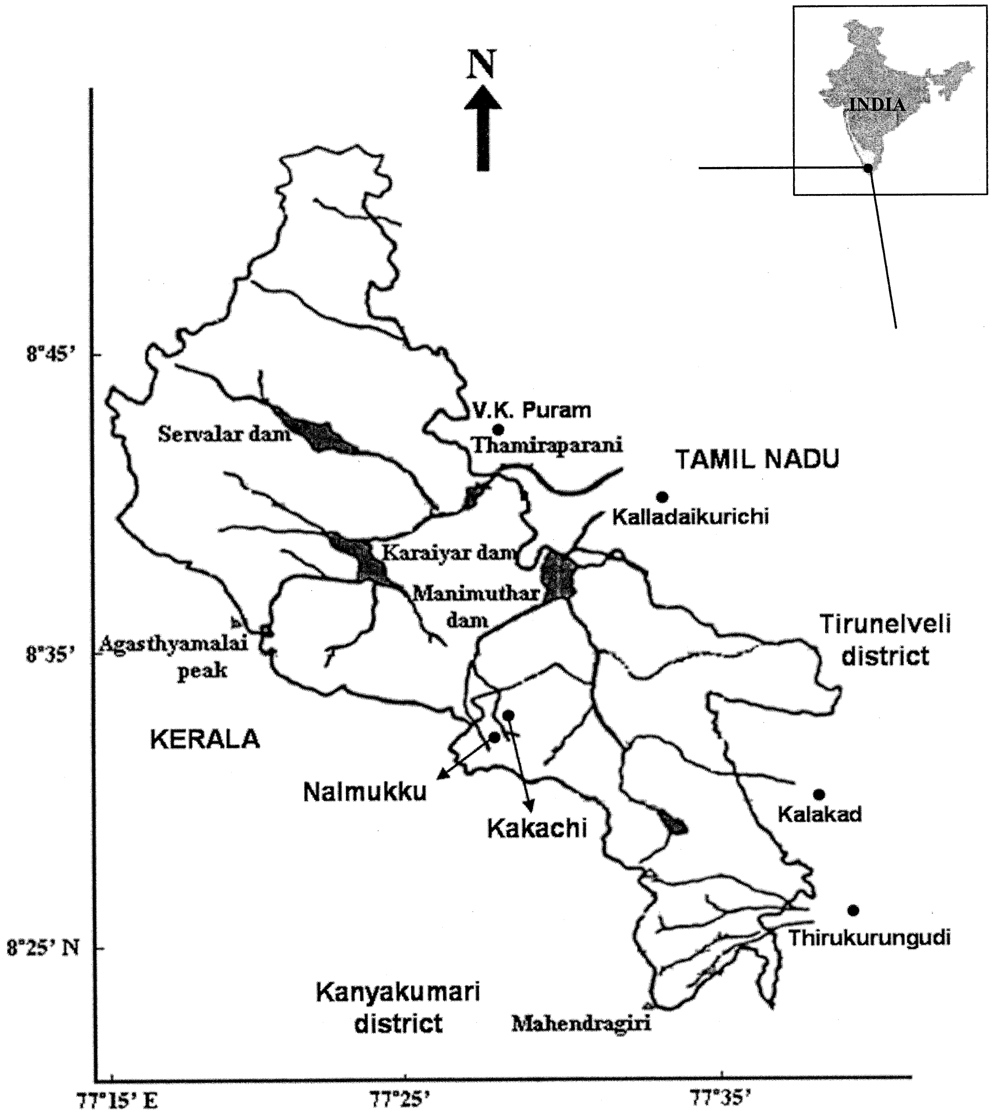

Fig. 1. Location of study sites in the map of Kalakad-Mundanthurai Tiger Reserve (KMTR) in southern Western Ghats of India.

specimens were collected for confirmation of identification later at the camp site with aid of earlier herbarium collections and regional floras (Gamble & Fischer 1915-1935; Pascal & Ramesh 1987).

Data analysis

Based on the succession stage to which species belongs, each species was assigned to one of the three succession guilds such as pioneer, secondary and climax. Various modes of dispersal *viz.* anemochory, autochory, bird, bird/mammal and mammal were assigned to each species following the literature (Ganesh & Davidar 2001) and considering the fruit traits (van der Pijl 1982). Enumerated species were examined for endemism referring pertinent literatures (Ahmedullah & Nayar 1986; Ramesh *et al.* 1997b) and list of species endemic to Western Ghats from the study sites was prepared. One-way ANOVA was used to analyse the degree of variation in tree species diversity and density across 25-EP, 40-EP and cleared evergreen forests in three regeneration stages. To examine the independence of succession and dispersal guilds, and *Eucalyptus* plantations and cleared evergreen forests with respect to native tree species composition, *G*-test was performed. Correlation coefficient was used to examine the influence of native adult trees and standing *Eucalyptus* trees on regeneration relating the diversity and density of tree saplings and seedlings with diversity and density of adult trees, and with density of *Eucalyptus* trees.

Results and discussion

Native tree diversity and stand structure

In the forty sampling plots each in 25 year-old *Eucalyptus* plantations (25-EP), 40 year-old *Eucalyptus* plantations (40-EP) and cleared evergreen forests (CF) studied, a total of 112 tree species in 77 genera and 40 families was enumerated in three regeneration stages (Appendix Table 1). The recorded number of native tree species was 64 (52 genera) in 25-EP and 58 (45 genera) in 40-EP, while CF registered 100 species (70 genera) (Table 1). Dominant families with high species richness include Lauraceae (19), Myrtaceae (13) and Euphorbiaceae (10). The native tree species richness and density in three regeneration stages: adult (≥ 10 cm dbh), sapling (≥ 1 < 10 cm dbh) and seedling were compared between the *Eucalyptus* plantations and cleared evergreen forests.

The adult tree (≥ 10 cm dbh) diversity was less

Table 1. A brief account on tree species diversity and dominant species in adult, sapling and seedling stage in the *Eucalyptus* plantations and cleared evergreen forests in southern Western Ghats, India.

Attributes	*Eucalyptus* plantations		Cleared evergreen forest
	25 years	40 years	
No. of tree species	64	58	100
No. of genera	52	45	70
No. of family	31	26	37
Adult tree (≥ 10 cm dbh)			
No. of species (indls)	25 (450)	27 (374)	62 (380)
Stand basal area	3.25 m^2 0.4 ha^{-1}	2.89 m^2 0.4 ha^{-1}	11.92 m^2 0.4 ha^{-1}
Dominant species (% in total no. of individuals)	*Eucalyptus* (70%), Lit wig (6%), Cle vis (3%), Ela mun (3%)	*Eucalyptus* (70%), Lit wig (8%), Acr ped (3%), Mac pel (3%)	Lit wig (23%), Acr ped (10%), Mac pel (7%), Sym coc (4%)
Tree sapling (≥ 1 < 10 cm dbh)			
No. of species (indls)	54 (1472)	47 (1588)	88 (1915)
Dominant species (% in total no. of individuals)	Cle vis (41%), Lit wig (13%), Mae ind (11%), Syz car (5%)	Cle vis (30%), Mae ind (20%), Acr ped (11%), Cal tom (11%)	Rap wig (12%), Acr ped (7%), Lit wig (6%), Cle vis (5%)
Tree seedling			
No. of species (indls)	39 (268)	36 (431)	58 (551)
Dominant species (% in total no. of individuals)	Lit wig (13%), Mae ind (10%), Cle vis (10%), Ela mun (10%)	Sym coc (18%), Lit wig (15%), Cle vis (14%), Acr ped (7%)	Sym coc (31%), Lit wig (8%), Tri api (8%), Rap wig (5%)

Species: Lit wig - *Litsea wigtiana*; Cle vis - *Clerodendrum viscosum*; Ela mun – *Elaeocarpus munronii*; Acr ped – *Acronychia pedunculata*; Mac pel – *Macaranga peltata*; Sym coc – *Symplocos cochinchinensis*; Mae ind – *Maesa indica*; Syz car – *Syzygium caryophyllum*; Cal tom – *Callicarpa tomentosa*; Rap wig – *Rapanea wightiana*; Tri api – *Tricalysia apiocarpa* in 25-EP (25 species) and 40-EP (27 species) comparing CF (62 species) (Table 1). The maximum adult tree density was recorded in 25-EP (450) followed by CF (380) and 40-EP (374). The contribution of *Eucalyptus* spp. towards total stem density in 25-EP and 40-EP was 70% each. Mean dbh of the native adult trees was 17.35 cm (± 8) in CF, 15.70 cm (± 6.8) in 25-EP and 15.91 cm (± 8.4) in 40-EP. The native tree basal area was maximum in CF (11.92 m^2 0.4 ha^{-1}) followed by 25-EP (3.25 m^2 0.4 ha^{-1}) and 40-EP (2.89 m^2 0.4 ha^{-1}), while *Eucalyptus* spp. had maximum basal area in 25-EP (16.22 m^2 0.4 ha^{-1}) than in 25-EP (13.32 m^2 0.4 ha^{-1}). Other dominant native adult tree species in the *Eucalyptus* plantations and cleared evergreen forests were *Litsea wightiana*, *Acronychia pedunculata*, *Macaranga peltata*, *Clerodendrum viscosum*, *Elaeocarpus munronii* and *Symplocos cochinchinensis*, contributed not less than 3% of the total stem density. The proportion of adult tree species with single occurrence (unique species) was more in 40-EP (52%) followed by 44% in 25-EP and 37% in CF, while similar pattern was also found in the proportion of species represented with single individual (44% each in 40-EP and 25-EP and 32% in CF).

The cleared evergreen forests had maximum tree sapling diversity (88) and density (1915), while in the *Eucalyptus* plantations, it was 54 species with 1472 individuals in 25-EP and 47 species with 1588 individuals in 40-EP (Table 1). The enumeration of native tree seedlings in sub-quadrats of 1 x 1 m size at the four corners of 100 m^2 quadrat yielded minimum of 36 species with 431 individuals in 40-EP and 39 with 268 individuals in 25-EP to the maximum of 58 species with 551 individuals in CF (Table 1). The proportion of tree species with single occurrence in sapling stage was 35%, 21% and 20% respectively in 25-EP, 40-EP and CF, while in tree seedlings, it was 41%, 31% and 40% in 25-EP, 40-EP and CF respectively. Interestingly, there were no saplings and seedlings of *Eucalyptus* spp. in the *Eucalyptus* plantations and cleared evergreen forests. The common native trees species in sapling and seedling stages were *Clerodendrum viscosum*, *Litsea wightiana*, *Maesa indica*, *Elaeocarpus munronii*, *Acronychia pedunculata* and *Symplocos cochinchinensis* in the *Eucalyptus* plantations, and *Rapanea wightiana*, *Litsea wightiana*, *Symplocos cochinchinensis* and *Tricalysia apiocarpa* in the cleared evergreen forests. The results of one-way ANOVA revealed that tree species diversity and density were differed significantly across 25-EP, 40-EP and cleared evergreen forests in three regeneration stages (Table 2).

In three regeneration stages, the proportion of native tree species with single occurrence became high as species diversity increases, while the reduction of species with single individual was found as stem density increases. Morisita-Horn index measuring the species similarity (1.0 indicates total similarity) among the CF plots was minimal in three regeneration stages: adult (0.317), sapling (0.255) and seedling stage (0.155). In the *Eucalyptus* plantations, species similarity among the plots declined from adult (0.803 in 25-EP; 0.812 in 40-EP) to sapling (0.479 in 25-EP; 0.538 in 40-EP) and seedling stage (0.164 in 25-EP; 0.244 in 40-EP). Greater heterogeneity in the native tree species composition was prevailed among the plots in the *Eucalyptus* plantations and cleared evergreen forests in sapling and seedling stages, indicating the new recruitment of many native tree species in the sapling and seedling stages.

The recorded native woody species diversity under the *Eucalyptus* plantations in KMTR is in conformity with other studies (da Silva Junior *et al*. 1995; Eshetu 2001; Lemenih *et al*. 2004; Loumeto & Huttel 1997; Mathur & Soni 1983; Michelsen *et al*. 1996; Senbeta & Teketay 2001; Senbeta *et al*. 2002) and underline the potential role of *Eucalyptus* plantations in restoring the native woody tree species. The native adult tree (≥10 cm dbh) diversity in a study area of 0.8 ha in

Table 2. One-way ANOVA results showing the variations in tree species and density across *Eucalyptus* plantations and cleared evergreen forests in three regeneration stages.

Regeneration stage	One-way ANOVA (*F* value)	
	Diversity	Density
Adult	30.95** a, b	3.23*
Sapling	50.98** a, b	3.31* a
Seedling	5.55** a	6.54** a

* = <0.05, ** = <0.001, a – Cleared evergreen forests Vs 25 years-old *Eucalyptus* plantations, b – Cleared evergreen forests Vs 40 years-old *Eucalyptus* plantations, c – 25 years-old *Eucalyptus* plantations Vs 40 years-old *Eucalyptus* plantations.

the *Eucalyptus* plantations was 36 species, and comparable to the adjacent undisturbed primary wet evergreen forests at Kakachi, which registered 31, 36 and 48 tree species in three transects of 0.5 ha each (Ganesh *et al.* 1996). The high recovery of native tree species under plantations may be attributed to (a) buried seeds (seed bank) in the top soil that germinate and colonize in the condition of more light availability and enough radiation after forest clearance for raising the plantations (Bellairs & Bell 1993; Hopkins & Graham 1984) (b) vicinity of the natural forests as seed source, facilitates regeneration of native species and increases the proportion of saplings and seedlings without adult representation (Keenan *et al.* 1997; Loumeto & Huttel 1997; Senbeta & Teketay 2001; Wunderle 1997); (c) increasing of soil nutrients following clearing and plantation establishment (Prescott 1997; Smethurst & Nambiar 1990).

Native trees in succession guilds

Around 54% of the total native tree species inventoried in the *Eucalyptus* plantations and cleared evergreen forests, was climax species (60 species). The maximum proportion of climax species was obtained in CF (54%) followed by 25-EP (52%) and 40-EP (49%). In cleared evergreen forests, the proportion of climax species was recorded high in three regeneration stages (Fig. 2). In the *Eucalyptus* plantations, proportion of pioneer species was slightly higher than the secondary and climax species among the trees in adult stage, whereas in sapling stage, more proportion of climax species was found. In seedling stage, the greater proportion of secondary species in 25-EP and equal proportion of secondary and climax species in 40-EP were noticed. In terms of stem density, the pioneer species was dominant in the *Eucalyptus* plantations and cleared evergreen

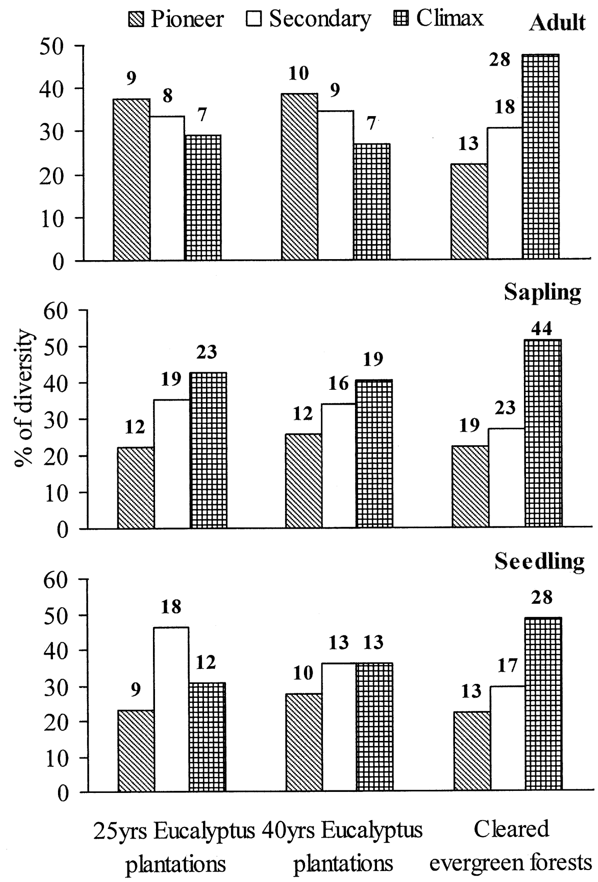

Fig. 2. Percentage of native tree species diversity (number of species is given above the bar) in three succession guilds across *Eucalyptus* plantations and cleared evergreen forests in three regeneration stages.

forests in three regeneration stages. *G*-test showed no significant difference in number of tree specie in three succession guilds between the *Eucalyptus* plantations and cleared evergreen forests in three regeneration stages, but in the case of species density, it was significantly varied as pioneer species in 25-EP and 40-EP and climax species in

Table 3. *G*-test results showing the independency in occurrence of tree species and density in the *Eucalyptus* plantations and cleared evergreen forests with respect to succession and dispersal guilds in three regeneration stages.

Variables	Succession guilds (λ value; df = 4)				Dispersal guilds (λ value; df = 8)			
	Adult	Sapling	Seedling	Sap & Seed#	Adult	Sapling	Seedling	Sap & Seed#
Diversity	5.14	2.07	4.08	5.92	4.76	2.89	4.43	4.56
Density	32.1**	1118***	69.5**	240***	13.1*	437***	69.0**	163***

Species found only in sapling and seedling stages without adult trees, *P<0.05; **P<0.01; ***P<0.0001.

CF had maximum representation (Table 3).

Native trees in dispersal guilds

Overall, zoochory was the common mode of dispersal among trees in the *Eucalyptus* plantations and cleared evergreen forests, in which bird dispersal (38%) had greater proportion in total species diversity, followed by mammal (26%) and bird/mammal (25%). In three regeneration stages, the proportion of tree species in the *Eucalyptus* plantations and cleared evergreen forests dispersed by birds was high among other dispersal modes (Fig. 3). The smaller percentage of autochorous tree species in the *Eucalyptus* plantations and cleared evergreen forests was found in adult, sapling and seedling stages. The two anemochory species, *Vernonia peninsularis* in

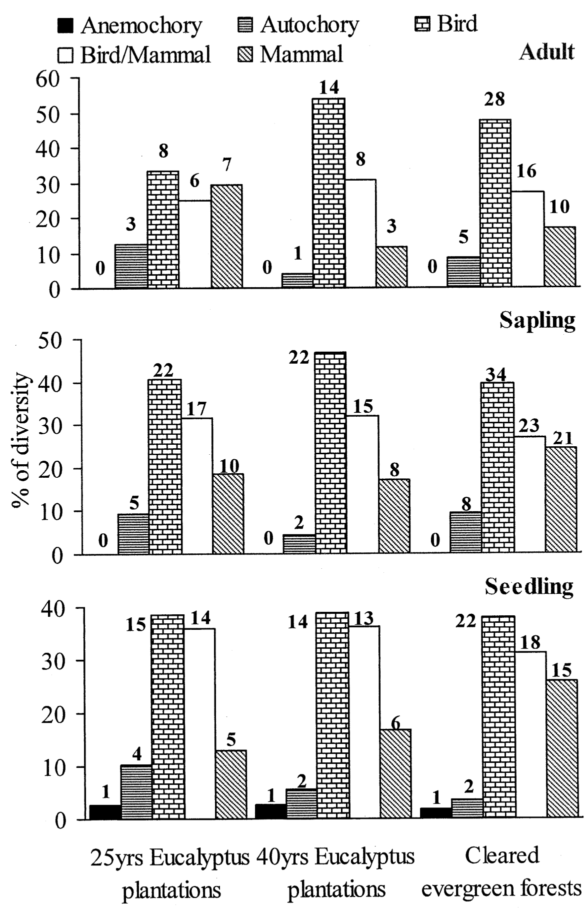

Fig. 3. Percentage of native tree species diversity (number of species is given above the bar) in five dispersal guilds across *Eucalyptus* plantations and cleared evergreen forests in three regeneration stages.

the *Eucalyptus* plantations and *V. travancorica* in the cleared evergreen forests were recorded only in seedling stage. Birds were the main seed dispersers among pioneer (43%) and secondary tree species (50%), while climax species (42%) were dispersed primarily by mammals. The bird-dispersed tree species had greater stem density in adult and sapling stage, whereas bird/mammal dispersal dominated the tree stand in seedling stage in the *Eucalyptus* plantations and cleared evergreen forests. *G*-test resulted that the number of native tree species in five dispersal guilds was same between the *Eucalyptus* plantations and cleared evergreen forests in three regeneration stages, whereas it differed in species density (Table 3).

The bird dispersed tree species was common in the *Eucalyptus* plantations and cleared evergreen forests in three regeneration stages. A similar pattern was also reported in the nearest undisturbed wet evergreen forests at Kakachi in KMTR, wherein about 59% of the total 82 tree species was dispersed by birds, primarily Black Bulbul (*Hypsipetes leucocephalus*), Yellow-browed Bulbul (*Iole indica*), Red-whiskered Bulbul (*Pycnonotus jocosus*) and White-cheeked Barbet (*Megalaima viridis*) (Ganesh & Davidar 2001). These small frugivory birds had frequent detections in the *Eucalyptus* plantations of the present study, as they were left abandoned for a longer period without any major human interventions, and adjacent to the undisturbed wet evergreen forests (Raman & Sukumar 2002). Mammal dispersal accounted for 28% and 26% of native tree species in the *Eucalyptus* plantations and cleared evergreen forests respectively. Among mammals, civets and bats were the common, and together dispersed 67% of the mammal dispersed species in the nearest undisturbed wet evergreen forests at Kakachi in KMTR (Ganesh & Davidar 2001). The mammal dispersed tree species had greater proportion in the sapling and seedling stages, as standing adult trees provided structurally complex habitat supporting seed dispersers (Wunderle 1997).

Nature of tree occurrence

About 38% (42 species) of the total native tree species enumerated, was found only in sapling and seedling stages without representation in adult stage and the proportion was high in 25-EP (61%)

Table 4. Number of native tree species recorded in their nature of occurrence with respect to three regeneration stages in the *Eucalyptus* plantations and cleared evergreen forests.

Nature of occurrence	Number of tree species (% in total species)		
	Eucalyptus plantations		Cleared evergreen forests
	25 years	40 years	
Adult only	2 (3%)	4 (7%)	7 (7%)
Sapling only	15 (23%)	12 (21%)	16 (16%)
Seedling only	7 (11%)	6 (10%)	4 (4%)
Adult & sapling	7 (11%)	5 (9%)	18 (18%)
Adult & seedling	0 (0%)	0 (0%)	0 (0%)
Seedling & sapling	17 (27%)	13 (22%)	18 (18%)
Adult, sapling & seedling	15 (23%)	17 (29%)	36 (36%)

followed by 40-EP (53%) and CF (38%) (Table 4). Many species belonged to the category of sapling and seedling stage without adult trees, were climax species (28 species, 67%) (Fig. 4) and mainly dispersed by mammal (15 species, 36%) and birds (15 species, 36%) (Fig. 5). Out of 13 pioneer species in the *Eucalyptus* plantations, only two species, *Antidesma menasu* and *Miliusa wightiana* were found in the sapling and the seedling stages without adult representation. The proportion of species present in all three regeneration stages was 23%, 29% and 36% in 25-EP, 40-EP and CF respectively (Table 4). Around 53% of the climax species (32 species) in the *Eucalyptus* plantations and cleared evergreen forest had presence in adult stage, while 19 climax species represented in all three regeneration stages. Majority of the secondary species (22 species, 73%) had adult trees and the bird dispersal was common among them. The *Eucalyptus* plantations had less species diversity and density of tree saplings and seedlings than the cleared evergreen forests, but the proportion of species found only in sapling and seedling stages without adult representation was more in the *Eucalyptus* plantations. The results of *G*-test revealed that the diversity of species in sapling and seedling stages without adult trees was independent of succession and dispersal guilds across *Eucalyptus* plantations and cleared evergreen forests, whereas the species density was varied significantly across succession and dispersal guilds (Table 3).

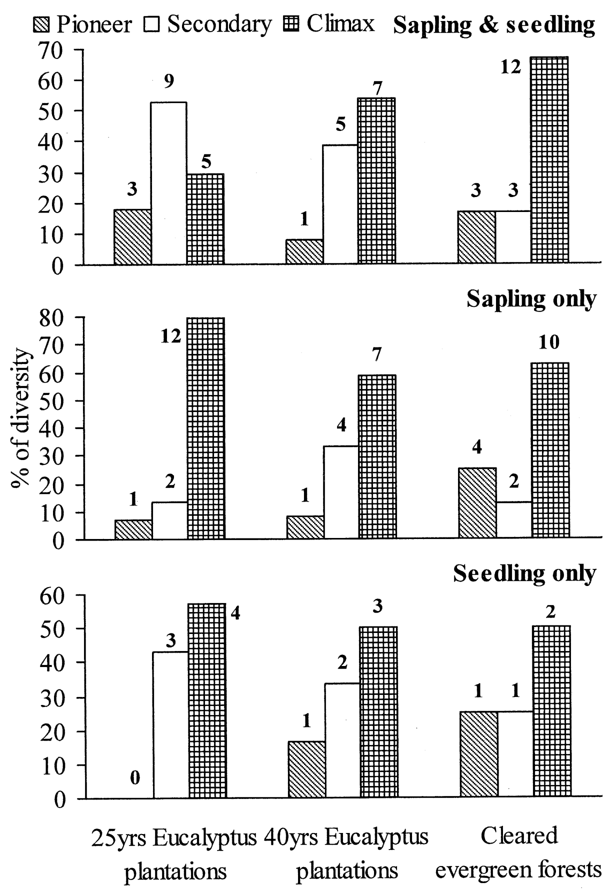

Fig. 4. Percentage of native tree species diversity (number of species is given above the bar) in three succession guilds across *Eucalyptus* plantations and cleared evergreen forests with respect to the species recorded in sapling only, seedling only and sapling and seedling stages.

Plantation age on native trees regeneration

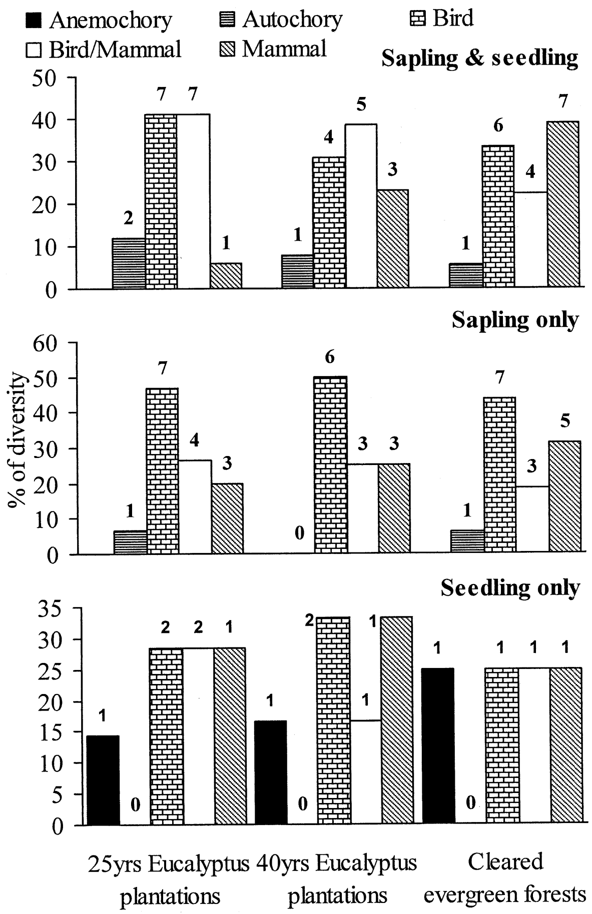

Fig. 5. Percentage of native tree species diversity (number of species is given above the bar) in five dispersal guilds across *Eucalyptus* plantations and cleared evergreen forests with respect to the species recorded in sapling only, seedling only and sapling and seedling stages.

In this study, plantation age had little influence on tree species diversity and density. There was an increase of tree species richness in adult stage (8%, 2 species) from 25-EP to 40-EP, whereas in sapling and seedling stages, tree diversity was maximum in 25-EP (15%, 7 species) than 40-EP (8%, 3 species). The number of individuals in sapling and seedling stages has increased from 25-EP to 40-EP, but the reverse pattern was noticed in the tree density in adult stage. The statistical analysis proved no significant difference between the 25-EP and the 40-EP with respect to tree diversity and density in three regeneration stages (Table 2). An increase in native woody species diversity was observed with increasing plantation age (Senbeta *et al.* 2002; Oberhauser 1997), and it was not the case in this study with an exception of tree species in adult stage. Oberhauser (1997) attributed that increasing gaps due to partial removal and cutting of plantation trees in the older stands encourage woody species colonization under their canopy. To support this, 40-EP had 263 *Eucalyptus* trees with 6.57 average and 13.32 m^2 0.4 ha^{-1} basal area, which was less than that of *Eucalyptus* trees in 25-EP (315 individuals with 7.88 average and 16.22 m^2 0.4 ha^{-1} basal area). It was also reported that the native stems become dense as plantations age increases, particularly noticeable after 10 years (Geldenhuys 1997; Keenan *et al.* 1997; Parrotta 1999). Similar pattern was evidenced in the density of tree saplings and seedlings, that increased from 25-EP to 40-EP.

Endemism in native trees

Of the 112 tree species encountered, 45 species were endemic to Western Ghats region. Around 40% of the tree species in three regeneration stages in the *Eucalyptus* plantations and cleared evergreen forests were endemics, while 63% endemism was reported among the evergreen tree species of the Western Ghats of India (Ramesh *et al.* 1997b). Families such as Lauraceae (12), Myrtaceae (6) and Meliaceae (4) constituted larger number of endemic species. The CF harbored more number of endemic tree species (42 species, 42%) than 25-EP (24 species, 38%) and 40-EP (23 species, 39%). In three regeneration stages, the proportion of endemic tree species was high among tree seedlings (49%) followed by tree saplings (41%) and adults (39%) (Fig. 6). There were 16 endemic species that occurred only in the CF, while 3 species occurred only in the *Eucalyptus* plantations. Majority of the endemics were climax species (64%), and dispersed by birds (40%) and mammals (29%). Out of 45 endemic species, 18 (40%) were found only in the sapling and seedling stages without adult trees. Species such as *Litsea wightiana*, *Rapanea wightiana*, *Tricalysia apiocarpa*, *Elaeocarpus munronii*, *Aglaia bourdillonii* and *Cinnamomum filipedicellatum* were the dominant endemic tree species in *Eucalyptus* plantations and cleared evergreen forests. The proportion of endemic tree species in three regeneration stages across the *Eucalyptus* plantations and cleared evergreen forests was

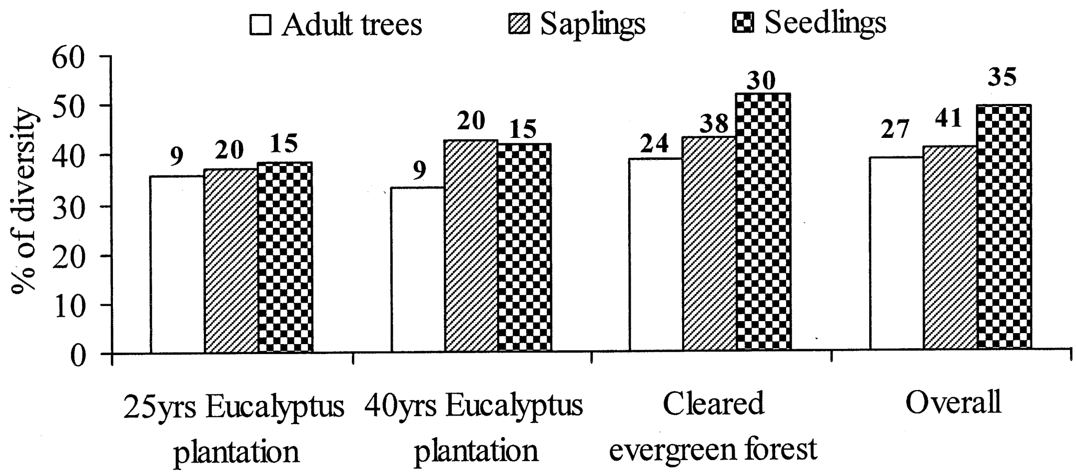

Fig. 6. Percentage of endemic (to Western Ghats) tree species diversity (number of species is given above the bar) in three regeneration stages across *Eucalyptus* plantations and cleared evergreen forests.

almost the same (Fig. 6) and *G*-test also revealed no significant difference.

Influence of standing adults & Eucalyptus *on regeneration*

In 25 year-old *Eucalyptus* plantations, the correlations between adult trees and tree saplings revealed that adult tree species diversity and density was found to influence more number of sapling species diversity, but reduce the sapling density (Table 5). The diversity and density of tree seedlings in 25-EP had significant negative correlation with adult tree diversity and density and positive correlation with *Eucalyptus* stem density. It showed that native tree seedling species and density in the quadrats of 25-EP increased with increasing number of *Eucalyptus* spp. individuals, and with decreasing adult tree species and density. In 40 year-old *Eucalyptus* plantations, there was no significant correlation found between diversity and density of adult trees and diversity and density of tree seedlings and saplings, however, there was a negative correlation between diversity and density of native adult trees and saplings. No significant correlations were found between standing adults and regeneration stages in the cleared evergreen forests. The reduced regeneration potential and high adult:sapling ratio with less adult density have been attributed for poor regeneration among dominant climax tree species in the selective and clear-felled forests as compared to unlogged forests at Kakachi in KMTR (Ganesan & Davidar 2003). In this study, the low adult:sapling and adult:seedling ratio revealed more recruitment of tree sapling and seedling density in the *Eucalyptus* plantations and cleared evergreen forests.

Conclusions

The potential role of *Eucalyptus* plantations in recovering the native tree species under their canopy has been studied comparing the cleared evergreen forests through evaluation of succession status of the tree species, modes of seed dispersal, nature of species occurrence in three regeneration stages: adult, sapling and seedling and endemism, apart from floristic richness and density. If *Eucalyptus* plantations are left undisturbed for a period of time, it can recover the native species, and accelerate the natural succession processes at faster rate by providing complex habitat that increases the seed movement from the surrounding forests by attracting more dispersal agents. The *Eucalyptus* plantations in a total area of 0.8 ha contained 79 tree species in three regeneration stages; adult, sapling and seedling, in which 54% were climax species, and 37% were endemics. The large contiguous wet evergreen forests, known for its rich plant biodiversity and high endemism in the vicinity would be the important seed sources, besides, buried soil seed bank. The plantation age had little influence on

Table 5. Correlation results showing the relationship between diversity and density of adult trees and diversity and density in sapling and seedling stage, and the relationship between the *Eucalyptus* density and tree diversity and density in sapling and seedling stage in the *Eucalyptus* plantations and cleared evergreen forests.

Variables	*Eucalyptus* plantations (*r*)		Cleared evergreen forest (*r*)
	25 years	40 years	
Adult & Sapling			
Diversity vs. diversity	0.433**	-0.184	0.084
Diversity vs density	-0.451**	-0.164	-0.215
Density vs diversity	0.494**	-0.177	0.079
Density vs density	-0.429**	-0.098	-0.037
Adult & Seedling			
Diversity vs diversity	-0.443**	0.061	-0.005
Diversity vs density	-0.441**	0.135	-0.05
Density vs diversity	-0.449**	0.01	-0.101
Density vs density	-0.467**	0.06	-0.031
Eucalyptus & Sapling			
Density vs diversity	-0.276	0.272	-
Density vs density	0.208	0.076	-
Eucalyptus & Seedling			
Density vs diversity	0.315*	0.046	-
Density vs density	0.337*	-0.129	-

*P<0.01; **P<0.001.

tree species diversity and density, as there was no significant difference between the 25-EP and the 40-EP in three regeneration stages. It implies that there are less chances of increase in native tree diversity, when the plantations are left without coppicing for a longer period. Our results could not provide any clue to determine the age at which plantations can be coppiced, because only two age-class plantations (25 and 40 years) were compared. While the influence of factors like the distance from the contiguous forests, tree canopy height and cover, site (altitude and irradiance) and soil characters and other disturbances etc. in the regeneration of native tree species cannot be ignored and need further investigation. However, understanding on ecological and conservation significance value of *Eucalyptus* plantations in regenerating the native tree species, and facilitating the natural forest succession would definitely be helpful in the silvicultural management of plantations without compromising their economic value.

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Appendix Table 1. List of tree species recorded and their nature of occurrence in three regeneration stages (Ad, Adults; Sa, Saplings; Se, Seedlings) in the *Eucalyptus* plantations and cleared evergreen forests in southern Western Ghats, India. (Species endemic to Western Ghats are in bold).

Tree species	Family	*Eucalyptus* Plantation		Cleared evergreen forest
		25 years	40 years	
Acronychia pedunculata (L.) Miq.	Rutaceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Actinodaphne bourdillonii **Gamble**	Lauraceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Actinodaphne campanulata **Hook. f.**	Lauraceae			Sa
Aglaia bourdillonii **Gamble**	Meliaceae		Sa	Ad,Sa,Se
Aglaia indica **(Hook. f.) Harms**	Meliaceae		Se	Sa,Se
Aglaia jainii **Viswa. & Ramachan.**	Meliaceae			Sa
Aglaia lawii **(Wight) Saldanha**	Meliaceae		Sa,Se	
Agrostistachys borneensis Becc.	Euphorbiaceae			Ad,Sa
Aleurites moluccana (L.) Willd.	Euphorbiaceae	Ad		
Antidesma menasu (Tul.) Miq.ex Muell.-Arg.	Stilaginaceae	Sa	Sa,Se	Ad,Sa,Se
Aphanamixis polystachya (Wall.) Parker	Meliaceae			Ad,Sa,Se
Apollonias arnottii **Nees**	Lauraceae			Sa,Se
Artocarpus heterophyllus Lam.	Moraceae	Ad,Sa,Se		Ad,Sa
Beilschmiedia wightii **(Nees) Benth. ex Hook. f.**	Lauraceae	Se	Se	Sa,Se
Calicarpa tomentosa (L.) Murr.	Verbenaceae		Ad,Sa	Ad,Sa
Calophyllum austroindicum **Kosterm. ex Stevens**	Clusiaceae		Sa	Ad,Sa,Se
Canthium dicoccum (Gaertn.) Teijsm & Binn.	Rubiaceae		Sa	Ad,Sa
Casearia ovata (Lam.) Willd.	Flacourtiaceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Celtis tetrandra Roxb.	Ulmaceae	Ad,Sa	Sa,Se	
Cinnamomum filipedicellatum **Kosterm.**	Lauraceae	Sa,Se	Ad,Sa,Se	Sa,Se
Cinnamomum sulphuratum **Nees**	Lauraceae	Ad,Sa,Se	Ad,Sa	Ad,Sa,Se
Cinnamomum travancoricum Gamble	Lauraceae	Sa	Sa	Ad,Sa,Se
Clerodendrum viscosum Vent.	Verbenaceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Croton laccifer L.	Euphorbiaceae	Ad,Sa,Se		Sa
Croton zeylanicus Muell.-Arg.	Euphorbiaceae			Sa,Se
Cryptocarya bourdillonii **Gamble**	Lauraceae	Sa	Sa,Se	Ad,Sa,Se
Cryptocarya lawsonii Gamble	Lauraceae		Sa	Sa
Cullenia exarillata **A. Robyns**	Bombacaceae	Ad,Sa	Ad	Ad,Sa,Se
Daphniphyllum neilgherrense (Wight) K. Rosenth.	Daphniphyllaceae	Sa		
Dimocarpus longan Lour.	Sapindaceae			Ad
Diospyros foliolosa **Wall. ex DC.**	Ebenaceae			Sa,Se
Diospyros malabarica (Desr.) Kostel.	Ebenaceae	Se	Se	
Diospyros sylvatica Roxb.	Ebenaceae	Sa,Se	Sa,Se	Sa,Se
Ehretia wightiana **Wall. ex G. Don**	Boraginaceae	Sa	Sa	Ad,Sa,Se
Elaeocarpus munronii **(Wt.) Mast.**	Elaeocarpaceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa
Elaeocarpus serratus L.	Elaeocarpaceae	Sa,Se	Sa	Ad,Sa,Se
Epiprinus mallotiformis (Muell.-Arg.) Croizat	Euphorbiaceae			Ad,Sa

Contd…

Appendix Table 1. Continued

Tree species	Family	*Eucalyptus* Plantation		Cleared evergreen forest
		25 years	40 years	
Erythroxylum moonii Hochr.	Erythroxylaceae			Ad,Sa
Erythroxylum obtusifolium (Wight) Hook. f.	Erythroxylaceae	Sa	Se	
Eucalyptus sp.	Myrtaceae	Ad	Ad	Ad
***Eugenia floccosa* Bedd.**	Myrtaceae	Sa	Sa	
***Eugenia mooniana* Gardner**	Myrtaceae			Ad,Sa,Se
Eugenia sp.	Myrtaceae			Sa
***Eugenia thwaitesii* Duthie**	Myrtaceae			Sa,Se
Eurya nitida Korth.	Theaceae	Sa,Se	Ad,Sa,Se	
Fagraea ceilanica Thunb.	Loganiaceae	Ad,Sa	Sa	
Ficus hispida L. f.	Moraceae		Sa,Se	
Glochidion fagifolium Bedd.	Euphorbiaceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa
Gomphandra coriacea Wight	Icacinaceae	Ad,Sa	Ad,Sa,Se	
***Goniothalamus wightii* Hk. f. & Thoms.**	Annonaceae	Sa		
***Gordonia obtusa* Wall. ex Wight & Arn.**	Theaceae	Sa	Ad,Sa	
Helicia travancorica Bedd. ex Hook. f.	Proteaceae	Sa	Sa	Sa,Se
***Holigarna nigra* Bourd.**	Anacardiaceae			Ad
***Hydnocarpus alpina* Wight**	Flacourtiaceae	Ad		Ad,Sa,Se
Ixora sp.	Rubiaceae			Sa
Kirgnalia reticulata Baill.	Euphorbiaceae	Sa,Se	Se	
Ligustrum perrottetii DC.	Oleaceae	Sa,Se	Sa,Se	Ad,Sa,Se
***Litsea beddomei* Hook. f.**	Lauraceae	Sa,Se	Sa,Se	Ad,Sa,Se
***Litsea glabrata* (Wall.ex Nees) Hook. f.**	Lauraceae	Ad,Sa,Se		Sa
Litsea insignis Gamble	Lauraceae			Ad,Sa
***Litsea wightiana* (Nees) Hook. f.**	Lauraceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Macaranga peltata (Roxb.) Muell.-Arg.	Euphorbiaceae	Ad,Sa	Ad,Sa,Se	Ad,Sa,Se
Maesa indica (Roxb.) DC.	Myrsinaceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Mallotus muricatus (Wight) Thw.	Euphorbiaceae			Ad,Sa,Se
Mallotus tetracoccus (Roxb.) Kurz	Euphorbiaceae	Ad,Sa	Ad,Sa	Ad,Sa
***Mastixia arborea* (Wight) Bedd.**	Cornaceae			Ad,Sa
***Meiogyne ramarowii* (Dunn.) Gandhi**	Annonaceae			Se
Meliosma arnotiana (Wight) Walp.	Meliosmaceae	Sa		
***Memecylon malabaricum* (Clarke) Cogn**.	Melastomataceae		Sa	
Memecylon sp.	Melastomataceae			Sa
***Memecylon wightianum* Triana**	Melastomataceae			Ad,Sa,Se
***Michelia nilagirica* Zenk.**	Magnoliaceae			Ad
***Miliusa wightiana* Hk. f. & Thoms.**	Annonaceae	Sa,Se	Sa,Se	Ad,Sa,Se
Murraya paniculata (L.) Jack	Rutaceae	Sa,Se	Sa	Sa
Mussaenda frondosa L.	Rubiaceae		Se	Sa,Se
Myristica dactyloides Gaertn.	Myrsticaceae			Sa

Contd…

Appendix Table 1. Continued

Tree species	Family	*Eucalyptus* Plantation		Cleared evergreen forest
		25 years	40 years	
Nageia wallichiana **(Presl.) Kuntze**	Podocarpaceae			Sa,Se
Neolitsea cassia (L.) Kosterm.	Lauraceae	Se	Sa	Sa,Se
Neolitsea fischeri **Gamble**	Lauraceae	Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Neolitsea foliosa (Nees) Gamble	Lauraceae	Sa,Se	Ad,Sa,Se	
Neolitsea sp.	Lauraceae		Ad	
Nothopegia heyneana **(Hk. f.) Gamble**	Anacardiaceae			Sa,Se
Nothapodytes nimmoniana (Graham) Mabberly	Icacinaceae	Sa,Se	Sa,Se	Sa,Se
Ochnaceae member	Ochnaceae			Ad
Olea dioica Roxb.	Oleaceae		Ad	Ad,Sa
Olea glandulifera Wall. ex G. Don	Oleaceae		Sa	Ad,Sa
Ormosia travancorica **Bedd.**	Fabaceae	Sa,Se	Sa,Se	Sa
Pavetta sp.	Rubiaceae			Sa
Persea macrantha (Nees) Kosterm.	Lauraceae	Ad,Sa,Se	Ad,Sa,Se	Ad
Phoebe lanceolata Nees	Lauraceae	Sa	Ad,Sa,Se	Ad,Sa,Se
Prunus ceylanica (Wight) Miq.	Rosaceae		Ad	Ad,Sa
Rapanea wightiana **(Wall. ex DC.) Mez.**	Myrsinaceae	Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Schefflera stellata (Gaertn.) Harms	Araliaceae	Sa	Ad	
Scolopia crenata (Wt. & Arn.) Clos.	Flacourtiaceae		Se	Ad,Sa,Se
Symplocos cochinchinensis (Lour.) Moore	Symplocaceae	Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Symplocos monantha **Wight**	Symplocaceae			Sa,Se
Symplocos pendula Wight	Symplocaceae	Sa		
Syzygium benthamianum **(Wight ex Duthie) Gamble**	Myrtaceae	Se	Sa,Se	Ad,Sa,Se
Syzygium caryophyllatum (L.) Alston	Myrtaceae	Sa,Se	Ad,Sa,Se	Ad,Sa,Se
Syzygium gardneri Thw.	Myrtaceae	Ad,Sa,Se	Ad,Sa,Se	Ad,Sa
Syzygium mundagam **(Bourd.) Chithra**	Myrtaceae	Ad,Sa	Ad,Sa	Sa,Se
Syzygium myhendrae **(Bedd. ex Brandis) Gamble**	Myrtaceae			Ad,Sa
Syzygium sp1.	Myrtaceae			Ad,Sa
Syzygium sp2.	Myrtaceae			Sa
Syzygium sp3.	Myrtaceae			Ad
Tricalysia apiocarpa **(Dalz.) Gamble**	Rubiaceae	Ad,Sa,Se	Sa,Se	Ad,Sa,Se
Trichilia connaroides (Wt. & Arn.) Bentvelzen	Meliaceae	Se	Sa,Se	Sa,Se
Vepris bilocularis **(Wt. & Arn.) Engler**	Rutaceae	Se	Sa	
Vernonia peninsularis (Clarke) Clarke ex Hk. f.	Asteraceae	Se	Se	
Vernonia travancorica **Hook. f.**	Asteraceae			Se
Viburnum punctatum Buch.-Ham. ex D. Don	Caprifoliacaeae	Sa,Se	Ad,Sa	Ad,Sa,Se
Xanthophyllum flavescens Roxb.	Xanthophyllaceae	Sa		