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Vegetation composition and structure of *Tectona grandis* (teak, Family Verbanaceae) plantations and dry deciduous forests in central India

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Abstract

Vegetation structure and composition of abandoned *Tectona grandis* (teak) plantations was compared with the neighboring dry deciduous secondary forests in Satpura Conservation Area located in central India. Species diversity and stem density were compared between plantations and secondary dry deciduous forests separately for adults and seedlings of trees, shrubs and lianas (collectively termed woody species). No significant difference was found between the two vegetation types in the seedling and adult species diversity. The adult stem density was significantly higher in plantations compared to the secondary forests, but the opposite was found to be true for basal area perindividual. Species abundance in plantations deviated from log-normal distribution while the secondary forests showed log-normal species abundance distribution. The size-class distribution of adults in plantations had greater positive skewness than the secondary forests due to high relative abundance of species in smaller size-classes. Overall results show that plantations have similar species richness as secondary forests, but have disproportionate abundance of sprouting and asexually reproducing species. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Plantations; Teak; India; Restoration; Secondary forests

1. Introduction

Single and mixed species plantations are chiefly established for economic benefit; ≈1% of the tropical land mass is under commercial plantations (Lowery et al., 1993). The necessity to fulfil economic goal leads to intensive management activities (periodic thinning by removal of brushwood and clearance of understory) preventing the accumulation of native species and influence soil sustainability (Cole, 1995; Haggar et al., 1997). Though the cost-benefit analysis associated with trade-off in plantation productivity and native species diversity is not available, moderate management activities are known to facilitate forest restoration in plantations, given their proximity to seed source (see other references in Parrotta et al., 1997; Parrotta, 1999). Several studies have examined the understory diversity and nutrient accumulation patterns in plantations of indigenous species (Haggar et al., 1997; Keenan et al., 1997; Stanley and Montagnini, 1999) and found the patterns to be influenced by age and life-history traits of plantation species.

Understanding the ecological characteristics of plantations is very important in the tropics where

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the reserves set aside for conservation purpose are not enough (Lugo, 1992; Perry, 1998). Especially in a country like India where large-scale *Tectona grandis* (henceforth teak, Family Verbanaceae) plantations failed due to unsuitability of habitat for teak growth. Teak is an indigenous and important plantation species of the Indian subcontinent because of its value and suitability for a wide range of uses (FAO, 1985). Teak plantations were first established in central India in mid–late 19th century (Gangopadhyay, 1985). The distribution and regeneration requirements of teak are well studied (Kulkarni, 1951; Chandrashekara, 1996; Jayasankar et al., 1999; Amponsah and Meyer, 2000; Okoro et al., 2000, see also references in Troup, 1921), the ability of teak plantations to support the native plant diversity, density and growth needs to be investigated.

Abandoned plantations of teak in Satpura Conservation Area (SCA) located in central India provide the opportunity to test the hypothesis that abandoned monoculture plantations are similar to nearby secondary forests in species richness, diversity and species abundance distribution of trees, shrubs and lianas (collectively referred to as woody species). The study also compares the functional traits of species between secondary forests and plantations, given the similarity in their structure and composition before establishment of plantations.

2. Study site

The study was conducted in 1994 in SCA 22°19′–22°30′N, 77°56′–78°20′E in central India and consisted of parallel measurements in secondary forests and abandoned teak plantations. The forests are classified as southern dry deciduous forests (Champion and Seth, 1968) that shed leaves during the dry period between January and April, depending on the local soil-water availability. The area receives annual rainfall of 1600–1800 mm brought by southwesterly monsoons between mid-June and September. Mean annual temperature is 25°C. Soils are well-drained vertisols and the parent rock material is principally basalt and sandstone. Soils occurring in plantations and secondary forests derived from sandstone are shallow with rocky outcrops and unfavorable for teak growth (Troup, 1921; Kulkarni, 1951).

SCA has been declared a high-priority area for biodiversity conservation by the National Wildlife Action Plan. It harbors one of the very few remaining contiguous deciduous forest tracts (<12% of the country's area is under deciduous forests, whereas the actual potential is 75%, Meher-Homji, 1994), and forms habitat for several rare and endangered faunal and floral species. Thus, restoration of the degraded sites in the SCA is of great consequence to the health of native species populations and also to the watershed quality of important river systems. SCA comprises secondary dry and moist deciduous forests selectively logged under different rotation cycles, teak plantations and bamboo plantations.

Plantations and secondary forests were worked under similar logging operations under a 40-year rotation cycle. Abandoned plantations occupy an area of 20,456 ha and were established between 1976 and 1978 (Gangopadhyay, 1985). The teak plantations were established purely for commercial purpose, but due to unsuitability of soil characteristics the teak plantations did not meet the growth expectations and, subsequently, were abandoned (Chaubey et al., 1988). Management practices associated with maintenance of plantations, for example, thinning of trees and removal of understory, were halted after 4–5 years (Gangopadhyay, 1985).

At the time of sampling the plantations were 16–18 years old since establishment. The secondary forests were estimated to be 30–35 years since last logging was done, hence the time since last disturbance was greater for the secondary forests. The secondary forests and plantations, being spatially juxtaposed, experience low-intensity anthropogenic fires. The dominant species in secondary forest canopy are *Terminalia alata*, *Anogeissus latifolia* and *Diospyros melanoxylon*, and the middlestory species are *Caesaria graveolens*, *Kydia calycina* and *Cassia fistula*.

3. Methods

A total of 9 and 13 plots, 1000 m^2 each, of plantations and secondary forest, respectively, were sampled. Stratified random sampling was done after identifying the forest areas under distinct silvicultural practices. The distance between any two plots was >50 m and all plots were located within an area of

4 km^2. The aim of the larger study, of which this is a small part, was to evaluate the vegetation structure and composition in the entire sanctuary area in relation to the logging history. All individuals of woody plants (trees, lianas, and shrubs) $\geq$1.5 cm stem diameter at the height of 1.35 m were sampled and referred to as adults (not implying their sexual maturity). A strip transect of 100 m^2 within the large plot was sampled for individuals of woody plants <1.5 cm stem diameter at the height of 1.35 m and individuals <1.3 m in height (termed seedlings). The woody species were identified with the help of forest department records and the herbarium at the Wildlife Institute of India, Dehradun.

Species diversity was measured using the Shannon–-Weiner's index and indexes were compared using a *t* test (Zar, 1999). Seedling and adult data were analyzed separately. Density of adults and seedlings was compared among plantations and secondary forests using the *t* test. Normality of all the data before using parametric methods was tested using the Kolmogorov–Smirnov test. Statistical software Statistica version 5.1, was used for all parametric and non-parametric tests, except for fitting of species-abundance data to a log-normal distribution.

Species similarity between two vegetation-type plantation and forest (seedlings and adults separately) and within each type between seedling and adult species composition was calculated using Sorenson's similarity index, $S=1-(2w)/(a+b)$, where w is number of species common to both types under comparison and a and b the total number of species in each type (Sorenson, 1948). The frequency of animal- and non-animal- (gravity and wind) dispersed species was compared to test for homogeneity of distribution among the plantations and secondary forests using a χ^2 test. Data on mode of dispersal was obtained from Troup (1921).

Log-normal species abundance distribution models were fitted to the species abundance data using the software program Statistical Ecology (Ludweig and Reynolds, 1988). The program compares frequency distribution consisting of a number of species found in abundance classes (octaves) with the log-normal distribution. The abundance classes are expressed as logarithms to the base 2 so that successive intervals correspond to population doubling. Generally, the log-normal distribution of species abundance indicates equilibrium status of a community governed by random processes (May, 1975; Bazzaz, 1997). The log-normal species abundance distribution is also reported in disturbed areas where time since disturbance is >35 years and the degree of disturbance is less intense compared to clear-felling (Hill et al., 1995). The mean basal area of an individual in secondary forests was expected to be greater than the plantations, and was compared using a two-sample one tailed *t*test. Total basal area per species was compared between the two vegetation types to examine whether the effect of density compensates for the individual size. Similarly, the adult and seedling densities between plantations and forests were compared using a *t* test. The frequency distribution of adult woody species in diameter-classes was plotted keeping the same size-classes for direct comparison between plantations and forests.

4. Results

4.1. Species diversity and density

Total species richness of secondary forest was greater than that of plantations (Table 1). Plantations had 46 and secondary forests had 50 species in total. No significant difference was found in Shannon–Weiner adult species diversity index between secondary forests and plantations having 35 and 42 species in total ($H'_{plantation}=2.82$, $H'_{secondary\ forest}=2.8$). No significant difference was found in the species diversity of seedlings between the plantation and secondary forest, with 40 and 35 species, respectively ($H'_{plantation}=2.824$, $H'_{secondary\ forest}=2.521$). No significant difference between the mean seedling densities of plantations and secondary forests was found; however, the density of adults was significantly greater in the plantations than the secondary forest ($p=0.03$, $t=2.07$, df=9).

4.2. Species abundance and size-class distribution

The species abundance distribution of plantations did not show log-normal species abundance distribution ($\chi^2=20.80$, df=8) as opposed to secondary forests that did show log-normal distribution ($\chi^2=9.23$, df=7) (Fig. 1). The plot depicting rank abundance

Table 1
Abundance, basal area, and mode of seed dispersal of species found in plantations and secondary forests

Family	Species	Habit	Plantations			Secondary forests			Dispersal mode
			Adults/ha	Seedlings/ha	Mean BA[a]	Adults/ha	Seedlings/ha	Mean BA[a]	
Anacardiaceae	*Buchanaia lanzan*	Tree	28	300	0.08	42	62	0.4	Animal
Anacardiaceae	*Lannea coromandalica*	Tree	9	0	0.035	11	0	0.682	Wind+gravity
Anacardiaceae	*Rhus parviflora*	Shrub	0	0	0	1	0	0.001	Na[b]
Anonaceae	*Saccopetalum tomentosum*	Tree	26	89	0.152	2	169	0.018	Animal
Apocynaceae	*Holarrhena antidysentrica*	Tree	1	0	0.001	3	0	0.012	Wind
Apocynaceae	*Wrightia tinctoria*	Tree	97	944	0.132	3	485	0.001	Wind
Bignoniaceae	*Stereospermum suaveolens*	Tree	0	78	0	3	0	0.12	Wind
Bombacaceae	*Bombax ceiba*	Tree	2	0	0.006	2	0	0.006	Wind
Caesariaceae	*Caesaria graveolens*	Tree	0	0	0	5	8	0.021	Animal+gravity
Combretaceae	*Anogeissus latifolia*	Tree	86	567	0.174	48	354	0.383	Gravity
Combretaceae	*Terminalia bellerica*	Tree	7	100	0.027	36	23	0.262	Animal+gravity
Combretaceae	*Terminalia chebula*	Tree	1	11	0.004	3	8	0.192	Animal+gravity
Combretaceae	*Terminalia alata*	Tree	93	800	0.359	68	31	1.219	Wind+gravity
Ebenaceae	*Diospyros melanoxylon*	Tree	119	1900	0.311	142	2008	1.56	Animal+gravity
Ehretiaceae	*Ehretia laevis*	Tree	0	0	0	1	23	0.035	NA
Euphorbiaceae	*Bridelia retusa*	Tree	4	0	0.022	1	15	0.007	Animal+gravity
Euphorbiaceae	*Emblica officinalis*	Tree	26	167	0.117	45	38	0.252	Animal+gravity
Fabaceae	*Acacia catechu*	Tree	7	33	0.034	5	0	0.013	Gravity
Fabaceae	*Acacia leucophloea*	Tree	2	0	0.002	1	0	0.001	Gravity
Fabaceae	*Acacia* spp.	Liana	0	22	0	1	0	0.001	Gravity
Fabaceae	*Albizzia odoratissima*	Tree	4	22	0.03	11	46	0.282	Gravity
Fabaceae	*Bauhinia racemosa*	Tree	20	78	0.075	4	46	0.023	Animal+gravity
Fabaceae	*Bauhinia vahili*	Liana	2	44	0.011	1	0	0.003	Animal+gravity
Fabaceae	*Butea monosperma*	Tree	3	22	0.011	2	0	0.022	Wind+gravity
Fabaceae	*Butea superba*	Liana	13	33	0.033	7	15	0.058	Wind+gravity
Fabaceae	*Cassia fistula*	Tree	9	0	0.043	7	46	0.057	Animal+gravity
Fabaceae	*Dalbergia paniculata*	Tree	3	22	0.004	8	8	0.096	Gravity
Fabaceae	*Milletia auriculata*	Liana	0	67	0	3	23	0	NA
Fabaceae	*Ougeinia oogenensis*	Tree	9	22	0.228	1	0	0.015	Wind+gravity
Fabaceae	*Pterocarpus marsupium*	Tree	31	100	0.106	16	0	0.064	Wind
Lecythediaceae	*Careya arborea*	Tree	18	56	0.058	15	0	0.295	Animal+gravity
Lythraceae	*Lagerstroemia parviflora*	Tree	46	267	0.228	18	46	0.079	Wind
Malvaceae	*Kydia calycina*	Tree	1	11	0.01	1	8	0.004	Gravity
Meliaceae	*Chloroxylon Sweiteinia*	Tree	59	111	0.125	37	431	0.346	Wind+gravity
Meliaceae	*Soymida febrifuga*	Tree	2	44	0.003	55	0	0.08	Wind+gravity
Moraceae	*Ficus benghalensis*	Tree	0	0	0	1	0	0	Animal
Moraceae	*Ficus hispida*	Tree	7	0	0.119	0	0	0	Animal
Myrtaceae	*Syzygium cumini*	Tree	21	22	0.308	2	154	0.036	Animal
Rhamnaceae	*Ventilago madraspatana*	Liana	1	11	0.004	5	269	0.019	Wind

Rhamnaceae	*Zizyphus mauritiana*	Tree	0	67	0	13	38	0.026	Animal+gravity
Rhamnaceae	*Zizyphus* spp.	Straggler	38	144	0.189	3	54	0.017	Animal+gravity
Rubiaceae	*Gardenia turgida*	Tree	0	22	0	1	0	0.009	Animal+gravity
Rubiaceae	*Haldinia cordifolia*	Tree	0	0	0	2	0	0.542	Wind+gravity
Rubiaceae	*Mitragyna parviflora*	Tree	1	33	0.001	0	0	0	Wind+gravity
Rubiaceae	*Randia uliginosa*	Tree	2	233	0.002	1	38	0.002	Animal
Rutaceae	*Aegle marmelos*	Tree	23	489	0.03	28	285	0.587	Animal+gravity
Sapindaceae	*Schleichera oleosa*	Tree	0	22	0	2	54	0.152	Animal
Sapotaceae	*Madhuca indica*	Tree	27	33	0.315	52	38	1.457	Animal+gravity
Sterculiaceae	*Helicteres isora*	Shrub	12	256	0.008	12	723	0.012	Gravity
Tiliaceae	*Grewia asiatica*	Shrub	7	144	0.007	0	46	0	Animal
Tiliaceae	*Grewia tilifolia*	Tree	24	67	0.051	8	77	0.121	Animal
Verbanaceae	*Tectona grandis*	Tree	297	156	0.967	4	15	0.171	Gravity

[a] Mean basal area/individual/species (m^2).
[b] Data not available

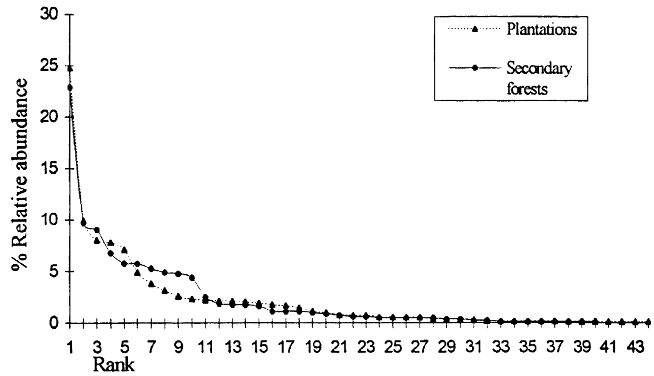

Fig. 1. The plot shows rank abundance distribution of tree species in plantations and secondary forests. The plantations have greater positive skewness compared to the secondary forests due to high relative abundance of teak in comparison with other tree species.

distribution of adults was steeper in plantations compared to secondary forest. Greater abundance of teak plants was found in plantations compared to the secondary forests, and only 14 and 2 teak seedlings were found in plantations and secondary forests, respectively. Plantations showed greater positive skewness (2.03, Fig. 2) in the size-class distribution than the secondary forests (0.700), as there were more individuals in the size-classes smaller than the mean size-class (Fig. 2). The mean basal area of an individual of a species was greater in secondary forests than plantations (t=20.6, p<0.001), but the mean basal area per species after taking into consideration the density is not significantly different between the two vegetation types.

4.3. Species similarity between plantations and secondary forest

Adult trees in plantations and secondary forests showed greater similarity in species composition than the seedlings (Sorenson's similarity index for adults=0.01, for seedlings=0.25). Within vegetation species, similarity between adults and seedling was lower for forests (0.17) than for the plantations (0.07). The frequency of animal-dispersed and non-animal-

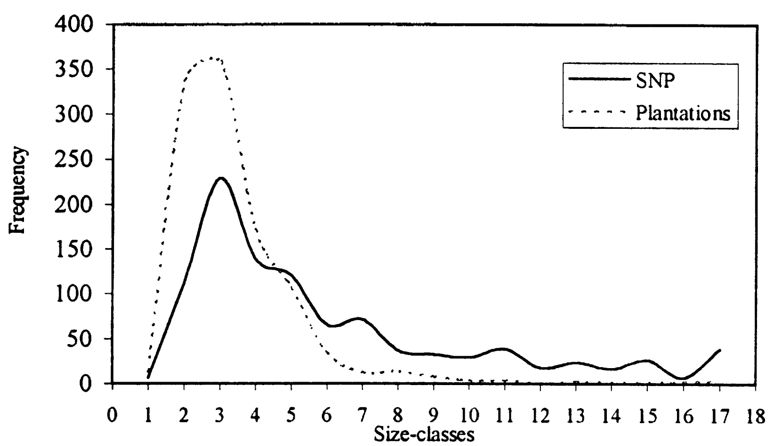

Fig. 2. Size-classes indicate the diameter classes of adults. The numbers on the x-axis correspond to the following diameter classes: 1, 1.59–3.99 cm; 2, 4–6.39 cm; 3, 6.4–8.78 cm; 4, 8.8–11.18 cm; 5, 11.19–13.58 cm; 6, 13.59–15.99 cm; 7, 16–18.37 cm; 8, 18.38–20.77 cm; 9, 20.78–23.17 cm; 10, 23.28–25.57 cm; 11, 25.58–27.99 cm; 12, 28–30.37 cm; 13, 30.38–32.76 cm; 14, 32.77–35.16 cm; 15, 35.17–37.56 cm; 16, 37.56–39.99 cm; and 17, >40 cm.

dispersed species showed homogeneity in distribution among the plantations and secondary forests. Of the total tree species, 43 and 46% were animal dispersed in plantations and secondary forests, respectively.

5. Discussion

The results show that plantations support species richness similar to the neighboring secondary forest, as shown in several other studies (Lugo, 1992; Keenan et al., 1997; Loumeto and Huttel, 1997; Parrotta, 1999). The presence of forest tree species in the understory and overstory indicated that species pool for colonization was made available by old stumps/root stocks for coppice and ramet production, and seed rain via animals and wind from the neighboring forests. As was expected, the density of teak adults in plantations was higher (teak was planted) compared to the secondary forests, and to the other species in the plantations. The low density of teak seedlings in plantations and secondary forests is a result of poor regeneration due to unfavorable habitat. The trees in plantations did not reach the large size-classes as those of the secondary forests, creating a positive skewness in size-class distributions, which is not surprising as the plantations were of a younger age compared to the secondary forests, and the teak trees did not grow at the expected rate. The greater density of trees per species in plantations compensated the size per individual of a species. It resulted in similar basal area of adults in both vegetation types.

Seedling density was found to be similar at both sites, an important result considering the intensity of disturbance and time since last major anthropogenic disturbance was greater in secondary forests compared to that in the plantations. This may not be the case in plantations that undergo regular thinning and understory removal (Lugo, 1992). Dominance of seedling species known to sprout vigorously, such as *Terminalia tomentosa*, *Aegle marmelos*, *Stereospermum suaveolens*, *Anogeissus latifolia*, *Diospyros melanoxylon* and *Wrightia tinctoria*, in plantations suggests that coppice and ramet production may be of greater relative importance in plantations compared to the secondary forests. The seedling density of liana species was greater in plantations compared to the secondary forests, indicating that light is not a limiting factor in plantations. The similarity of composition between adults and seedlings within plantations, and the difference in seedling composition between plantations and secondary forests, supports the argument that seedling composition varies between the two vegetation types, with greater preponderance of species able to sprout and reproduce asexually in plantations. Seedlings could not be distinguished into coppice shoots, asexual ramets and individuals established from seeds, precluding statistical analysis based on mode of reproduction. The test of homogeneity comparing the distribution of species among the two vegetation types in categories based on mode of reproduction will have a limited meaning as many asexually reproducing coppicing species are also animal dispersed. It may confound the effect of dispersal pattern and mode of reproduction in a situation where the seedling cannot be identified as ramet, coppice shoot or an individual originated from seed.

Tree sprouts play an important role in restoration of tropical moist forest after slash-and-burn agriculture, whereas the primary forests show small fraction of sprouts and fewer species that have sprouting ability compared to the secondary forest (Kammersheidt, 1998). This may be due to the fact that tropical evergreen forest species show differential ability in sprouting with some species not able to sprout at all (Kauffman, 1991). On the other hand most tropical deciduous forest species possess the ability to sprout and coppice (Troup, 1921; Lugo, 1992; Murphy and Lugo, 1986; Rico-Gray and Garcia-Franco, 1992; Lieberman and Mingguang, 1992, but see Mizrahi et al., 1997). The secondary forests described in this study have a long history of human interference and, therefore, the high density of some sprouting species, *D. melanoxylon* for example, is not surprising. The deviation of species abundance in plantations from log-normal distribution indicates that the plantations have not fully achieved the similarity in processes governing the composition and structure. The patterns in stem density and diversity suggest that restoration of biomass to pre-disturbance level can be attained by abandoned plantations given the species pool for colonization is available, but the same cannot be concluded for diversity of functional types and dominance pattern.

Dry deciduous forests are one of the most threatened of all ecosystems, occupying almost 40% of tropical lowland sites (Murphy and Lugo, 1986; Janzen, 1988). It is highly crucial to restore ecosystem function and diversity of the forests and plan for sustainable use of the forests. Teak is by far the most important commercial tree species in India and will be an important timber resource in future also. This study highlights the need of great care and planning in site selection for establishment of teak plantations. The failed teak plantations can deplete the species diversity and soil resources irrevocably if species pool for colonization of plantations is not available.

6. Conclusion

Abandoned teak plantations were similar in woody species richness to the dry deciduous secondary forests. This study showed that native tree species can grow and regenerate under teak plantations and that teak does not seem to have negative effect, such as allelopathy, on growth of native tree species. The disproportionate contribution of ramets and sprouts can lead to dominance of a few species and reduced abundance of sexual species and the species that do not exhibit vigorous sprouting. Findings from this study highlight the need to study, the patterns in species and functional diversity of plantations over long-term period, and a cost-benefit analysis of teak plantations for restoration of native plant diversity and economic gains.

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