Structure and diversity of 80-yr-old plantations after successional colonization of the natives

R. K. Manhas[1,*], P. S. Chauhan[2], Mukesh[3], Lokender Singh[4] and J. D. S. Negi[4]

[1]Department of Botany, Sri Pratap College, Srinagar 190 001, India
[2]Department of Forestry, College of Horticulture and Forestry, MPUAT, Jhalawar 326 001, India
[3]58 Toy City, Greater Noida, District Gautambudh Nagar 201 306, India
[4]Forest Ecology and Environment Division, Forest Research Institute, Dehra Dun 248 006, India

Forest plantations are viewed as a source of income by some and as a threat to forest diversity and ecological function by others. In the past two decades, area under tropical plantations has increased immensely as a measure of damage control to a large-scale deforestation. In this study we have studied three native plantations raised in 1926. These plantations were not harvested after maturation and are now dying because of age or some infection. The gaps created thereafter are being colonized by the early successional native species, thus changing the structure and diversity of these 80-yr-old plantations. A total of 54 plants (22 trees, 25 shrubs, 4 climbers, 2 forbs and 1 grass) were present in these plantations. Species richness and diversity were significantly (*P* < 0.05) higher in the residential (sal) than the two non-residential (teak and pine) native species. All the plantations had rich life-form diversity and again significantly (*P* < 0.05) higher values were recorded for sal than teak and pine. Population structure of the top species in each site demonstrated that the planted species are not regenerating (seedling, sapling and pole crop of these species were absent) and are slowly being replaced by the native species. We also found that succession in these plantations is moving on different lines as shown by the variation in colonizing species in these sites and low similarity between the sites on the basis of tree, shrub and herb life forms.

Keywords: Colonization, diversity, life form, natives, species richness.

IN the past two decades, because of the burgeoning overlapping of several commercial, environmental and societal issues, plantation activities have intensified several fold in India. Some of these pressing issues are realization of 33% forest cover for the country and 66.7% for the hill states by augmenting reforestation and afforestation committed in the national forest policy, carbon offset mechanism, and commercial timber and pulpwood supply. Puyravaud *et al.*[1] reported that from 1995 to 2005, plantations in the country increased at a mean annual rate of ca. 1.54 m ha yr^{-1}. According to the estimates of the International Tropical Timber Organization[2], ca. 33 m ha of forested land in India is under plantations, placing the country second globally in the total area covered under plantations. Commonly planted species in India are *Eucalyptus* sp., *Tectona grandis*, *Acacia* sp., especially *Auriculiformis*, *Pinus* sp., *Casuarina equisetifolia*, *Hevea brasiliensis* and bamboo species.

In relation to conservation and maintenance of the existing biodiversity, there are two highly juxtaposed views concerning the importance of plantation forests. One group proclaims that monocultures, augmented by plantations, are of low value for the maintenance of biological diversity because of the simple forest structure[3–5]. The second group, however, states that plantations have the potential of increasing the biological diversity through successional development of the understorey vegetation and establishment of the middle canopy[6–11].

Krishnaswamy and Puri[6] in their 20-year observation of the New Forest plantations have stated that successional forces, over a period of time, promoted development of middlestorey and understorey vegetation. Several other studies also support this fact[12–15]. It is well known that removal of disturbance factors from the plantations creates conditions favourable for the onset of successional forces, which ultimately create the complex stand structure with multi-tier profile. This has cascading effects on the several ecosystem processes such as improvement of microclimatic conditions, top-soil enrichment through litterfall, increase in microbial diversity, enhanced biomass accumulation and productivity, enhanced immobilization (sequestration) capacity, etc. In addition, it protects the ecosystem from further degradation, by preventing soil erosion and reducing fire hazard and helps in conserving soil, water and biological diversity.

The New Forest estate was constituted on agricultural fields in 1921 and later notified as a reserve forest in 1942. These agricultural fields were surrounded by pure *Shorea robusta* forests. The change in land-use from rice fields to introduction of forestry species started with the initiation of plantation in 1926. A number of residential (*S. robusta*, bamboos, *Terminalia alata*, *Syzygium cumuni*, etc.) and non-residential (*T. grandis*, *Pinus roxburghii*, *Acacia catechu*, *Dalbergia latifolia*, *Michelia*

*For correspondence. (e-mail: manhasrk@rediffmail.com)

champaca, etc.) native species were planted. Today the anthropogenically created New Forest is an example of rich biodiversity providing habitat to 280 species of birds[16,17], 148 species of butterflies[18] and many mammals such as wild boars, jackals, leopards, civet cats, wild hare, giant fruit bats, rhesus monkey and langur.

Ito *et al.*[19] stated that the decision about adoption of particular management strategies should be based on ecosystem structure and functioning in terms of species diversity of a region. The structural complexity of the planted forest is an important determinant of subsequent biodiversity enrichment due to the importance of habitat heterogeneity for attracting seed-dispersing wildlife and microclimatic heterogeneity required for seed germination for a variety of species[8]. Therefore, in the absence of any major disturbance factors like extraction of wood, major fires and insect attack, homogenous stand structure will be replaced by heterogeneous structure and eventually as the succession proceeds plantation forests will transform into secondary forests.

Numerous studies on floristic diversity, structure and ecosystem processes are available from plantation forestry[6,15,20–25]. However, these studies were mostly done in the plantations to gauge the effects of stand development and application of different logging intensities on biological diversity. Studies on the old, abandoned plantations which are attaining a semi-natural state are lacking and fundamental aspects of tropical forest succession following agriculture remain poorly understood[26,27]. To understand the role of plantations as a refugium in terms of biological conservation and associated ecosystem processes, the composition, structure and the diversity of life-forms are need to be studied.

The aim of this study was to analyse the effect of plant colonization on structure, species richness and diversity of vascular plants, and life-form diversity in residential and non-residential native plantations. We also explored the level and rate of floristic diversity and successional development which these plantations accommodate following abandoning and subsequent removal of disturbance agents from these man-made ecosystems after they were ascended to reserved forests.

Study site

The study site is situated in the demonstration area of the New Forest, Forest Research Institute (FRI), Dehradun, located at 77°52′12″E long. and 30°20′40″N lat. at an altitude of 640 m amsl (Figure 1). Meteorological data for the last 75 years (Figure 2) show that the mean maximum and minimum temperatures for the study site are 27.65°C and 13.8°C respectively. The study area receives an average annual rainfall of 202.54 cm. Occurrence of frost is common during winter months. Severe frost occurs in December and January, and occasionally in November and the beginning of February.

According to Champion and Seth[28], the site falls under the tropical moist deciduous forests dominated by species such as *S. cumuni*, *Miliusa velutina*, *Lagerstoemia parviflora*, *T. alata*, *Mallotus philippensis*, *Woodfordia fruticosa*, *Indigofera pulcherima* and *Eulaliopsis binata*.

Various native and exotic plantations such as *S. robusta*, *P. roxburghii*, *T. grandis*, bamboo, *Gmelia arborea*, *M. champaca*, *A. catechu*, *T. alata*, *Acrocarpus fraxinfolius*, *D. latifolia*, *S. cumuni*, *Eucalyptus* sp. etc. were raised in the study area for the provenance trials. We selected three old native plantations, viz. *S. robusta* plantation (site I), *P. roxburghii* plantation (site II) and *T. grandis* plantation (site III), because they are well managed and various silvicultural operations are performed from time to time and are thoroughly documented in the Working Plans. Area covered under these plantations was 4.8–5.3 ha for *S. robusta*, 14.2 ha for *T. grandis* and 15.0 ha for *P. roxburghii*. Although *S. robusta* is a residential native species found locally in the Doon Valley, *P. roxburghii* and *T. grandis* are non-residential native species found naturally in sub-tropical Himalayas, and central and southern parts of India respectively.

Management practices

Plantations of *S. robusta* (sal), *T. grandis* (teak) and *P. roxburghii* (pine) were raised according to Howard's working plan (1921) in 1926 for provenance trails in the demonstration area of the New Forest, FRI. According to the forest records (Working Plans), in all the plantations, various operations like pruning, burning and weeding were carried out during different phases of the plantation growth. In the sal plantation (site I), frost-affected plants were cut in 1935. In 1944, saplings of 10 cm diameter at breast height (DBH) were removed; thereafter the whole compartment was coppiced. Thinning was done twice in 1962, and about 132 and 149 shoots were removed. In the pine plantation (site II), thinning was done in the whole compartment in 1936 and the process was repeated again in 1950, 1964 and 1967. All miscellaneous species were thinned in 1946. Controlled burning was done during 1944 and 1946. Similarly, in the teak plantation (site III), all frost-affected teak plants were removed during 1931 and 1934. Thinning operations were done in 1936 (26 trees), 1937 (23 trees), 1951 (91 trees) and 1954 (26 trees). In 1937, the miscellaneous plants were also weeded[29]. We did not find official records of silivicultural activity after 1962 in sal, 1967 in pine and 1954 in teak plantations, and according to the forest officials, these man-made ecosystems were left abandoned often these years.

Methodology

Phytosociological studies were conducted using nested quadrat method[30]. Quadrats were laid along a transect line

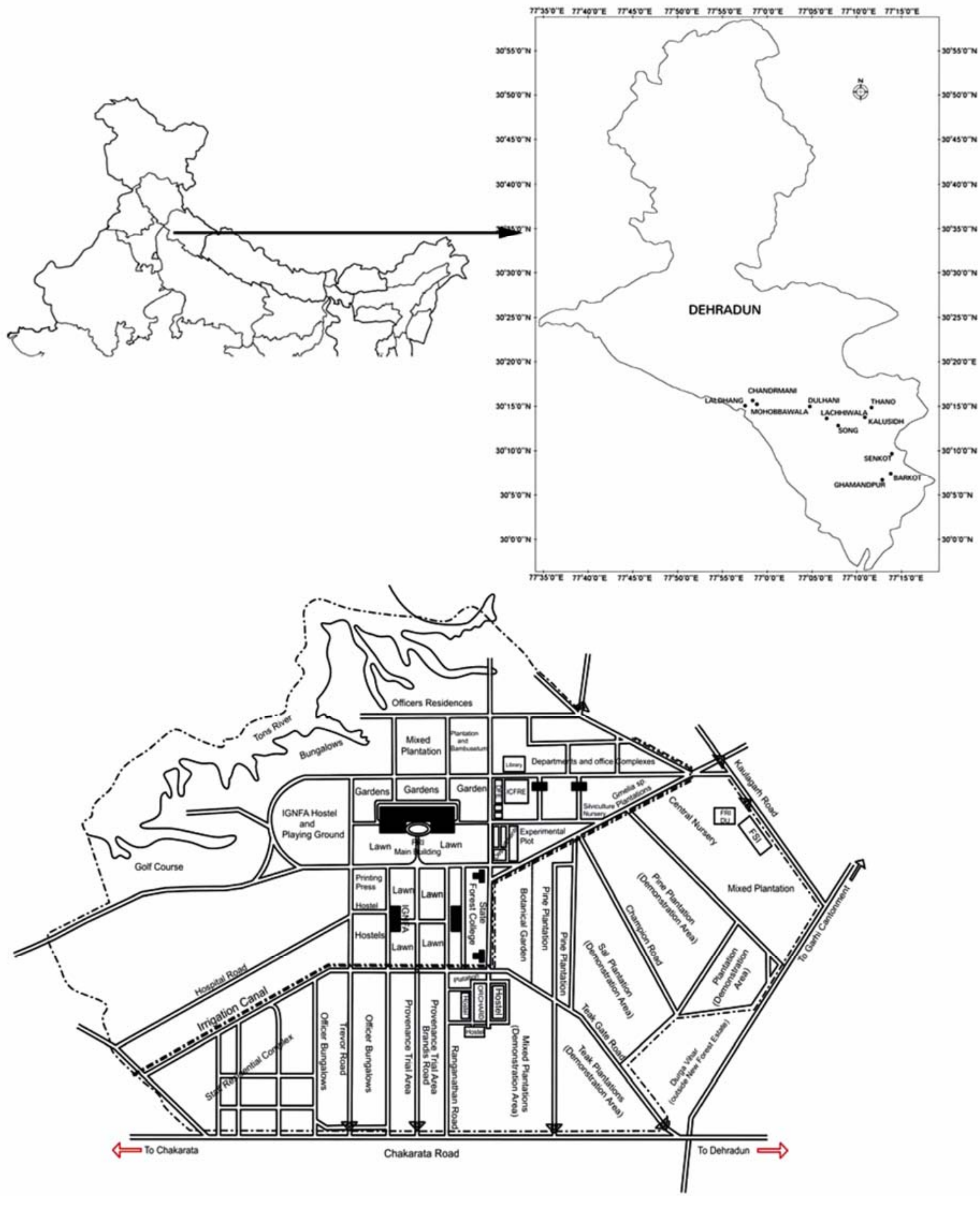

Figure 1. Location map of the study site.

and in continuity, i.e. no gap between two quadrats. A total of 132 quadrats (44 quadrats in each site for each stratum) were sampled from all the plantations. Sampling size of a quadrat for tree, shrub and herb layers was $10 \text{ m} \times 10 \text{ m}$, $3 \text{ m} \times 3 \text{ m}$ and $1 \text{ m} \times 1 \text{ m}$ respectively. In each quadrat data for the number of individuals (abundance) and diameter (DBH for tree, and collar diameter for shrub and herb layers) of each species were recorded. The data collected were then analysed for frequency, density and basal area, and finally importance value index (IVI) of each species was calculated as the sum of the relative values of frequency, density and basal area[30]. Shannon–Wiener index (H') and Simpson's concentration of dominance (Cd), were calculated from Maguran[31], and evenness (J) from Pielou[32].

Floristic similarity of all life-forms was compared between plantation sites using Jaccard's similarity index[30]. Additional comparisons of all species were made among

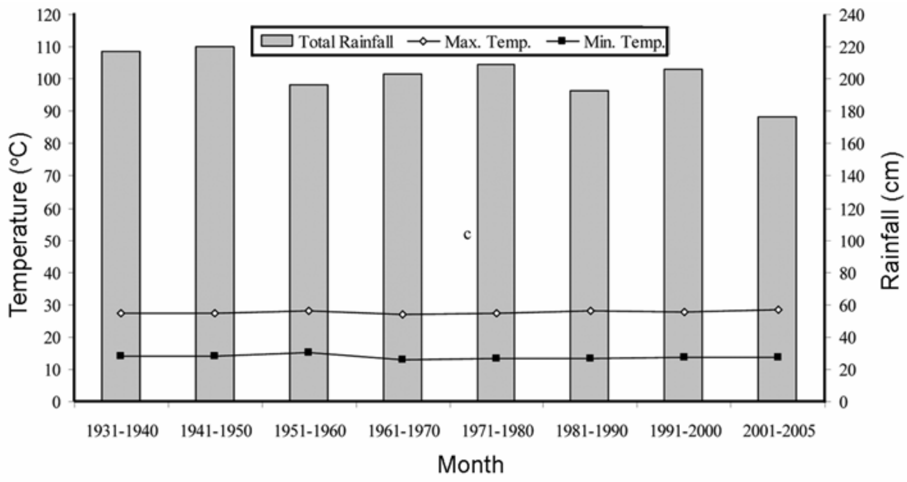

Figure 2. Ombrothermic diagram of the study site showing rainfall (cm), and mean minimum and maximum temperatures (°C) for the last 75 years.

the plantation sites using the modified Sørenson's quantitative index[33] and unique species were counted.

Distribution pattern of all the species was examined through abundance/frequency (A/F) ratio[34]. On the basis of these values (A/F ratio), the distribution was categorized either as regular (< 0.025), random (0.025–0.05) or contagious (> 0.05). Based upon the number of individuals, every species was grouped into very rare (represented by < 2 individuals), rare (2 to < 10 individuals), common (10 to < 25 individuals), dominant (25 to < 50 individuals) and predominant (> 50 individuals), following Kadavul and Parthasarthy[35]. To study the succession of species present in various plantations, we studied the population structures of the dominant species (on the basis of density) by plotting graphs between diameter class and relative density. Relative density was defined as the density of species in a particular diameter class divided by the total density of that species.

Soils were collected with the help of augers from all the sites at 0–50 cm depth (three replicates). The collected soil was air-dried, ground and sieved using a 2 mm sieve and soil pH was determined using a digital pH meter. Soil moisture was recorded using the electronic moisture analyser. Organic carbon was determined by Walkley and Black's rapid titration method[36].

Significance of difference in stand characteristics, Shannon–Wiener diversity index, Simpson's diversity index, and Pielou's evenness were tested using analysis of variance (ANOVA). Fisher's LSD multiple range test was applied for comparison of means. Pearson's correlation analysis was also performed to evaluate the influence of soil attributes and tree density on the species richness, Shannon–Wiener diversity index, Simpson's diversity index, and Pielou's evenness of shrub and herb layers. Homogeneity of variance was achieved as needed through log transformations. Microsoft EXCEL and STATISTICA software were used for various statistical analyses.

Results

Stand characteristics

Soil attributes of all the three plantation sites varied significantly among the sites and maximum pH (6.33) and soil moisture (11.24%) were recorded in sal plantation, and organic carbon (3.83%) in pine plantation (Table 1). Density of all the species planted at 2 m × 3 m spacing initially has decreased significantly (*t*-test, $P < 0.01$) in the last 80 years. Total tree density of sal plantations (809 trees ha^{-1}) was significantly higher than pine (330 trees ha^{-1}) and teak plantations (730 trees ha^{-1}). Contribution of density of the planted species towards the total density ranged between 71.2% (sal) and 90.9% (pine). Total basal area of trees was significantly ($P = 0.036$) higher in sal than the other two plantations. All the planted species were contagiously distributed. Most of the other species were also contagiously distributed in sal (88.64%), pine (53.85%) and teak plantations (60.0%). Only teak plantation had species (6.67%) with regular distribution pattern. Pine (80.77) had significantly higher percentage of very rare and rare species than teak (70.00) and sal plantations (22.73). For predominant and dominant status, sal plantation had significantly higher number of species than teak and pine plantations.

A total of 44 plant species belonging to 30 families and 43 genera were present in the three plantations. The maximum number of species (35), genera (34) and families (26) of plant species present in sal plantation are given in Table 1. Maximum number of species was recorded for Lauraceae family (4 species/3 genera) followed by Moraceae (3 species/3 genera) and Verbenaceae (3 species/3 genera). As many as 20 families had only one species (Table 2).

Importance value index

According to IVI, planted species were the most dominant trees in their respective sites (Table 3). The

Table 1. Stand characteristics of three plantation of New Forest, Forest Research Institute (FRI), Dehradun

	Sal	Pine	Teak	*F*-value	*P*-value
Aspect	Flat	Flat	Flat	–	–
Soil pH	6.33[a]	5.37[b]	6.01[a]	23.39	0.001**
Soil moisture (%)	11.24[a]	8.17[c]	10.04[b]	9.15	0.015*
Soil organic carbon (%)	1.17[b]	3.83[a]	1.60[b]	15.86	0.004**
Initial tree density of planted species (trees ha^{-1})	1650	1650	1650	ns	–
Present tree density of planted species (trees ha^{-1})	576[a]	300[c]	530[b]	34.67	0.001**
Total tree density (trees ha^{-1})	809[a]	330[c]	730[b]	4.47	0.022*
Total basal area (m^2 ha^{-1})	22.06[a]	15.00[c]	20.62[b]	3.82	0.036*
Number of species	35[a]	22[b]	22[b]	5.66	0.004**
Number of genera	34[a]	22[b]	21[c]	5.36	0.006**
Number of families	26[a]	16[c]	17[b]	4.81	0.010**
Exotic species (%)	17.14	27.27	13.64	–	–
Distribution pattern					
Regular	0	0	2	–	–
Random	5	12	10	–	–
Contagious	39	14	18	–	–
Distribution status					
Very rare	0	8	9	–	–
Rare	10	13	12	–	–
Common	15	3	4	–	–
Dominant	4	1	3	–	–
Predominant	15	1	2	–	–

Values given are means. Fisher's LSD was applied when ANOVA detected significant difference ($P < 0.05$) between plantations for various site characteristics. Values within a row followed by the same letter do not differ significantly. Probability values are significant at $P < 0.05$ and 0.01 when * and ** signs respectively, follows the *P* value.

Table 2. Floristic characteristics of various plantation sites

Family (species/genus)	Sal	Pine	Teak
Acanthaceae (1/1)	+	–	–
Achyranthaceae (1/1)	+	–	–
Alangiaceae (1/1)	+	+	+
Apocynaceae (2/2)	+	+	–
Asteraceae (1/1)	+	–	–
Boraginaceae (1/1)	+	–	–
Cesalpinaceae (1/1)	+	+	–
Dipterocarpaceae (1/1)	+	–	–
Ebenaceae (1/1)	–	+	+
Euphorbiaceae (2/2)	$+^2$	+	+
Flacourtiaceae (2/2)	$+^2$	–	+
Lauraceae (4/3)	$+^4$	$+^2$	$+^2$
Magnoliaceae (1/1)	+	–	+
Malvaceae (1/1)	+	–	–
Meliaceae (2/2)	+	–	$+^2$
Moraceae (3/3)	$+^3$	$+^3$	$+^2$
Myrtaceae (2/2)	+	$+^2$	+
Oleaceae (1/1)	+	–	+
Passifloraceae (1/1)	+	+	+
Pinaceae (1/1)	–	+	–
Poaceae (1/1)	+	+	+
Rhamnaceae (1/1)	+	–	+
Rosaceae (2/2)	$+^2$	$+^2$	–
Rubiaceae (2/2)	+	–	+
Rutaceae (1/1)	+	+	+
Sapindaceae (1/1)	+	–	–
Smilaceae (1/1)	–	+	–
Solanaceae (1/1)	–	+	–
Tiliaceae (1/1)	+	–	+
Verbinaceae (3/3)	$+^2$	$+^2$	$+^3$

+ and – denote presence and absence of species respectively. Superscripts represent the number of species, if more than one.

co-dominant species were *M. philippensis* (site I), *Cinnamomum camphora* and *Alangium chinense* (site II), and *Diosypros malabaricum* and *S. cumuni* (site III). Shrub layer was dominated by *Clerodendrum viscosum* in sites I and III, with importance values of 41.91 and 44.13 respectively and *Lantana camara* in site II with 82.65 IVI. *L. camara*, an exotic weed, *Murraya koenigii* and *Passiflora* sp. were the other dominant shrub species. Herb layer was not well developed and climber *Jasminum multiflorum* (site I) and grass *Oplismenus compositus* (sites II and III) were the most dominant species of the various sites. ANOVA of IVI of species was significant for all the three layers (tree, shrub and herb) at $P < 0.05$.

Similarity between vegetation and plantation sites

According to Sorenson's quantitative index, 11 species were common to all the three sites. Within plantations, sal had 35 species; seven of them were unique. Pine had 22 and four unique species and teak had 22 and 1 unique species (Figure 3). Sal and teak (61%) were the most strongly related sites, closely followed by teak and pine (59%), and sal and pine (57%) plantations. *M. philippensis*, *A. chinense*, *C. camphora* and *Litsea glutinosa* were the most common tree species. In shrub layer, shrubs such as *C. viscosum*, *L. camara*, *Murraya koenigii*, *Passiflora* sp. and saplings of *A. chinense* and *Litsea monopetela* were the most common species. Seedlings of *M. koenigii* and *O. compositus* were the most common species of the herb layer.

Table 3. Importance value index of plant species present in various strata of three plantations

Layer/species name	Plantation site Sal	Pine	Teak
Tree layer			
Alangium chinense (Lour.) Harms.	–	13.43	–
Cinnamomum camphora Linn.	4.21	9.89	–
Diosypros malabaricum (Gtn.) Gurke.	–	–	10.63
Flacourtia indica (Burm. f.) Merr.	4.49	–	–
Grewia glabra Linn.	5.18	–	–
Litsea glutinosa (Lour.) C.B. Robinson	4.79	–	10.74
Michelia champaca Linn.	20.83	–	–
Mallotus philippensis Muell. Arg.	4.22	10.03	39.12
Melia azedarach Linn.	–	–	5.30
Pinus roxburghii Linn.	–	266.65	–
Randia uliginosa DC.	4.25	–	–
Shorea robusta Gaertn. f.	252.03	–	–
Syzygium cumini (Linn.) Skeels.	–	–	23.51
Tectona grandis Linn.	–	–	200.04
Toona ciliata Roem.	–	–	10.66
Shrub layer			
Saplings of trees			
Alangium chinense (Lour.) Harms.	6.85	8.84	6.09
Anthocephalus indicus A. Rich	–	–	3.77
Caseria tomentosa Roxb.	1.72	–	–
Cassia glauca Lamk.	1.68	9.63	–
Cinnamomum camphora Linn.	1.75	6.64	–
Cordia myxa Linn.	1.79	–	–
Cudrania cochinchinensis (Linn.) K. & M.	2.32	22.34	–
Diospyros malabaricum (Gtn.) Gurke.	–	2.80	4.69
Ficus sp.	4.68	12.25	2.23
Flacourtia indica (B.F.) Merr.	27.56	–	9.89
Grewia glabra Linn.	–	–	3.13
Holarrhena antidysentrica Wall.	5.28	–	–
Litchi chinensis S.V.	1.81	–	–
Litsea glutinosa (Lour.) C.B. Robinson	–	–	2.79
Litsea monopetala (Roxb) Pers.	9.03	9.41	27.79
Machilus gamblei King Ms.	3.29	–	–
Mallotus philippensis Muell. Arg.	7.12	–	2.31
Michelia champaca Linn.	41.81	–	2.61
Morus alba Linn.	15.60	21.67	32.06
Psidium guyava Linn.	–	5.65	–
Putranjiva roxburghii Wall.	1.85	–	–
Syzygium cumini (Linn.) Skeels.	30.98	24.33	22.34
Toona ciliata Roem.	4.79	–	–
Shrubs			
Clerodendrum viscosum Vent.	41.91	44.34	44.13
Dicliptera sp.	3.01	–	–
Eupatorium adenophorum Mill.	9.59	–	–
Lantana camara Linn.	18.49	82.65	21.10
Murraya koenigii Spreng.	17.58	9.66	25.23
Rosa macrophylla Linn.	2.75	2.80	–
Solanum torvum Swartz.	–	13.88	–
Urena lobata Linn.	2.15	–	–
Ventilago calyculata Tulasne.	6.31	–	40.51
Climbers			
Jasminum multiflorum (B.F.) Ander.	15.57	–	11.87
Passiflora sp.	7.22	14.78	37.46
Rubus elipticus Sm.	5.51	5.58	–
Smilax vaginata Decne.	–	2.75	–

(*Contd.*)

Table 3. (*Contd.*)

Layer/species name	Plantation site Sal	Pine	Teak
Herb layer			
Seedlings of trees, shrubs and climbers			
Alangium chinense (Lour.) Harms.	–	13.39	–
Flacourtia indica (B.F.) Merr.	10.47	–	–
Mallotus philippensis Muell. Arg.	–	–	57.03
Syzygium cumini (Linn.) Skeels.	–	–	40.99
Lantana camara Linn.	15.68	–	45.07
Eupatorium adenophorum Mill.	16.98	–	–
Murraya koenigii Spreng.	11.89	–	–
Jasminum multiflorum (B.F.) Ander.	146.93	–	–
Passiflora sp.	15.77	–	–
Forbs			
Achyranthes aspera Linn.	10.57	–	–
Rauwolfia serpentina Benth.	–	45.05	–
Grass			
Oplismenus compositus (Linn.) O.K.	71.71	241.56	156.91

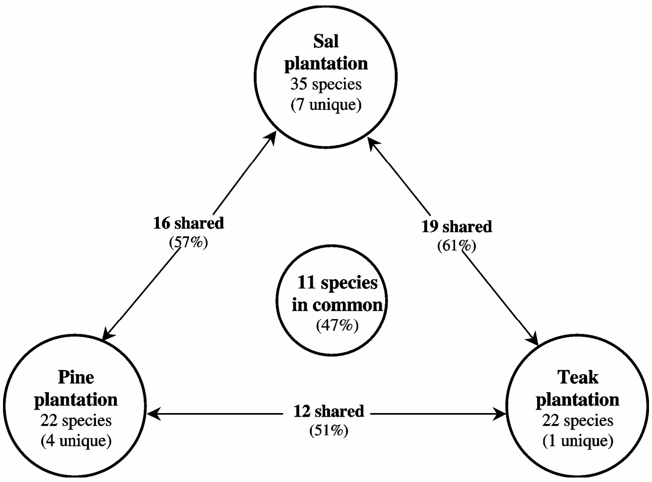

Figure 3. The number of species found in each plantation site and the number of species shared between plantations. Value in parenthesis is the similarity between sites on the basis of number of shared species calculated using modified Sørenson's quantitative index[33].

Life-form composition differed significantly among the three plantations. Sal plantation had significantly higher density ($P < 0.05$) and basal area ($P < 0.05$) of trees, tree saplings and seedlings. For shrub and forb life forms, pine plantation had significantly higher density ($P < 0.01$) and basal area ($P < 0.05$). Teak plantation had a significant higher density ($P < 0.05$) and basal area ($P < 0.01$) of climbers and grasses.

Similarity between the plantation sites was studied on the basis of the presence of various life forms. All the three sites were most closely related (100% similarity) on the basis of presence of *O. compositus*, a grass, and totally different (0.0% similarity) on the basis of presence of forbs and seedlings of trees, shrubs and climbers. Sal and teak plantations were the most closely related sites on the basis of presence of all life forms, shrubs and climbers, whereas sal and pine plantations were the most closely related sites on the basis of presence of trees and saplings of trees (Table 4).

Population structure and succession

Population structure of top (on the basis of IVI) two/three species was studied by plotting relative density of a species against the diameter class to assess the succession in all the three plantations (Figure 4). We found that the planted species were not regenerating, because no seedlings and saplings were present in all the three sites, but the early successional species such as *C. camphora*, *A. chinense*, *M. philippensis* and *S. cumini* have colonized the gaps and started establishing themselves in the plantation sites.

Species richness and diversity

Species richness of all three layers was maximum in sal plantation followed by teak plantation, whereas least number (all layers) of species was present in pine plantation (Table 5). Highest beta diversity for all the three layers was reported in pine plantation. The values of Shannon–Wiener diversity index (H') were highest in tree layer of teak plantation and in shrub and herb layers for sal plantation. The values of evenness showed that the vegetation of teak plantation was most evenly distributed in all the layers. Except for evenness of shrub layer, ANOVA of all the richness and diversity indices was statistically significant at different probabilities (Table 5).

Correlation analysis

Correlation analysis was performed among various soil attributes, tree density and richness, diversity indices and evenness of shrub and herb layers. The soil attributes, i.e. pH, soil moisture (%) and organic carbon (%) significantly influenced richness and diversity attributes of both shrub and herb layers. pH was positively correlated ($r = 0.98$, $P < 0.05$) with H' of herb layer, and negatively correlated with concentration of dominance (Cd) of herb ($r = 0.97$, $P < 0.05$) and shrub ($r = 0.98$, $P < 0.05$) layers. Soil moisture was positively correlated to richness of species of tree ($r = 0.99$, $P < 0.01$) and herb layers ($r = 0.97$, $P < 0.05$), and H' of herb layer ($r = 0.99$, $P < 0.01$), whereas it was negatively correlated with Cd of herb layer ($r = 0.97$, $P < 0.05$). Organic carbon was negatively correlated to the evenness of shrub layer ($r = 0.98$, $P < 0.05$) and positively correlated with Cd of shrub layer ($r = 0.99$, $P < 0.01$). The tree density was negatively correlated to Cd of shrub ($r = 0.99$, $P < 0.01$) and herb layers ($r = 0.98$, $P < 0.05$) and evenness of shrub layer ($r = 0.97$, $P < 0.05$).

Table 4. Jaccard's percentage of similarity of life forms present in various plantation sites of New Forest, Dehradun

Life form	Sal	Pine	Teak
All life forms			
Sal	1.00	0.32	0.33
Pine	–	1.00	0.30
Teak	–	–	1.00
Trees			
Sal	1.00	0.20	0.15
Pine	–	1.00	0.10
Teak	–	–	1.00
Saplings of trees			
Sal	1.00	0.40	0.36
Pine	–	1.00	0.38
Teak	–	–	1.00
Shrubs			
Sal	1.00	0.44	0.50
Pine	–	1.00	0.50
Teak	–	–	1.00
Climbers			
Sal	1.00	0.50	0.67
Pine	–	1.00	0.25
Teak	–	–	1.00
Seedlings of trees, shrubs and climbers			
Sal	1.00	0.00	0.13
Pine	–	1.00	0.00
Teak	–	0.00	1.00
Forbs			
Sal	1.00	0.00	0.00
Pine	–	1.00	0.00
Teak	–	–	0.00
Grasses			
Sal	1.00	1.00	1.00
Pine	–	1.00	1.00
Teak	–	–	1.00

Discussion

After major site degradation like agriculture and grazing (pastures), tree plantations can accelerate the restoration process while providing an income and other resources to local people. Tree plantations can stabilize soil conditions, attract animals, and help with the overall re-colonization of native plants by improving conditions for growth[22,37]. An example is the 80-yr-old plantations of New Forest, FRI, Dehradun, where the diversity of various plant life-forms[20] and local fauna has increased[16–18] since the inception of plantations in place of agricultural fields.

Forest plantations change the soil properties of a site[38–40]. As the soil properties prior to planting are unknown, we cannot conclude that the presence of one species has increased or another species lowered them. In this study, we observed significant difference in the soil properties

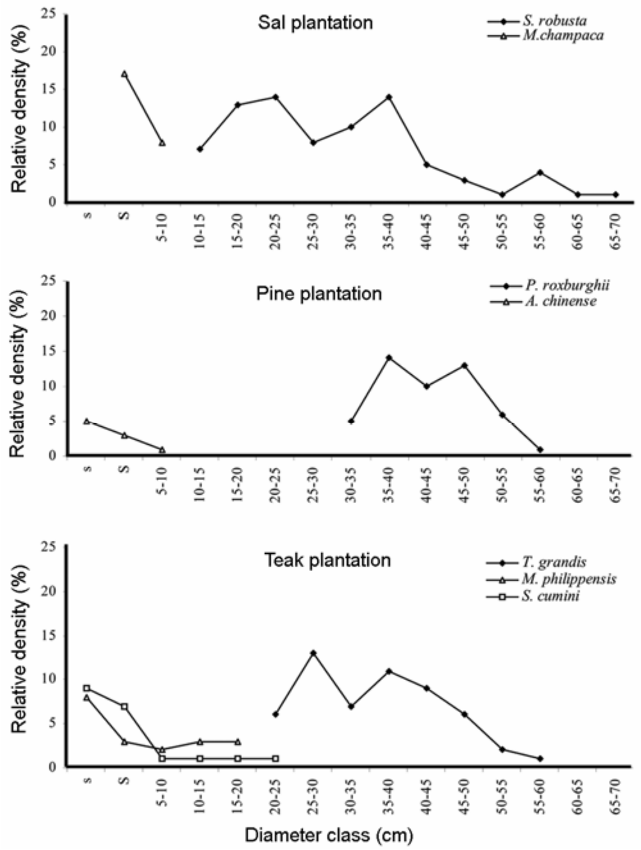

Figure 4. Population structure of the dominant tree species of all three plantation sites in New Forest. In the diameter class, *s* is for seedlings and *S* for saplings of tree species.

Table 5. Richness, diversity index and evenness of tree, shrub and herb layers in various plantation sites

Parameter	Component	Sal	Pine	Teak	$F_{2,6}$ value	*P*-value
Species richness (NO)	Tree layer	8[a]	4[c]	7[b]	13.00	0.007**
	Shrub layer	29[a]	18[b]	18[b]	40.33	0.000***
	Herb layer	8[a]	3[c]	4[b]	21.00	0.002**
Simpson's index (Cd)	Tree layer	0.73[a]	0.80[a]	0.48[b]	23.81	0.001**
	Shrub layer	0.09[b]	0.14[a]	0.10[ab]	7.88	0.021*
	Herb layer	0.32[b]	0.68[a]	0.36[b]	31.47	0.001**
Shannon–Wiener index (*H′*)	Tree layer	0.71[b]	0.47[c]	1.16[a]	23.51	0.001**
	Shrub layer	2.98[a]	2.50[b]	2.55[ab]	6.35	0.033*
	Herb layer	1.54[a]	0.60[b]	1.21[a]	17.76	0.003**
Evenness (J)	Tree layer	0.25[c]	0.40[b]	0.46[a]	6.98	0.027*
	Shrub layer	0.68	0.67	0.71	0.44	0.661[ns]
	Herb layer	0.58[b]	0.61[b]	0.84[a]	16.75	0.004**

Values given are means. Fisher's LSD was applied when ANOVA detected significant difference ($P < 0.05$) between plantations for various diversity and evenness indices. Values within a row followed by the same letter do not differ significantly. Probability values are significant at $P < 0.05$, 0.01 and 0.001 when *, ** and *** respectively, follow the *P* value, and are non-significant in the case of ns.

of the three plantations. Soil pH and moisture (%) were significantly ($P < 0.01$) higher in sal plantation and soil carbon (%) in pine plantation. The higher pH observed in sal (a deciduous species) plantation may be a result of rapid cycling of cations through litterfall[40] and high plant and life-form diversity and density. In a study of 50-yr-old stands planted in an abandoned agricultural field in northern United States, Binkley and Valentine[39] observed both higher soil pH and greater cation content in stands of *Fraxinus pennsylvanica*, a deciduous species, than *Pinus strobes* and *Picea abies*. Other studies have also documented changes in soil pH following changes in vegetation. In Australia, replacement of *Eucalyptus micrantha* forest with plantations of *Pinus elliotii* lowered the pH from 5.4 to 4.9 (ref. 38). Soil moisture (%) is an important attribute for the moist sal forests of the Doon Valley[41] and values of soil moisture in this study were in the range of these studies. But, the values of soil moisture in the present study are not reliable, as they represent values of a one-time study and not mean of periodic studies. High soil carbon content in pine plantation is in accordance with the natural and planted habitats of pine[29,42]. The possible reason for higher soil carbon in pine plantation may be low decomposition rate and high lignin content in the leaves of pine, both of which increase soil organic matter and thus carbon.

Long-term records of woodland succession on farmland are extremely rare[43,44]. Results of population structure of these plantations show that the colonization of early successional tree species is in its initial stage in sal and pine plantations, whereas in teak plantation, *M. philippensis* and *S. cumuni* have established themselves as shown by good number of seedlings, saplings and young crops. Although planted species were the most dominant taxa (according to density and importance values) in their respective sites, their population structure clearly shows that these species will soon be replaced by the early successional species as the most dominant ones. This is also supported by the significant decrease (from 63.5% to 84.8%) in the density of planted species since the inception of plantations in 1926. Possible reasons for the replacement of planted species may be canopy openings created after their mortality due to age, attack of pathogens or poor management. These canopy gaps resulted in favourable light conditions for early successional species[45].

In the present study, we found that succession in three plantation sites was moving on different lines as shown by variation in colonizing species in these sites and low similarity between sites on the basis of tree, shrub and herb life-forms. In case of sal, environmental conditions, especially soil, are favourable for its growth and dominance. It seems that various natural processes like the attack of *Hoplocerambyx spinicornis* are stabilizing the population to 576 trees ha^{-1} density, which is its normal density in the Doon Valley[41,47]. We did not find seedlings and saplings, but if the predominant disturbance of wild boars is taken care of, sal being the residential climax species will start regenerating again. For pine and teak plantations, however, the environmental conditions are not favourable for these species as they are not residential species of the Doon Valley and these species may also have stopped producing viable seeds as shown by the absence of individuals in seedling, sapling and lower diameter classes (up to 20–25 cm) of population structure.

The values of species richness were compared with the earlier study[20] of sal, teak and pine plantations. The results of this comparison show a significant increase (11.5–80.0%) in the total richness of these plantations. Species richness of herb layer has decreased (37.5% and 50.0%)

and shrub layers increased (37.9% and 44.4%) in sal and teak plantations respectively, since 1988. In pine plantation, no change was observed for herb and shrub layers; however, richness of the tree layer increased by 42.9%. These results are in accordance with Nicholson and Monk[48], who reported that in early pine stage (30–60 yrs) ground-layer richness stabilized at about 60% of maximum levels, but the number of woody species continues to increase, whereas herb species decline during succession. Somewhat later in the pine period (70 yrs) shrubs and understorey species attained their maximum richness. High species richness and diversity of shrub layer in the present study also support the above statement and so does the least-developed herb layer and presence of a number of understorey species like *M. philippensis, A. chinense*, *C. camphora*, *M. champaca*, *D. malabaricum*, etc. Reduction in herb richness may be due to the increase in shrub richness and dominance, which limits the supply of sunlight and other resources to the ground flora. Whittaker[49] stated that the dominance of one stratum may affect the diversity of another.

Plantations differ from natural forest ecosystems in a number of characteristics, but there is increasing interest in the potential for plantations to serve as nurse crops for establishing the native forest species[40]. Flinn and Vellend[50] stated that at stand ages between 70 and 80 years, the plantations approach a forest species comparable with that of many ancient woodlands, because all forest species of the regional species pool colonize plantations. Sal is the only planted species present naturally in the Doon Valley. We compared sal plantation with the natural sal forests[41,46,47] of the Valley and found that as many as six of the total eight tree species present in sal plantation (present study) were also present in these forests. Only *C. camphora* (exotic) and *M. champaca* (non-residential native species) are not reported in the natural sal forests of the Doon Valley. The source of these two species is the nearby arboretum, which houses 972 indigenous and exotic species[51].

It is generally hypothesized that in the absence of any major disturbance factors like silivicultural operation aimed at extraction of wood, major fires and insect attack, the homogenous stand structure is replaced by a more heterogeneous mixed stand structure. This heterogeneity is more due to the appearance of light-driven heliophytes and sciophytes in the understorey vegetation. Eventually as the succession proceeds, plantation forests will transform into secondary forests rich in vegetation and life forms. In the present study, we have also found that species richness (totally 44 plant species; 22 trees, 25 shrubs, 4 climbers, 2 forbs and 1 grass) and diversity of life forms of the studied plantations has increased since the setting up of plantations on agricultural fields in 1926 (assuming that only planted species were in the field at that time, as other species are weeded out at the time of plantation of the species). Species richness of these plantation sites was higher than the values reported for various natural forests by Pande[46] and Gautam *et al.*[41] for the Doon Valley, and Singh *et al.*[52] for Central Himalaya, and lower than the values reported by Uma Shanker[53] for Eastern Himalaya, Pandey and Shukla[54] for sal plantations in Gorakhpur, eastern Uttar Pradesh, India and Nicholson[55] for Asia.

In all the plantation sites, shrub layer was the most developed strata having the highest species richness and diversity. Dominance of the shrub layer may be assured due to wide canopy gaps, anthropogenic disturbances like collection of fuelwood and fodder, thick layer of organic matter and acidic soils. Shrubs having great elasticity can tolerate these stress conditions. *C. viscosum* was the most dominating shrub species in all the plantations. Dominance of *C. viscosum* may be ascribed to its high adaptability to acidic soils and humus-rich soils[41]. *L. camara*, a notorious weed, and *M. koenigii* have colonized the canopy gaps as both the species flourish better in open areas where plenty of sunlight is available.

Plantations are often treated as a source of income and destructor of biodiversity, with suitable management, both commercial benefits as well as increase in biodiversity can be achieved. Ito *et al*.[19] proposed different strategies for the management of plantations with the objectives of fulfilling perpetual commercial log supply, accommodation of multiple benefits and removing disturbance factors in order to allow the plantations to develop into semi-natural forest vegetation. They further reiterated that this decision about adoption of particular management strategies should be based on ecosystem functioning in terms of the species diversity of a region. To achieve this goal, a study of vegetation of plantation ecosystems at various successional stages is important. These studies help in framing proper management strategies for different aged plantations and forests. In the present study, we found high tree and shrub diversity along with high life-form diversity in three 80-yr-old plantations, with a reduction in the density of the planted species. These plantations, presently colonized by early successional species, will develop into a secondary forest in the due course of succession, as reported by Martin *et al.*[56]. Therefore, we can conclude that selective logging and removing disturbance factors will help in achieving both the goals of commercial logging and maintenance of local biodiversity. Also for plantations residential native species are better than the non-residential species.

1. Puyravaud, J.-P., Davidar, P. and Laurance, W. F., Cryptic destruction of India's native forests. *Conserv. Lett.*, 2010, **3**(6), 390–394.
2. ITTO, Encouraging industrial forest plantations in the tropics: report of a global study, International Tropical Timber Organization, Yokohama, Japan, 2009.
3. Hill, M. O., The development of a flora in even-aged plantations. In *The Ecology of Even-Aged Forest Plantations* (eds Ford, E. D., Malcolm R. C. and Atterson, J.), Institute of Terrestrial Ecology, Cambridge, 1979, pp. 175–192.

4. Hunter, M. L., *Wildlife, Forests and Forestry: Principles of Managing Forests for Biological Diversity*, Prentice-Hall, New Jersey, 1990.
5. Shahabuddina, G. and Rao, M., Do community-conserved areas effectively conserve biological diversity? Global insights and the Indian context. *Biol. Conserv.*, 2010; doi:10.1016/j.biocon.2010.04.040
6. Krishnaswamy, V. S. and Puri, G. S., Results of an experiment to study the succession of ground flora species under forest plantations raised on old agricultural land in the new forest, Dehradun, India. *Indian For.*, 1954, **80**, 522–530.
7. Lugo, A. E., The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. *For. Ecol. Manage.*, 1997, **99**, 9–19.
8. Parrotta, J., Turnbull, J. and Jones, N., Catalyzing native forest regeneration on degraded tropical lands. *For. Ecol. Manage*., 1997, **99**, 1–7.
9. Powers, J. S., Haggar, J. P. and Fisher, R. F., The effect of overstory composition on understory woody regeneration and species richness in seven year old plantations in Costa Rica. *For. Ecol. Manage*., 1997, **99**, 43–54.
10. Ashton, M., Gunatilleke, C., Singhakumara, B. and Gunatilleke, I., Restoration pathways for rain forest in southwest Sri Lanka: a review of concepts and models. *For. Ecol. Manage.*, 2001, **525**, 1–23.
11. Carnevale, N. J. and Montagnini, F., Facilitating regeneration of secondary forests with the use of mixed and pure plantations of indigenous tree species. *For. Ecol. Manage*., 2002, **163**, 217–227.
12. Rajvanshi, A., Soni, S., Kukreti, U. D. and Srivastava, M. M., A comparative study of undergrowth of Sal forest and Eucalyptus plantation at Golatappar, Dehra Dun during rainy season. *Indian J. For.*, 1983, **6**, 107–119.
13. Mathur, H. N. and Soni, P., Comparative account of undergrowth under eucalyptus and sal in three different localities in Doon Valley. *Indian For.*, 1983, **109**, 882–890.
14. George, S., Kumar, B. M. and Rajiv, G. R., Nature of secondary succession in the abandoned Eucalyptus plantations of Neyyar (Kerala) in peninsular India. *J. Trop. For. Sci.*, 1993, **5**, 372–386.
15. Webb, E. L. and Shah, R. N., Structure and diversity of natural and managed sal (*Shorea robusta* Gaertn.f.) forest in the Terai of Nepal. *For. Ecol. Manage.*, 2003, **176**, 337–353.
16. George, J., Birds of New Forest – 1957–62. *Indian For.*, 1962, **88**, 442–444.
17. Mohan, D., Birds of New Forest: new additions. *Indian For.*, 1993, **119**, 498–504.
18. Singh, A. P., New Forest, Dehradun, India: a unique man-made habitat for butterflies in the lower western Himalayas. *Indian For.*, 1999, **125**, 913–923.
19. Ito, S., Nakagawa, M., Buckley, G. P. and Nogami, K., Species richness in sugi (*Cryptomeria japonica* D. DON) plantations in southeastern Kyushu, Japan: the effects of stand type and age on understorey trees and shrubs. *J. For. Res.*, 2003, **8**, 49–57.
20. Pande, P. K., Bisht, A. P. S. and Sharma, S. C., Comparative vegetation analysis of some plantation ecosystems. *Indian For*., 1988, **114**(7), 379–389.
21. Parrotta, J. A., The role of plantation forests in rehabilitating degraded tropical ecosystems. *Agric*., *Ecosyst. Environ*., 1992, **41**, 115–133.
22. Parrotta, J. A., Influence of overstorey composition on understorey colonization by native species in plantations on a degraded tropical site. *J. Veg. Sci*., 1995, **6**, 627–637.
23. Parrotta, J. A., Catalyzing native forest regeneration on degraded tropical lands. *For. Ecol. Manage.*, 1997, **99**, 1–8.
24. Duncan, R. S. and Chapman, C. A., Consequences of plantation harvest during tropical forest regeneration in Uganda. *For. Ecol. Manage.*, 2003, **173**, 235–250.
25. Cusack, D. and Montagnini, F., The role of native species plantations in recovery of understorey woody diversity in degraded pasturelands of Costa Rica. *For. Ecol. Manage.*, 2004, **188**, 1–15.
26. Finegan, B., Pattern and process in neotropical secondary rainforests: the first 100 years of succession. *Trends Ecol. Evol.*, 1996, **11**, 119–124.
27. Foster, D. R., Fluet, M. and Boose, E. R., Human or natural disturbance: landscape-scale dynamics of the tropical forest of Puerto Rico. *Ecol. Appl.*, 1999, **9**, 555–572.
28. Champion, H. G. and Seth, S. K., *A Revised Classification of the Forest Types in India*, Manager Publications, GOI, New Delhi, 1968.
29. Pande, P. K. and Sharma, S. C., Seasonal changes in organic matter constituents in some plantation soils of Doon Valley. *Int. J. Ecol. Environ. Sci*., 1989, **15**, 37–45.
30. Mueller-Dombois, D. and Ellenberg, H., *Aims and Methods of Vegetation Ecology*, John Wiley, New York, 1974.
31. Magurran, A. E., *Ecological Diversity and its Measurement*, Princeton University Press, New Jersey, 1988.
32. Pielou, E. C., The measurement of diversity in different types of biological collections. J. *Theor. Biol.*, 1966, **13**, 131–144.
33. Bray, J. R. and Curtis, J. T., An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.*, 1957, **27**, 326–349.
34. Curtis, J. T. and Cottam, G., *Plant Ecology Work Book*, Laboratory Field Reference Manual, Burgers Publishing Co., Minnesota, USA, 1956.
35. Kadavul, K. and Parthasarathy, N., Structure and composition of woody species in tropical semi-evergreen forest of Kalrayan Hills, Eastern Ghats, India. *Trop. Ecol.*, 1999, **40**, 247–260.
36. Kalra, Y. P. and Maynard, D. G., Organic carbon determination by wet digestion (modified Walkley–Black procedure). In *Methods Manual for Forest Soil and Plant Analysis*, 1991, pp. 27–30.
37. Hartley, M. J., Rationale and methods for conserving biodiversity in plantation forests. *For. Ecol. Manage.*, 2002, **155**, 81–95.
38. Jones, J. M., and Richards, B. N., Effect of reforestation on turnover of ^{15}N-labeled nitrate and ammonia in relation to changes in soil microflora. *Soil Biol. Biochem.*, 1977, **9**, 383–392.
39. Binkley, D. and Valentine, D., Fifty-year biogeochemical effects of green ash, white pine and Norway spruce in a replicated experiment. *For. Ecol. Manage.*, 1991, **40**, 13–25.
40. Harrington, R. A. and Ewel, J. J., Invasibility of tree plantations by native and non-indigenous species in Hawaii. *For. Ecol. Manage.*, 1997, **99**, 153–162.
41. Gautam, M. K., Tripathi, A. K. and Manhas, R. K., Plant diversity and structure of sub-tropical *Shorea robusta* Gaertn. f. (Sal) forests of Doon Valley, India. *Indian J. For.*, 2008, **31**(1), 131–140.
42. Jha, M. N., Gupta, M. K., Saxena, A. and Kumar, R., Soil organic carbon store in different forests of India. *Indian For.*, 2003, **129**, 714–724.
43. Harmer, R., Peterken, G., Kerr, G. and Poulton, P., Vegetation changes during 100 years of development of two secondary woodlands on abandoned arable land. *Biol. Conserv.*, 2001, **101**, 291–304.
44. Brunet, J., Plant colonization in heterogeneous landscapes: an 80-year perspective on restoration of broadleaved forest vegetation. *J. Appl. Ecol.*, 2007, **44**, 563–572.
45. Whitmore, T. C., Tropical rain forest dynamics and its implications for management. In *Rain Forest Regeneration and Management*, Man and Biosphere Series 6, UNESCO, Parthenon Publishing Group, Paris, New Jersey, 1991, pp. 67–90.
46. Pande, P. K., Comparative vegetation analysis and sal (*Shorea robusta*) regeneration in relation to their disturbance magnitude in some sal forests. *Trop. Ecol*., 1999, **40**, 51–61.
47. Chauhan, P. S., Manhas, R. K. and Negi, J. D. S., Demographic and diversity analysis of trees species in sal (*Shorea robusta*

Gaertn. f.) forests of Doon Valley. *Ann. For.*, 2001, **9**(2), 188–198.
48. Nicholson, S. A. and Monk, C. D., Plant diversity in old field succession on the Georgia piedmont. *Ecology*, 1974, **55**, 1075–1085.
49. Whittaker, R. H., Evolution and measurement of species diversity. *Taxon*, 1972, **21**, 213–251.
50. Flinn, K. M. and Vellend, M., Recovery of forest plant communities in post-agricultural landscapes. *Front. Ecol. Environ.*, 2005, **3**, 243–250.
51. Raizada, M. B. and Hingorani, G. R., *A List of Plants Grown in the Arboretum and Botanical Garden of Forest Research Institute*, Dehradun, 1954, p. 49.
52. Singh, A., Reddy, V. S. and Singh, J. S., Analysis of woody vegetation of Corbett National Park, India. *Vegetatio*, 1995, **120**, 69–79.
53. Uma Shankar, A case of high tree diversity in a sal (*Shorea robusta*)-dominated lowland forest of Eastern Himalaya: floristic composition, regeneration and conservation. *Curr. Sci*., 2001, **81**, 776–786.
54. Pandey, S. K. and Shukla, R. P., Plant diversity in managed sal (*Shorea robusta* Gaertn.) forests of Gorakhpur, India: species composition, regeneration and conservation. *Biodivers. Conserv.*, 2003, **12**, 2295–2319.
55. Nicholson, D. I., A study of virgin forest near Sandakan, North Borneo. In Proceedings of the Symposium on Ecological Research into Humid Tropics Vegetation, Kuching, UNESCO, Paris, 1965.
56. Martin, P. H., Sherman, R. E. and Fahey, T. J., Forty years of tropical forest recovery from agriculture: structure and floristics of secondary and old-growth riparian forests in the Dominican Republic. *Biotropica*, 2004, **36**(3), 297–317.

ACKNOWLEDGEMENTS. We thank the scientists of the Botany Division, FRI, Dehradun for identification of the plant species, and the staff of Forest Ecology and Environment Division, FRI for their cooperation during field study and analysis work in the laboratory. We also thank the anonymous reviewer for valuable comments.

Received 27 January 2010; revised accepted 11 November 2010