

Value of Ecological Services of Exotic *Eucalyptus tereticornis* and Native *Dalbergia sissoo* Tree Plantations of North-Western India

Kamaljit K. Sangha and Rajesh. K. Jalota

Abstract: Value assessment of exotic and native tree plantations based upon short-term gains from wood has suggested that exotic plantations are more profitable than native tree plantations. Such estimations have largely ignored the value of ecological services. This study estimates the ecological-economic value of forest floor vegetation, soil nutrients and return of nutrients from litter in exotic *Eucalyptus tereticornis* and native *Dalbergia sissoo* plantations in north-western India. Two age groups of plantations, i.e. 6-8 years (young) and 19-21 years (old) were selected to compare net benefits as exotics deliver most of their benefits (especially wood) by eight years of age, while natives deliver benefits after 12-15 years of age. The diversity of plant species, nutrient content in soil and nutrient return through litter were greater in *Dalbergia* than in *Eucalyptus* plantations. A comparison of plantations at eight years suggested that the total monetary value of tangible (timber, fuel, fodder, eucalypt oil and ash) and ecological services (phytodiversity, soil nutrient content and nutrient return through litter) was 1.6 times greater in *Eucalyptus* than in *Dalbergia* plantations, chiefly because of timber. However, ecological benefits were 1.8 times greater in *Dalbergia* than in *Eucalyptus* plantations. At 19-21 years of age, *Dalbergia* supported 2.7 times more total benefits than *Eucalyptus*. Thus there seems to be a need to consider both tangible and intangible services over the long term and to carry out total value assessment of exotic and native tree plantations to design appropriate policy.

Keywords: *Eucalyptus tereticornis*, *Dalbergia sissoo*, monoculture plantations, ecological services.

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INTRODUCTION

PRE-1988 FOREST POLICIES in India promoted wide-scale plantations of exotic tree species such as *Populus deltoides*, *Acacia* spp., *Eucalyptus* spp., *Leucaena leucocephala* and *Prosopis juliflora* to meet the increasing industrial and fuel-wood demands of the public (Bajaj 1997). *Eucalyptus tereticornis* was preferred to other exotic trees because of short-term visible gains for straight bole, fast growth rate, more productivity per unit area and least post-plantation care (Mathur et al. 1984; Kushalappa 1985; Rajan 1987; Sharma et al. 1988; Kapur and Dogra 1989; Chatha et al. 1991). But the scientific community, private growers and the public have been divided over the merits and demerits of *Eucalyptus* plantations for economic gains from wood, and for ecological functions such as water usage, understorey ground cover and allelopathic effects (Mathur and Soni 1983; Dabral and Raturi 1985; Shiva and Bandyopadhyay 1987; Bahuguna et al. 1990; Narain et al. 1990; Geetha et al. 1994; Jalota and Kohli 1996; Jalota 1997; Jalota et al. 2000; Sangha et al. 2000; Singh and Singh 2003).

The total value estimations based on monetary returns from wood in short rotation exotic plantations led to undervalue native trees such as *Dalbergia sissoo*, mainly due to their longer life span. Many native trees, e.g. *Dalbergia* have better timber quality than *Eucalyptus* (Shiva and Bandyopadhyay 1987) and are preferentially used for good quality furniture. The ecological services (shade, shelter, fodder and medicinal value) rendered by native trees are essential for the common man, especially in some rural communities of India, but the value of these 'unseen' ecological benefits is invariably ignored in our accounting system for forest resources. Moreover, the negative effects of exotic plantations, such as reduced plant diversity (Jalota 1997) are neglected in such an accounting system. Hence, they fail to provide an accurate estimate of costs and benefits of native or exotic plantations.

Most of the reports available to date (Bahuguna et al. 1990; Chatha et al. 1991; Kushalappa 1985; Mathur et al. 1983; Rajan 1987; Shiva and Bandyopadhyay 1987) have focused on either economic benefits from wood products or on the ecological aspects of exotic and native tree plantations, but none has integrated ecological and economic potential for tangible and intangible benefits. Jalota and Sangha (2000) compared the tangible benefits of *Dalbergia* and *Eucalyptus* plantations, and showed that over a short-term the tangible benefits from *Eucalyptus* were greater than *Dalbergia*, while these benefits were greater for *Dalbergia* if considered over 21 years of age. This led us to consider the importance of ecological services that are otherwise overlooked such as phytodiversity, nutrient return from litter and soil nutrients, and to rationally evaluate their ecological and economic potential in *Eucalyptus* and *Dalbergia* monoculture plantations for two age groups, i.e. young (6-8 year) and old (19-21 year). The monetary equivalence of ecological services is reported here in addition to tangible gains, to determine the total value of *Eucalyptus* and *Dalbergia* plantations from the ecological and economic perspectives.

METHODS

Two sets of *Eucalyptus* and *Dalbergia* plantations, each 6-8 year (young) and 19-21 year (old), in triplicate, were selected for the study during 1996-1999, in the territory of Chandigarh, in north-west India (30° 42' N, 76° 54' E 333) under similar edapho-climatic conditions.

The selection of these age groups was important as 6-8 years and 19-21 years represent the mature age in *Eucalyptus* and *Dalbergia* respectively. A representative area of 4 ha was marked at each site for various measurements.

Ground Vegetation

Species diversity and biomass productivity of various plants growing on the floor of *Eucalyptus* and *Dalbergia* plantations were measured during summer, autumn, winter and spring in three consecutive years following the quadrat method (Misra 1968). Ten 1 m x 1 m quadrats were laid randomly in each season at each of the sites. Indices of diversity, dominance, richness and evenness were computed using the statistical software ECOSTATS. The importance value index (IVI) (sum of relative values of density, frequency and dominance) was also calculated for each species. The formulae used to calculate density, frequency and dominance (Misra 1968) are as follows:

- Density of a species = number of plants of a certain species/area
- Relative density = density of a species/total density of all species x 100
- Frequency = number of quadrats of occurrence of a species/total quadrats sampled
- Relative frequency = frequency of a species/total frequency of all species x 100
- Dominance = basal area of a species/total area sampled
- Relative dominance = basal area of a species/basal area of all the species x 100

The average value of the importance value index and the relative biomass of each species was calculated from the seasonal readings taken over a year.

The ground floor species contribute to the ecological sustainability of an ecosystem by contributing to soil stability, maintaining hydrological and nutrient balance. Some of these species are also used in food preparation. A review of the literature (Singh et al. 1983; Kamal 1988; Husain et al., 1992; Rastogi and Mehrotra 1993; CSIR 1994) and local surveys (conducted by the authors) revealed that the plant species found on the floors of *Eucalyptus* and *Dalbergia* had five main uses: food, fuel, fodder, medicine and soil stabilisation.

In the absence of local markets to capture the value of these usages, we opted for the ordinal analysis method (Henderson and Quandt 1980) for assigning monetary value to each component of ground-floor vegetation. The monetary equivalence for each plant species was estimated in relation to its use for the selected five categories: food, fuel, fodder, medicine and soil

stabilisation. Each species was assigned scores based on the lifespan (longevity) and biomass production. On the basis of longevity, scores were assigned as 1 for annual, 2 for biennial and 3 for perennial life cycles, and for biomass production, scores were assigned according to the plant weight (1 for weight <10 g/plant, 2 for 10-100 g/plant and 3 for >100 g/plant).

The total scores for each species for all five categories were calculated in relation to their life cycle and biomass production as number of uses \times (life cycle score + biomass score). For example, a plant with three uses (food, medicine and soil stabilisation) having a perennial life cycle and biomass > 100 g, was scored 18. In the absence of any information on a particular use of a species, its score was assigned the value zero. The function of soil stabilisation was considered in all species, so its value was counted for all species. A plant with all five uses, perennial life cycle and biomass productivity >100 g/plant, scored the maximum, i.e. 30. The total economic value was then computed for all the usages by applying the following method (Chopra et al. 1997 a and c):

$$Pt = Pi \times Si / St$$

where

Pt = Total economic value for all the uses of a plant species;

Pi = Mean market price of a species per plant;

Si = Score obtained for the various uses of a plant;

St = Total maximum score for all the five uses.

The total monetary value of phytodiversity in *Eucalyptus* and *Dalbergia* plantations was calculated according to the total number of plants per hectare in each plantation. The total number of individuals of a species per hectare per year was calculated from the seasonal data collected over year (as mentioned earlier). The monetary value of each plant type was then multiplied with the number of plants per hectare of a species to estimate the total value per hectare.

While the utility and adequacy of this approach need to be confirmed by other studies, it is useful at the small scale (farm) to assess the value of various usages of plant diversity in the absence of any direct market value. A similar approach was used by Belal and Springuel (1996) to estimate the traditional value of particular uses of plants, however they did not calculate the monetary equivalence for a particular use of plant species. The present approach provides an estimate for use and ecosystem function for each plant species. This approach could be particularly useful in developing countries where people make use of wild plants/herbs in their daily diet and rely upon the natural diversity of these plants.

Soil

At each site, six litter-free soil samples were collected at the same time to a depth of 30 cm during summer, autumn, winter and spring for three consecutive years. The samples were air dried and sieved (0.2 mm mesh). The fresh and dry weights were also taken to determine soil moisture content. The samples were bulked for chemical analysis. The available content of phosphorus (Olsen et

al. 1954), nitrogen (Kjeltec system I), potassium (flame photometer), organic carbon (Walkey and Black's titration method, Piper 1950) and micronutrients, viz. Cu, Zn, Fe and Mn (extraction with diethylene triamine penta acetic acid, using atomic absorption spectrophotometer) were analysed. The pH and electrical conductivity (EC) were measured with pH and EC meters. Data were analysed using Duncan's multiple range test (DMRT) (Duncan 1955).

The monetary value was assigned to nutrient content available at a site following the Surrogate Valuation Technique (Chopra et al. 1997b). It uses the information based on a marketable good to infer the value of an associated non-marketable good. This technique provides an economic measure to assign value for soil nutrients based upon the market value of fertilisers.

The value of soil nutrients was computed in relation to the market price of chemical fertilisers (see Chivaura-Mususa et al. (2000) and Guo et al. (2001) for similar approaches). Market surveys were conducted for price value of nitrogen, phosphorus, potassium, copper, zinc, iron and manganese. This helped to account for standing value of soil nutrients and assess it in relation to plantation type.

Soil pH, electrical conductivity (EC), moisture content and organic carbon hold no direct or indirect market value, hence these were evaluated on the basis of quantity and for their positive or negative importance in productivity. For example, soils were scored as -1 for pH < 6.0 (acidic), 2 for pH 6-8.5 (medium range, allows to grow most plant types), and -1 for > 8.5 (alkaline). Soil with EC < 0.8 (normal to grow most plants) was assigned 2 scores, with EC 0.8-1.6 (critical for salt sensitive crops) as -1, and for EC 1.6-2.5 (critical for salt-tolerant crops) as -2 scores. Moisture content was scored as 1 for low (0-3.5%) and 2 for > 3.5%. The content of organic carbon was scored as 1 for < 0.4% (low), 2 for 0.4-0.75% (medium), and 3 for > 0.75% (high).

Total soil value index (%) for pH, EC, moisture content and organic carbon (OC) was calculated according to the following formula:

Total Value Index: S score for soil pH, EC, moisture content and OC at a particular site/total score (i.e. 9) x 100.

Litter Production and Nutrient Release

The amount of litter production was quantified at regular three-month intervals for each season in a year from five permanent 1 m x 1 m quadrats. The measurements were taken only at old plantations of *Eucalyptus* and *Dalbergia*. Surface litter decomposition following the litter bag technique (Pauley and Little 1998), and annual release of nutrients (N, P and K) were studied. Nutrient loss over a one-year period of decomposition was computed in relation to the amount of litter produced at each site.

For monetary valuation, the release of nutrients from litter was considered as return of nutrients to the soil. The surrogate valuation technique (as applied for soil nutrients) was used to estimate the value of a particular nutrient. The monetary value of nutrient return calculated for 19-21 year old plantations was considered to be the same for 6-8 year old plantations in the absence of data from young plantations.

RESULTS

Ground Vegetation

Ecological Evaluation

The density of plants (no. of plants per hectare) in young *Dalbergia* plantations was double that of same age *Eucalyptus* plantations and more than four times that of old *Eucalyptus* plantations (Table 1). Young and old *Eucalyptus* plantations had 17 and 18 ground species of plants respectively, whereas young and old *Dalbergia* plantations supported 34 and 28 plant species (Digital Appendix 1).

Table 1
Values of ground floor vegetation found in 6-8 year and 19-21 year old plantations of *Eucalyptus* and *Dalbergia*

Parameters	6-8 year old plantations		19-21 year old plantations	
	<i>Eucalyptus</i>	<i>Dalbergia</i>	<i>Eucalyptus</i>	<i>Dalbergia</i>
1. Use:				
Food	6	13	8	10
Fuel	7	7	4	6
Fodder	4	13	7	11
Medicine	13	25	15	20
Soil stabilisation	17	34	18	28
2. Total no. of plants per ha (x10 ³)	139	329	221	1034
3. Number of plant species in relation to longevity				
Annual	8	17	7	14
Biennial	1	-	1	-
Perennial	8	17	10	14
4. Number of plant species in relation to biomass per plant (g)				
<10	14	28	16	21
10-100	2	4	1	4
>100	1	2	1	3
5. Total biomass of all plants (g/m ²)	108.23	220.48	64.81	206.13

The plant species specific to *Eucalyptus* were few (three in young and six in old) compared to *Dalbergia* plantations (20 in young and 16 in old) (Digital Appendix 1). The importance value index was maximum for *Cynodon dactylon* in young plantations of *Dalbergia* and *Eucalyptus*. In old plantations, the importance value index was greatest for *Saccharum munja* in *Eucalyptus* and for *C.dactylon* in *Dalbergia* plantations (Digital Appendix 1).

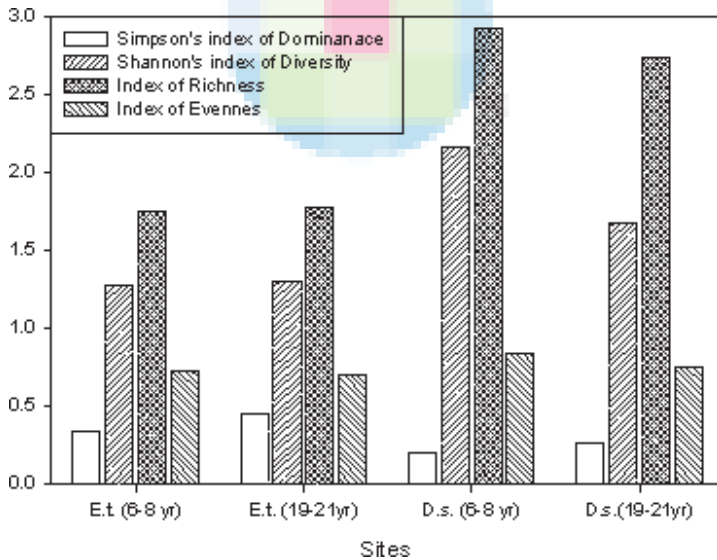
The greater diversity of plant species on the floor of *Dalbergia* compared to *Eucalyptus* was clear from Shannon's index of diversity (Figure 1). The indices of richness and evenness demonstrated uniform distribution of abundance of different plant species in *Dalbergia* compared to *Eucalyptus* plantations (Figure 1).

Economic Evaluation

The number of plant species that have use value for food, fuel, fodder, medicine, and soil stabilisation was greater in *Dalbergia* compared to *Eucalyptus* plantations, regardless of plantation age (Table 1). More plant species with annual and perennial life cycles were present in *Dalbergia* than in *Eucalyptus* plantations. The total biomass productivity of all plants was twice in younger, and more than three times greater in older plantations of *Dalbergia* compared to *Eucalyptus* plantations (Table 1).

Figure 1

Values for Simpson's index of dominance, Shannon's index of diversity, indices of richness and evenness of various plant species found in 6-8 year and 19-21 year old *Eucalyptus* (E.t.) and *Dalbergia* (D.s.) plantations



Based on the criteria of biomass productivity and life cycle of a plant, the monetary equivalence was computed for the five selected uses of a species. In 6-8 year old plantations, *C. dactylon* had the maximum value among all plant species in *Eucalyptus* and *Dalbergia* plantations, but had 1.24 times greater

Ecological services of exotic and native plantations / 99

value in *Dalbergia* than in *Eucalyptus* (Digital Appendix 2). In 19-21 year old plantations, *S. munja* had the maximum value followed by *C. dactylon* in *Eucalyptus* plantations; and *Cannabis sativa* followed by *C. dactylon* had maximum values in *Dalbergia* plantations. The total monetary equivalence for all plant species was 1.83 times and 5.78 times greater in respective young and old plantations of *Dalbergia* compared to *Eucalyptus* plantations (Digital Appendix 2).

Soil Nutrients**Ecological Evaluation**

In both young and old plantations, the content of available N was in the soil was significantly greater in *Dalbergia* plantations (1332.95 kg/ha and 1774.57 kg/ha respectively) compared to that in respective young and old plantations of *Eucalyptus* (1112.8 kg/ha and 1520.74 kg/ha) (Table 2). Similarly, the available content of K was significantly greater in *Dalbergia* plantations (1173.88 kg/ha at young and 703.75 kg/ha at old plantations) compared to that in respective young and old *Eucalyptus* plantations (935.15 kg/ha at young and 454.8kg/ha at old plantation soils). Available content of P did not differ between *Dalbergia* and *Eucalyptus* plantations of the same age group, but it was greater in soils of young plantations (18.51 kg/ha in *Dalbergia*, 17.71 kg/ha in *Eucalyptus*) compared to old plantations (16.09 kg/ha in *Dalbergia*, and 15.33 kg/ha in *Eucalyptus*). *Dalbergia* soils also had greater content of Fe and Mn compared to soils of *Eucalyptus*. Zn content did not show any difference at young age plantations, however, there was a greater content at old age in *Dalbergia* plantations. Only Cu content was greater in *Eucalyptus* than in *Dalbergia* soils (Table 2).

Table 2

Mean values (nutrient content and monetary equivalence (Rs/ha)) of macro- and micro-nutrients, nutrient return from litter (Rs/ha/yr) and the amount and score for soil parameters- organic carbon, pH, electrical conductivity and moisture content, in Dalbergia and Eucalyptus plantations at 6-8 years and 19-21years of growth

Sites	6-8 year old plantations		19-21 year old plantations	
	<i>Eucalyptus</i>	<i>Dalbergia</i>	<i>Eucalyptus</i>	<i>Dalbergia</i>
Macro-nutrients*:				
Available N (kg/ha) content	1112.8 ^d	1332.95 ^c	1520.74 ^b	1774.57 ^a
-Monetary value	9 670^d	11 583^c	13 215^b	15 421^a
Available P (kg/ha) content	17.71 ^a	18.51 ^a	15.33 ^b	16.09 ^b
-Monetary value	398^a	416^a	344^b	362^b
Available K (kg/ha) content	935.16 ^b	1173.88 ^a	454.80 ^d	703.75 ^c
-Monetary value	42 082^b	52 824^a	20 466^d	31 668^c

Table 2...continued

100 / Sangha and Jalota

Micro-nutrients:

Cu (kg/ha) content	4.17 ^a	2.17 ^b	4.07 ^a	0.97 ^c
-Monetary value	6 115^a	3 182^b	5 969^a	1 422^c
Zn (kg/ha) content	2.79 ^{ab}	2.60 ^{ab}	1.52 ^b	3.26 ^a
-Monetary value	4 140^{ab}	3 858^{ab}	2 255^b	4 837^a
Fe (kg/ha) content	8.25 ^b	10.96 ^a	8.32 ^b	10.89 ^a
-Monetary value	12 210^b	16 220^a	12 313^b	16 117^a
Mn (kg/ha) content	7.48 ^c	18.26 ^a	7.04 ^c	12.54 ^b
-Monetary value	10 472^c	25.564^a	9 856^c	17 556^b

Total monetary value

for macro-and micro-

nutrients (Rs/ha) 85 087 113 647 64 418 87 383

Nutrient return from litter

(kg/ha/yr)

N content	-	-	74.18 ^b	246.15 ^a
-Monetary value	-	-	645^b	2139^a
P content	-	-	2.3 ^b	5.98 ^a
-Monetary value	-	-	52^b	135^a
K content	-	-	41.43 ^b	98.57 ^a
-Monetary value	-	-	1864^b	4435^a

Total value for nutrient

return from litter

(Rs/ha/yr)#

Other soil parameters:

Soil organic C (%)	0.69 ^b	0.88 ^{ab}	1.45 ^{ab}	1.95 ^a
-Score value	2	3	3	3
pH	6.67 ^a	7.65 ^a	7.15 ^a	8.04 ^a
-Score value	2	2	2	2
EC (dS/m)	0.87 ^a	0.31 ^a	0.89 ^a	0.42 ^a
-Score value	(-) 1	2	(-) 1	2
Moisture content (%)	1.86 ^b	6.32 ^a	3.66 ^{ab}	5.88 ^a
-Score value	1	2	2	2

Total Soil Value Index (%)

44 100 67 100

Soil texture Sandy loam Sandy loam Sandy loam Sandy loam

Notes: *Different superscripts in a row represent significant difference at 0.05% level after applying DMRT (Duncan 1955).

In the absence of measurements for litter production and nutrient return from litter at 6-8 year old plantation the values were taken the same as for 19-21 year old plantations.

Ecological services of exotic and native plantations / 101

Soil organic carbon was maximum in old *Dalbergia* plantations (1.95%), and differed only with *Eucalyptus* at young age (0.69%) after applying DMRT (at 0.05% level) (Table 2). Although soil pH and EC did not differ significantly between *Dalbergia* and *Eucalyptus* plantations, soil EC was more than double in *Eucalyptus* soils (0.87 dS/m in young and 0.89 dS/m in old plantations) than that in *Dalbergia* soils (0.31 dS/m in young and 0.42 dS/m in old plantations) which could adversely affect plant growth. Soil moisture content was greater in *Dalbergia* (6.32% at young and 5.88% at old plantation) plantations compared to *Eucalyptus* (1.86% at young and 3.66% at old) plantations (Table 2).

Economic Evaluation

The monetary equivalence for available N, K, Fe and Mn was greater in *Dalbergia* than in *Eucalyptus* plantations (Table 2). *Eucalyptus* had greater monetary equivalence for Cu content than *Dalbergia*. Soil Zn content did not differ in its value in *Eucalyptus* and *Dalbergia* plantations, except old *Dalbergia* plantation, which had the maximum value (Table 2).

The total monetary equivalence for all the studied soil nutrients was 1.34 times greater in *Dalbergia* compared to *Eucalyptus* at both young and old age of plantations (Table 2). *Dalbergia* soils had greater score for soil organic carbon and soil moisture than *Eucalyptus* soils. This led to a greater total soil value index in *Dalbergia* (100% in both young and old) compared to *Eucalyptus* soils (50% in young and 75% in old plantations) (Table 2).

Litter Production and Nutrient Return

The amount of litter produced in a year was 1.44 times greater in *Dalbergia* plantations (5698 kg/ha/yr) compared to *Eucalyptus* (3946 kg/ha/yr). The content of N, P and K was greater in litter collected from *Dalbergia* plantations compared to *Eucalyptus* plantations (Table 2), owing to their greater mass and concentration.

Value of Nutrient Return from Litter

The total monetary equivalence for the amount of nutrients released from litter in relation to the total amount of litter produced in *Dalbergia* plantations was 2.61 times greater (6709 Rs/ha) than that at *Eucalyptus* (2561 Rs/ha) (Table 2).

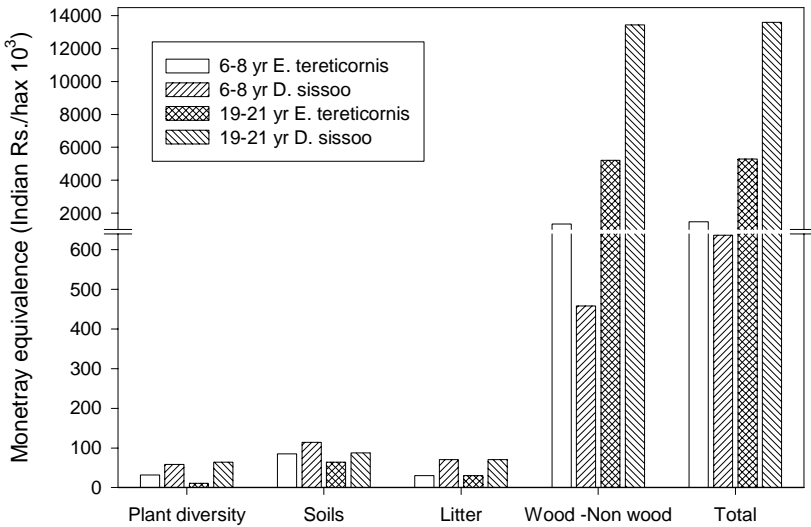
Total Benefits from Phytodiversity, Soil Nutrients and Litter

The ecological benefits represented only 0.09% proportion of total tangible benefits in young *Eucalyptus* and 0.39% of total tangible benefits in young *Dalbergia*, and 0.01% of total tangible benefits in both old *Eucalyptus* and *Dalbergia* plantations (Table 3), when counted only once. But, there is a continuum of benefits from these services over the age of a plantation. Therefore, the value of these

services over the age of a plantation i.e. for 8 year and 21 year was calculated, which represented 0.27% of tangible benefits in young and 0.07% of tangible benefits in old *Eucalyptus*; and 1.38% in young *Dalbergia* and 0.12% of total tangible benefits in old *Dalbergia* plantations (Table 3). Overall benefits from wood, non-wood products, plant diversity, soils and litter nutrient return (computed over the age of a plantation) were 1.6 times greater in *Eucalyptus* than *Dalbergia* at 8 year age of plantations (Table 3 and Figure 2). These were chiefly from timber in young *Eucalyptus* while *Dalbergia* had no timber value at this age, but *Dalbergia* supported 1.8 times greater value of ecological services than that of *Eucalyptus*. At 19-21 years of growth, *Dalbergia* supported 2.7 times more value for its tangible and ecological services than *Eucalyptus* plantations (Figure 2).

Figure 2

Monetary equivalence for understorey plant diversity, soil nutrients, nutrient return through litter decomposition, and wood and non-wood products (timber, fuel-wood, eucalypt oil, fodder and ash) of *Eucalyptus* and *Dalbergia* plantations at 6-8 yrs and 19-21 yrs of growth



Note: Values for nutrient return through litter are x 10² Rs/ha

Increment in total benefits with age of plantation was more in *Dalbergia* (from 1,090,284 Rs/ha at young to 15,008,889 Rs/ha at old) than that in *Eucalyptus* (1,698,686 Rs/ha at young and 5,561,981 Rs/ha at old plantations) (Figure 2 and Table 3).

Table 3

Total monetary benefits (Indian Rs/ha) for various tangible and intangible benefits from Eucalyptus and Dalbergia plantations

Monetary gains (Rs /ha) from:	6-8 year old plantations		19-21 year old plantations	
	<i>Eucalyptus</i>	<i>Dalbergia</i>	<i>Eucalyptus</i>	<i>Dalbergia</i>
Ratio of benefits from plant diversity, soil nutrients, and nutrients return through litter compared to timber and other non-wood benefits, taken for once*	0.09 (119, 328)	0.39 (178, 451)	0.01 (78, 032)	0.01 (157, 986)
Ratio of benefits from plant diversity, soil nutrients, and nutrients return through litter compared to timber and other non-wood benefits, over age of a plantation*	0.27 (359, 015)	1.38 (632, 079)	0.07 (350, 312)	0.12 (1, 570, 046)
Tangible benefits from timber and other non-wood products	1, 339, 671	458, 205	5, 211, 669	13, 438, 843
Total returns (Rs/ha) for plant diversity, soil nutrients and nutrient return through litter, wood and non wood products (timber, fuel, eucalypt oil, ash and fodder) over age of a plantation	1, 698, 686	1, 090, 284	5, 561, 981	15, 008, 889

Note : * Figures in parantheses represent the actual value (Rs/ha).

DISCUSSION

Native plantations of *Dalbergia* supported greater species diversity, soil nutrient content and litter production for more nutrient return than exotic plantations of *Eucalyptus*. The meagre understorey plant diversity in *Eucalyptus* plantations has been attributed to allelopathy (Kohli et al. 1990, Kohli and Singh 1991; Reid et al. 1992; Srivastava et al. 1994; Verma and Totey 1999) and/or the toxic effects of allelochemicals on soil micro-organisms (Dellacasa et al. 1989; Chander et al. 1995). Poor soil status in *Eucalyptus* plantations was also reported by Jha et al. (1999). Despite such evidence for the negative effects of eucalypts in monoculture plantations, it has been favoured over native trees due to the economic gains for wood (Shiva and Bandyopadhyay 1987; Jalota 1997). The ignorance of the costs associated with the negative effects of *Eucalyptus*, and the non-accounting of ecological

services of native trees in total value assessment, resulted in the prediction of greater economic benefits for eucalypts over native trees.

Why are ecological services, such as species diversity or litter, so important? Tilman et al. (1997) report that diverse plants perform different ecosystem functions which contribute to the sustainability of an ecosystem. Ecosystem functions performed by one species may be complementary to the other species. Niche matching and the probability of presence of one species in promoting the existence of other species, are important mechanisms that determine species diversity in a sustainable ecosystem (Tilman 1999). According to the diversity-productivity hypothesis (Tilman et al. 1996; 1997), greater species diversity supports greater biomass productivity. Such a relationship was evident for plants growing under the canopy of *Dalbergia*, which showed greater total biomass compared to plants under *Eucalyptus* plantations, though there could be other factors such as soil nutrients that promote plant growth under the canopy of *Dalbergia*.

In addition to ecosystem functions of diverse plant species, various wild plants growing under native plantations are also important as medicine and food. The diversity and growth of plants are related to soil nutrient content and nutrient return from litter decomposition in an ecosystem. In *Eucalyptus* and *Dalbergia* monoculture plantations, the ground vegetation, soil nutrients and litter, which provide habitat for soil microorganisms, are important for ecosystem sustainability. Ground vegetation is also important to some extent to fulfil the needs of the local people. Therefore, the main ecological benefits from understorey plants in terms of food, fodder, fuel, medicine and soil stabilisation, from soil for major nutrients that support plant growth, and nutrient return from litter are considered in this study. There are many other ecological services e.g. carbon sequestration, aesthetic value of a plantation and the existence value of diverse plant species, which also contribute to the total value of an ecosystem, which are not accounted for in this study.

The study highlights the importance of native trees for their value of ecological services as the benefits were twice greater in *Dalbergia* than in *Eucalyptus* plantations, when calculated over the age of a plantation. Although at young age of these plantations, *Eucalyptus* scored over *Dalbergia* owing to its prominent timber gains, at 21 years of age, the total returns from *Dalbergia* were about thrice greater than from *Eucalyptus*. There was also a greater increase in benefits from 8 to 21 years of age in *Dalbergia* compared to that in *Eucalyptus*. It is important to note that in *Eucalyptus* (21 year-old plantation), tangible benefits (timber and other non-wood products) were calculated at a rotation of eight years over a 21-year time period (i.e. for 2.5 crops, as *Eucalyptus* is generally harvested at 8-10 years of age) (Jalota and Sangha 2000). Our earlier study (Jalota and Sangha 2000) reported the main tangible benefits from these two plantations, though at a young age the benefits were greater from *Eucalyptus*, but at an old age, *Dalbergia* performed better than *Eucalyptus*.

The present results further suggest that *Dalbergia* plantations are more profitable at 21 years of age with greater ecological services from understorey plant diversity, litter and soil nutrient content than *Eucalyptus* plantations. Moreover, over the period of growth for *Dalbergia* plantations, ecological services will be in a continuum to sustain the system over a longer time, whereas in *Eucalyptus* rotational harvest at every 8-year intervals will disturb the dynamics of ecological services.

The methodology used here to assign monetary value to intangible services would need further improvements but such a tool is appropriate in a developing country such as India where common herbs/plants are used in daily life. The application of standard techniques (Contingent Valuation Method (CVM), Choice Modelling (CM) Method, Contingent Ranking, Travel Cost Method (TCM), and so on) cannot be generalised as they largely depend upon the culture and financial status of a society (Sangha et al. 2000). Other methods based upon ecosystem functions have been proposed. Nunes et al. (2001) estimated the value of biodiversity at four levels, i.e. genes, species, ecosystems and functions, but they missed the social value attached to a particular usage which is important for people in developing countries.

Human interactions with environment are important when considering valuation of ecological services (Daily 1999). In developing countries, common valuation methods (CVM, CM or TCM) may not work due to regional variations and societal differences to use a plant species, to make aesthetic sense of a site or differences in cultural values. There is a lot of integration/cross-linkage of use and non-use benefits from forests, and their interaction with people; and this emphasises the need to develop some indigenous methods to evaluate ecological services. The methodology used in this paper was based on the actual use of plant species.

This paper emphasises the importance of ecological services in total value over the long term for fast-growing exotic and steady-growing indigenous trees in terms of all direct and indirect benefits before implementing any forest policies/decisions. The total value judgment over a long term could provide a better idea about the potential of a tree plantation. The development of indigenous methods to evaluate the use of indigenous plants by locals will help to assess their accurate value for future policy decisions.

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Ecological services of exotic and native plantations / 109

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Digital Appendix 1

Importance Value Index (IVI) and Relative Biomass (RB) of various plant species found on the floors of 6-8 year and 19-21 year old *Eucalyptus* and *Dalbergia* plantations.

URL: <http://www.conservationandsociety.org/archive/digitapp-sangha-3-1-05-6a.org>

Digital Appendix 2

Monetary value (in terms of Indian Rupees) per hectare of various plant species found on the floors of 6-8 year and 19-21 year old *Eucalyptus* (Et) and *Dalbergia* (Ds) plantations.

URL: <http://www.conservationandsociety.org/archive/digitapp-sangha-3-1-05-6b.org>