

Plant Diversity Development Under Planted Woody Species on Coal Mine Spoil in a Dry Tropical Environment, India: A Case Study

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ABSTRACT

The development of reconstructed woody vegetation on coal mine dumps during the trajectory of reclamation was explicitly investigated by means of a rehabilitation technique. However, limited information is available about the composition of herbaceous species during the ecosystem re-development on mine dumps. The present study attempted to assess the composition of herbaceous vegetation beneath plantation stands of four native woody species on the coal mine spoil in a dry tropical environment. After a thorough survey of the study site, a total of 44 species of herbaceous plants belonging to 14 families were recorded. Among the recorded plant families, the Poaceae contributed the highest number of species (18) across all ages of all plantation stands. The biodiversity parameter such as species richness exhibited an increasing trend with age under plantation stand of *T. grandis* only, while the rest of the plantations showed a decreasing trend. In terms of the similarity index, the plantation stands of *A. procera* and *T. grandis* were closer to each other while *A. lebbeck* and *D. strictus* were farthest apart. However, the highest IVI was recorded in the seedling of *A. lebbeck* under the planted stand of *A. lebbeck* while lowest of *Rungia repens* (2.85) under *A. procera* stands at 17th-year of age. In conclusion, the plantation age, dominant tree species, and species specificity have a significant impact on the development of herbaceous vegetation beneath the plantation stand of four native woody species.

Keywords: biodiversity development, coal mine spoil, herbaceous vegetation, phytosociology, rehabilitation.

INTRODUCTION

Coal is one of the main energy sources in developing countries and the expansion of industrialization needs massive energy generation for which huge quantity of coal is extracted through mining, causing extensive landscape destruction [Singh and Singh, 2006]. Quarrying for coal and minerals creates huge deposits of dumps and overburden on the unmined earth's surface. These overburdens are mostly acidic in nature, highly toxic, with poor content of nutrients [Mensah, 2015; Tripathi et al., 2016a; Singh et al., 2017; Festin et al., 2019] and compacted soil texture which reduces the draining capacity of the soil [Jha and Singh, 1992; Tripathi and Singh, 2008; Feng et al., 2019] making it unfavourable for the establishment of vegetation.

Moreover, the natural succession in the nutrient impoverished mine spoil is a slow process [Jha and Singh, 1993] with little vegetation development; therefore, artificial revegetation [Bradshaw, 1983; Leopold and Wali, 1992; Singh et al., 2004a, 2004b] and human intervention is necessary to speed up the process of rehabilitation. Hence, successful restoration of mine spoil requires the establishment of the plant species which can thrive best in nutrient-poor soil as well as improve the physico-chemical and microbial status of the soil.

In order to restore the soil fertility and amelioration of micro-climatic conditions, tree plantations are often recommended [Singh et al., 2002; Sinha et al., 2009; Mukhopadhyay et al., 2013; Ahirwal et al., 2017]. Several restoration programs by planting either native or exotic

tree species on coal mine spoils have been successfully attempted [Chaturvedi, 1983; Parrotta, 1999; Dutta and Agrawal, 2003; Singh and Singh, 2004]. Initial colonization of mine spoils by hardy grasses and nitrogen-fixing herbaceous legumes improves the soil fertility by adding nutrients and providing aid to colonize other herbaceous species [Singh, 2004]. The rapid growth and the aggressive nature of herbaceous species can provide an important aid to check the soil erosion on the reclaimed mine sites [Franklin et al., 2012].

Herbaceous vegetation is essential for nutrient dynamics, ecological balance and modification of the prevailing conditions to some extent. It is imperative to study the herbaceous species composition and diversity of a particular area; in order to identify the key species for their conservation and restoration of the degraded environment [Jharia et al., 2013] as well as to figure out the community and ecosystem stressors. Furthermore, inventorization of the floristic elements on overburdened spoils can be helpful to predict the path of existing succession, when compared with the surrounding forest floras [Das et al., 2013].

The information on the floristic inventories of coal mined areas is very limited, particularly in India. Few studies have been carried out on naturally revegetated coal mined spoil [Deo and Panda, 2005; Singh, 2006; Ekka and Behera, 2011; Kompała-Bąba et al., 2019] but the studies dealing with floristic explorations in the plantation stands are very exiguous. Therefore, the present study was undertaken to document the herbaceous vegetation development beneath the plantations stand of four selected native woody species on coal mined spoil in a dry tropical environment, India.

MATERIAL AND METHODS

Study area

The present work was carried out at the Jayant block of Singrauli coalmine fields in the Singrauli district (the former part of the Sidhi district), Madhya Pradesh, India (Fig. 1). The Singrauli coal mines situated at (Lat. 24° 6' 45"–24° 11' 15" N, Long. 82° 36' 40"–82° 41' 15") are one of the largest coalfields and power complexes in the world and contribute 13% of India's coal production through opencast mining [Singh and Singh, 2004]. The climate of the area is a tropical monsoonal type with annual rainfall averages of

1069 mm. Annual mean temperature ranges from a minimum 6–28 °C in winter and a maximum of 20–40 °C in summer. The detailed information about the study area and type of vegetation is given elsewhere in Jha and Singh [1992]; Singh et al. [1995]; Singh and Singh [2004].

Plantation stand characteristics

The plantations stand was established by planting nursery raised seedlings of four woody species viz. *Albizia lebbbeck*, *A. procera*, *T. grandis*, and *D. strictus* in previously dug pits of 40×40×40 cm in size at a spacing of 2×2 m. The plantations of *A. lebbbeck*, *A. procera*, and *T. grandis* were raised in 1990, the former two covering an area of 1.5 ha each, while the latter – 0.5 ha. The plantation of *D. strictus* was raised in 1991 covering an area of 0.5 ha. The physicochemical properties of the stand were determined once in 1995 when plantations were 5 years of age and it had indicated a slightly lower bulk density, neutral pH (6.58–7.22), higher water holding capacity and poor concentration of nutrients in comparison to the fresh mine spoils [Singh et al., 2004a].

Stocking density and Stand basal cover of woody plantation stand

The number of individuals (clumps in *D. strictus*) in each plot was inventoried in 1995 (at 5th-year age) and after a long period in 2007 (at 17th-year of age); the existing stocking density is presented in Table 1. There was a drastic change in the stocking density of all planted woody species after such a long duration. About 50% of individuals in each planted species have declined due to competition or space problems. According to the forest department personnel (MP Ban Nigam, Sidhi), neither thinning nor pruning were done in these experimental plots. However, the stocking density at the time of plantation (1990, 1991) was 2500 individuals ha⁻¹ for each species.

Phytosociological analysis of herbaceous vegetation

The herbaceous vegetation under plantations was analyzed through fifteen 50×50 cm quadrats laid down in each plantation (i.e. a total of 60 quadrats for four sites at each time of sampling) at a peak time of floristic development (in the month of October 1995 and 2007, respectively).

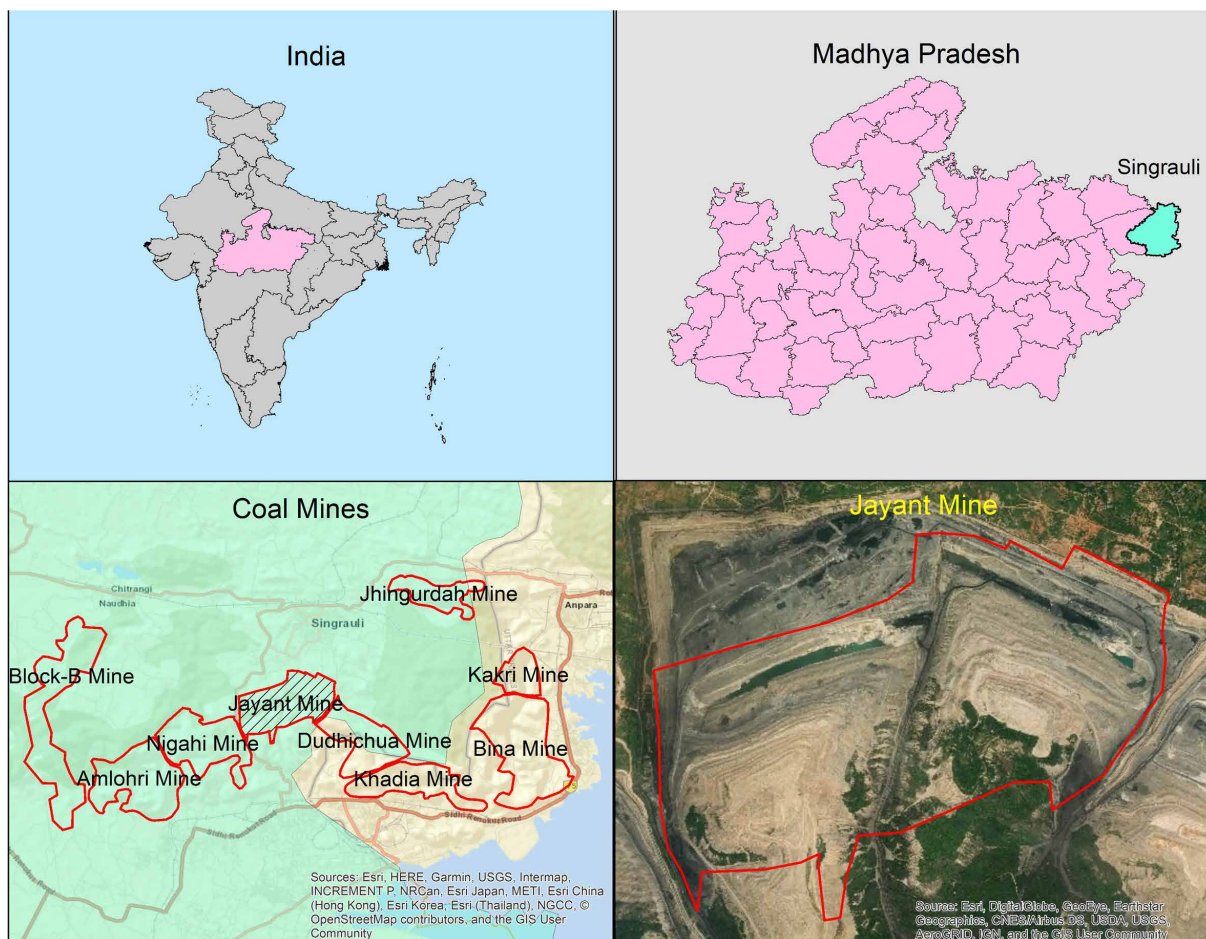


Figure 1. Map showing location of study sites

The quadrats were laid down randomly in the plantation plots; afterwards, all individuals of each quadrat were counted through tiller analysis [Singh and Yadava, 1974]. The unidentified species were recorded in the notebook, carefully collected, and stored in a modified hardboard sheet for preparing herbarium for proper identification by a well-known authority. The remaining plant samples were brought to the laboratory for further analysis. The vegetation data were quantitatively analyzed for phytosociological studies such as frequency, density, dominance, and IVI by following the method of Curtis and McIntosh [1950] and Misra [1968]:

$$\text{Density} = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of quadrats studied}}$$

$$\begin{aligned} \text{Relative density (\%)} &= \\ &= \frac{\text{Density of a species}}{\text{Density of all the species}} \times 100 \end{aligned}$$

$$\text{Frequency} =$$

$$= \frac{\text{Total no. of individuals of a species}}{\text{No. of quadrats in which species present}}$$

$$\text{Relative frequency (\%)} =$$

$$= \frac{\text{Frequency of a species}}{\text{Frequency of all the species}} \times 100$$

$$\text{Relative dominance (\%)} =$$

$$= \frac{\text{Biomass of a species}}{\text{Biomass of all the species}} \times 100$$

$$\begin{aligned} \text{IVI} &= \text{Relative density} + \text{Relative frequency} + \\ &+ \text{Relative dominance} \end{aligned}$$

Table 1. General characteristics such as stocking density, basal cover of planted woody species on coal mine spoil. Values (mean ± 1 SE) are means of three replicate plots. Values in the rows suffixed with different letters are significantly different with each other at p < 0.05

Parameters	Plantation age (year)		Statistical values	
	5	17	t	p
Stocking density (individuals ha ⁻¹)				
<i>A. lebbbeck</i>	2187 ± 24.44 ^a	1817 ± 71.44 ^b	10.13	0.010
<i>A. procera</i>	2208 ± 16.00 ^a	1722 ± 62.82 ^b	17.73	0.003
<i>T. grandis</i>	1778 ± 117.36 ^a	1434 ± 68.38 ^b	4.25	0.05
<i>D. strictus</i> *	2029 ± 50.81 ^a	1469 ± 54.00 ^b	18.05	0.003
Mean basal cover (m ² individual ⁻¹)				
<i>A. lebbbeck</i>	0.006 ± 0.0003 ^a	0.023 ± 0.002 ^b	-19.02	0.003
<i>A. procera</i>	0.007 ± 0.0006 ^a	0.022 ± 0.004 ^b	- 6.79	0.021
<i>T. grandis</i>	0.003 ± 0.0003 ^a	0.100 ± 0.008 ^a	- 1.40	0.296
<i>D. strictus</i> *	0.001 ± 0.0002 ^a	0.001 ± 0.000 ^a	0.58	0.621
Stand basal cover (m ² ha ⁻¹)				
<i>A. lebbbeck</i>	13.79 ± 0.4 ^a	42.25 ± 4.39 ^b	- 43.60	0.001
<i>A. procera</i>	14.98 ± 1.36 ^a	37.58 ± 7.28 ^b	- 46.50	0.000
<i>T. grandis</i>	5.81 ± 0.58 ^a	13.47 ± 11.21 ^b	- 35.92	0.001
<i>D. strictus</i> *	2.58 ± 0.3 ^a	1.80 ± 0.21 ^b	- 46.84	0.000

* Plantation age is 16-year old.

Diversity indices:

Species richness index was calculated by following the method of Margalef [1958]:

$$SR = \frac{S-1}{\ln(N)}$$

Index of evenness (Ew) was calculated using the formula given by Whittaker [1972]:

$$Ew = \frac{S}{\ln Ni - \ln Ns}$$

Beta diversity (βw) was computed as per the formula given by Whittaker [1972]:

$$\beta = \frac{Sc}{\bar{S}}$$

The similarity index between pairs of planted trees was calculated by using the IVI value similarity coefficient between the pair of planted stand vegetation types with the help of the following expression:

$$S = \frac{2C}{a + b} \times 100$$

where S = Number of species; whereas
 N = Total number of individuals;
 Ni = Number of individuals of most abundant specie;

Ns = Number of individuals of least abundant species;

Sc = Total number of species;

\bar{S} = Average number of species per sample;

C = sum of lowest IVI of common species; “a” and “b” are the sum of IVIs of all species under both planted stands.

RESULTS

Species composition

A total of 44 species of herbaceous plants belonging to 14 families were recorded from the plantation stand (Fig. 2). The maximum number of species (23) was recorded from the 17th-year-old plantation stand of *Tectona grandis* (Fig. 3) while the 5th-year-old stand of *Albizia lebbbeck* showed the lowest number of species (9) (Fig. 4).

Across all ages and all plantation stands, the Poaceae family (18) was dominant, followed by Asteraceae (11) and Fabaceae (10) families (Fig. 2). Among the 5-year-old plantations of all species, maximum RF was recorded for *Hyptis suaveolens* (21.21%) under plantation stand of *A. procera* and minimum (2.17% each) for *Blumea alata*, *Bothriochloa pertusa*,

Corchorus capsularis, *Oldenlandia corymbosa* and *Phyllanthus niruri* under plantation stand of *D. strictus*. However, the corresponding parameter at the 17th-year of all plantation stand was maximum for woody seedlings of *A. lebbbeck* (21.74%) and minimum for *Desmodium triflorum*, *Justicia gendarussa*, *Pennisetum pedicellatum* (1.16% for each) under the plantations of *D. strictus* (Table 2).

The relative density of the herbaceous species beneath plantations, however, reflected the same trend as shown in RF; although, the values for RD were in the range of 0.31–49.13% at 5th-year and 0.31–56.39% at 17th-year of plantation age. Moreover, the same species (*Hyptis suaveolens*) reflected maximum RD (49.13%) and minimum (0.31%) by *Borreria stricta*, *Corchorus capsularis*, *Oldenlandia corymbosa* and *Phyllanthus niruri* under 5th-year old plantation stand of *D. strictus*. At age of 17, the maximum RD was

found in the seedling of *A. lebbbeck* (56.39%) under *A. lebbbeck* stand and a minimum of *Rungia repens* (0.31%) under plantation stand of *A. procera* (Table 2).

However, if the seedlings of *A. lebbbeck* been neglected, then one invader *Hyptis suaveolens* had highest RD (35.50%) under *A. procera* plantation across all planted stands (Table 2). The relative biomass of herbaceous species across all ages and all planted stands, was maximally estimated in the seedling of *A. lebbbeck* (72.80 g dry wt. basis) under the stand of *A. lebbbeck*, while minimum of *Rungia repens* (0.14 g dry wt. basis) under *A. procera* stand at 17th-year (Table 2).

Although the values for RB in the present study were varied from 0.17–59.58 g at 5th-year, being maximum in *Aristida adscensionis* (59.58 g, dry wt. basis) and minimum of *Cyperus compressus* (0.17 g dry wt. basis) under the stand of

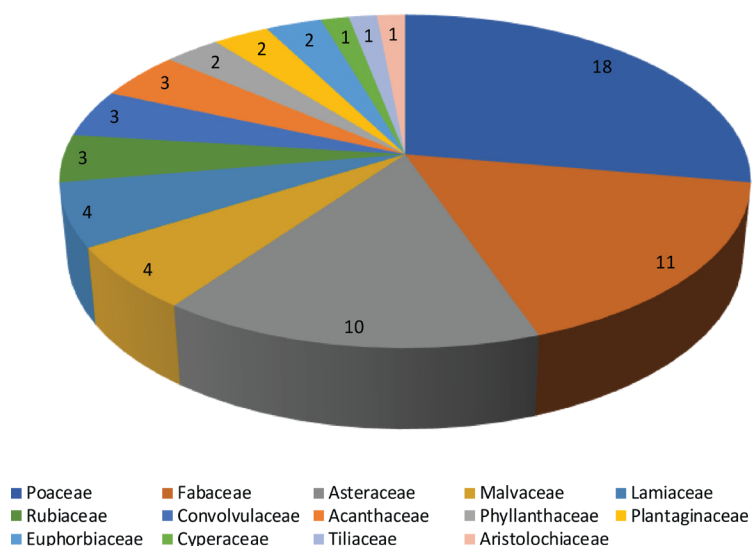


Figure 2. Family-wise number of herbaceous species recorded under all age all plantations stands of coal mine spoil

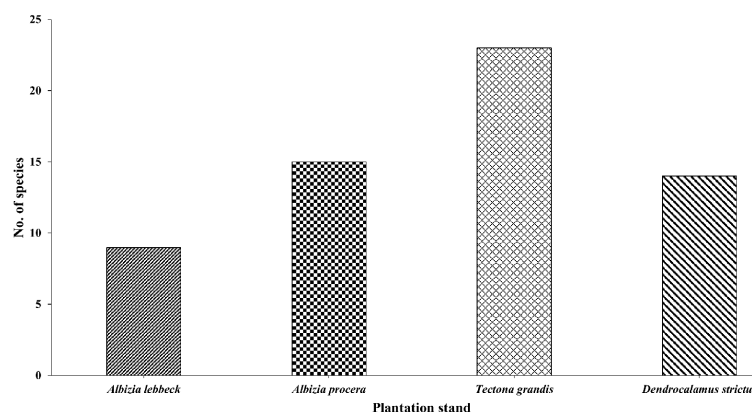


Figure 3. Total number of herbaceous species recorded under 17-year old plantation stand

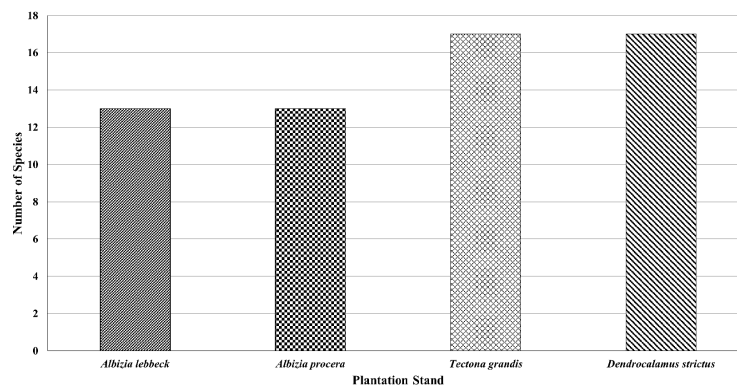


Figure 4. Total number of herbaceous species recorded under 5-year old plantation stand

A. procera plantation, the corresponding values were substantially in better range of 0.14–72.80 g at 17th-year of all planted stands (Table 2).

Total IVI of the herbaceous species were significantly varied in the range of 3.04–94.91 at 5 year and 2.85–150.93 at 17th-year-old plantation age of all planted species (Table 2). Across the planted stands and plantation age, the greatest IVI was recorded in the seedling of *A. lebbek* under the *A. lebbek* stand and lowest was of *Rungia repens* (2.85) under *A. procera* stand at 17th-year of age (Table 2).

Species Richness, Evenness, Diversity and Similarity Index

The species richness index of herbaceous species under planted stand varied from 2.34 (*A. lebbek*) to 2.82 (*D. strictus*) at 5th – and 1.21 (*A. lebbek*) to 3.07 (*T. grandis*) at 17th-year of age. However, the variation in the values was apparently increased from 5th- to 17th-year old plantation stands in *T. grandis* only, while decreased in the planted stand of *A. lebbek* followed by *A. procera* and *D. strictus* plantation (Fig. 5). However, the effect of age, species and their interaction (age × species) on them were strongly significant (age: $F_{1,16} = 16.78$, $P = 0.001$; species: $F_{3,16} = 39.41$, $P = 0.000$ and interaction: $F_{3,16} = 18.44$, $P = 0.000$).

The species evenness is an important parameter that explains the number of individuals of the present species. A decreasing trend was observed in the present study due to the age in all planted species (Fig. 6). ANOVA indicated significantly different due to age ($F_{1,16} = 8.91$, $P = 0.009$) and species ($F_{3,16} = 108.65$, $P = 0.000$) but their interaction was insignificant ($F_{3,16} = 1.630$, $P = 0.222$).

Across the planted stand of all species, the alpha-diversity of herbaceous species was varied from 1.38–2.23 at 5th- and 1.20–2.28 at 17th-year of plantation age, being highest in *T. grandis* under both plantation age (5th- and 17th-year) and lowest in the *D. strictus* at 5th- and *A. lebbek* at 17th-year of stand (Fig. 7). Analysis of Variance (ANOVA) exhibited significant differences due to species ($F_{3,16} = 27.20$, $P = 0.000$) and interaction with age (age × species) ($F_{3,16} = 23.02$, $p = 0.000$), but the effect of age was non-significant ($F_{3,16} = 0.66$, $p = 0.430$).

In turn, in this study, the β -diversity calculated between two planted stands showed insignificant differences between both plantation age (5th- and 17th-year age); however, the values reflected were in the range of 1.41–1.66 in 5th- and 1.35–1.56 in 17th-year of the planted stand. Among all the planted stands and age, maximum diversity was recorded in the stand of *A. procera* vs *D. strictus* in 5th-year age plantation stands and lowest in *T. grandis* and *D. strictus* stand at 17th-year old plantation stand (Table 3).

The similarity index of the herbaceous species under the planted stands of all selected species varied from 28.53–47.67 and 19.40–56.00, in 5th- and 17th-year of plantation, respectively. This index was also calculated between the stands of two planted species. Although the values widely differed in between the planted stands in both ages of plantations, the highest values (47.67) under 5 years of age was reflected by *T. grandis* vs *D. strictus* plantation while the lowest (28.53) recorded under *A. lebbek* vs *D. strictus* plantation. Similarly, in the 17th-year of planted stand, the corresponding values were the highest (56.00) under *A. procera* vs *T. grandis* plantation and lowest (19.40) under *A. lebbek* vs *A. procera* plantation (Table 3).

Table 2. Phytosociological assessment of herbaceous vegetation across different plantation stands

Species name	A. lebbeck								A. procera								Tectona grandis								Dendrocalamus strictus											
	Plantation age (Years)																																			
	5-				17-				5-				17-				5-				17-				5-				16-							
	RD	RF	RB	IVI	RD	RF	RB	IVI	RD	RF	RB	IVI	RD	RF	RB	IVI	RD	RF	RB	IVI	RD	RF	RB	IVI	RD	RF	RB	IVI	RD	RF	RB	IVI	RD	RF	RB	IVI
Albizia lebbeck (seedling)	-	-	-	-	56.39	21.7	73	151	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Albizia procera (seedling)	-	-	-	-	-	-	-	-	-	-	-	-	3.68	4.8	10.6	19.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alysicarpus monilifer	-	-	-	-	-	-	-	-	11.68	15.2	5.18	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aristida adscensionis	-	-	-	-	-	-	-	-	27.89	6.06	59.6	93.5	-	-	-	-	10.2	8.98	7.35	26.5	4.41	5.4	4.89	-	4.18	8.59	8.54	21	6.5	10.2	8.26	25				
Aristolochia elegans	-	-	-	-	-	-	-	-	-	-	-	-	1.99	4.8	1.34	8.14	-	-	-	-	-	-	-	-	14.7	-	-	-	-	-	-	-				
Blumea alata	6.63	11.11	6.64	24.38	1.09	8.59	0.5	10.2	-	-	-	-	-	-	-	-	6.56	6.74	13.6	26.9	3.18	4.3	7.48	-	0.67	2.17	1.13	4	-	-	-	-				
Borreria stricta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	0.31	2.77	1.13	4.2	-	-	-				
Bothriochloa pertusa	46	11.11	37.9	94.91	4.54	11.6	1.6	17.8	-	-	-	-	1.78	6	1.39	9.19	4.22	5.61	3.49	13.3	2.72	5.4	1.02	-	2.4	2.17	3.98	8.6	10.5	10.2	10.7	31.3				
Cassia tora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.01	3.8	2.67	9.14	-	-	-	-	1.28	2.06	0.77	4.11				
Chloris barbata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.54	3.37	2.87	8.78	-	-	-	-	10.5	-	-	-	-	-	-	-				
Clitoria ternatea	7.81	11.11	6.08	25	1.09	5.79	0.7	7.56	8.04	12.1	1.29	21.5	0.63	3.6	0.2	4.44	16.3	13.5	20.1	49.9	5.15	7	7.19	-	5.9	10.9	5.8	23	11.8	8.16	7.19	27.2				
Corchorus conniveans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.4	0.31	2.17	0.79	3.3	-	-	-				
Cynodon dactylon	5.99	2.77	1.69	10.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Cyperus compressus	-	-	-	-	-	-	-	-	0.66	3.02	0.17	3.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Desmodium triflorum	3.63	8.33	2.4	14.36	1.65	10.1	0.5	12.3	11.68	9.09	9.93	30.7	1.78	6	2.83	10.6	7.83	4.49	6.86	19.2	5.6	4.9	5.46	-	0.67	4.34	5.69	11	6.5	1.16	9.4	17.1				
Dichanthium annulatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.36	5.61	2.87	11.8	1.13	3.8	1.23	15.9	5.22	4.34	8.42	18	8.48	8.16	7.97	24.6				
Digitaria setigera	-	-	-	-	-	-	-	-	-	-	-	-	3.89	6	4.52	14.4	3.17	4.49	3.24	10.9	2.72	3.8	2.96	6.14	1.35	4.34	0.45	6.1	6.5	1.66	1.73	9.89				
Eragrostis tenella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.51	3.8	1.04	9.46	-	-	-	-	-	-	-	-				
Euphorbia hirta	1.18	5.55	0.84	7.57	-	-	-	-	1.43	6.06	1.72	9.21	-	-	-	-	1.46	5.61	1.39	8.46	-	-	-	-	6.33	2.77	6.52	4.78	14	-	-	-				
Euphorbia tirucalli	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.6	6.74	5.99	24.3	-	-	-	-	-	-	-	-	-	-	-	-				
Evolvulus alsinoides	4.81	11.11	6.08	22	0.95	8.59	0.3	9.85	-	-	-	-	-	-	-	-	-	-	-	-	1.66	3.2	3.69	-	0.67	4.34	1.7	6.7	3.94	6.12	3.99	14.1				
Glossocardia bosvallea	-	-	-	-	-	-	-	-	-	-	-	-	1.15	4.8	0.3	6.26	-	-	-	-	-	-	-	-	8.59	-	-	-	-	-	-	-				
Heteropogon contortus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.48	2.24	6.16	9.88	-	-	-	-	21.2	10.9	35.2	67	-	-	-	-				
Hyptis suaveolens	10.3	11.11	13.3	34.66	5.22	10.1	1.4	16.8	21.27	21.2	4.74	47.2	35.5	16	14.1	65.2	16.1	11.2	12.5	39.8	22.5	5.9	20	-	49.1	17.4	17.1	84	11.1	8.16	2.26	21.6				
Indigofera linifolia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.68	2.7	0.35	48.4	-	-	-	-	-	-	-	-				
Ipomoea eriocarpia	-	-	-	-	-	-	-	-	0.66	3.02	1.72	5.4	-	-	-	-	-	-	-	-	-	-	-	-	3.73	-	-	-	-	-	-	-				
Justicia gendarussa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.5	1.16	2.77	14.4				
Leucaena leucocephala	4.81	8.33	18.2	31.38	-	-	-	-	-	-	-	-	0.41	3.6	0.25	4.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Leucas aspera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.93	4.3	2.36	-	-	-	-	-	-	-	-	-				
Ocimum basilicum	-	-	-	-	-	-	-	-	-	-	-	-	21	12	40.3	73.3	-	-	-	-	-	-	-	-	9.39	4.9	17.9	10.6	-	1.97	4.06	2.99	9.02			
Oldenlandia corymbosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32.2	0.31	2.17	1.13	3.6	1.97	4.08	3.99	10			
Oplismenus baumannii	-	-	-	-	27.9	13	22	62.5	5.84	6.06	2.5	14.4	23.4	12	14.8	50.3	-	-	-	-	14.3	5.9	6.35	-	-	-	-	-	-	-	-	-				
Panicum maximum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.99	8.25	3.77	19	5.15	5.4	2.97	26.6	-	-	-	-	-	-	-	-				
Parthenium hysterophorus	1.80	2.77	1.69	6.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13.5	-	-	-	-	-	-	-				
Pennisetum pedicellatum	-	-	-	-	-	-	-	-	-	-	-	-	1.67	6	0.96	8.65	-	-	-	-	3.25	3.8	1.5	-	-	-	-	-	14.4	1.16	9.38	24.9				
Phyllanthus niruri	5.99	8.33	3.45	17.77	-	-	-	-	0.66	3.02	0.17	3.85	-	-	-	-	-	-	-	-	1.28	3.8	1.23	8.53	0.31	2.17	0.56	3	4.53	6.12	4.66	15.3				
Rungia repens	-	-	-	-	-	-	-	-	-	-	-	-	0.31	2.4	0.14	2.85	-	-	-	-	-	-	-	-	6.29	-	-	-	-	-	-	-				
Scoparia dulcis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.63	2.24	1.02	3.89	1.2	3.2	2.23	-	-	-	-	-	-	-	-	-				
Sida acuta	-	-	-	-	-	-	-	-	5.07	6.06	6.04	17.2	0.83	4.8	1.88	7.52	-	-	-	-	-	-	-	-	6.67	-	-	-	-	-	-	-				
Sida cordata	0.54	2.77	0.28	3.59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.83	3.2	0.77	-	-	-	-	-	-	-	-	-				
Sonchus brachyotes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.81	5.61	5.13	14.6	3.1	4.3	4.73	4.84	2.77	8.59	1.25	13	-	-	-	-				
Tridax procumbens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.09	5.61	2.05	9.75	0.9	3.2	1.01	12.2	1.35	6.52	2.27	10	-	-	-	-				
Urochloa panicoides	-	-	-	-	-	-	-	-	2.2	3.02	0.86	6.08	-	-	-	-	-	-	-	-	-	-	-	-	5.14	-	-	-	-	-	-	-				
Vernonia cineria	1.18	5.55	1.41	8.14	1.09	10.1	0.5	11.7	2.86	6.06	6.04	15	1.89	7.2	7.4	16.5	1.69	2.66	1.6	5.95	1.66	4.9	1.77	8.29	-	-	-	-	-	-	-	-				

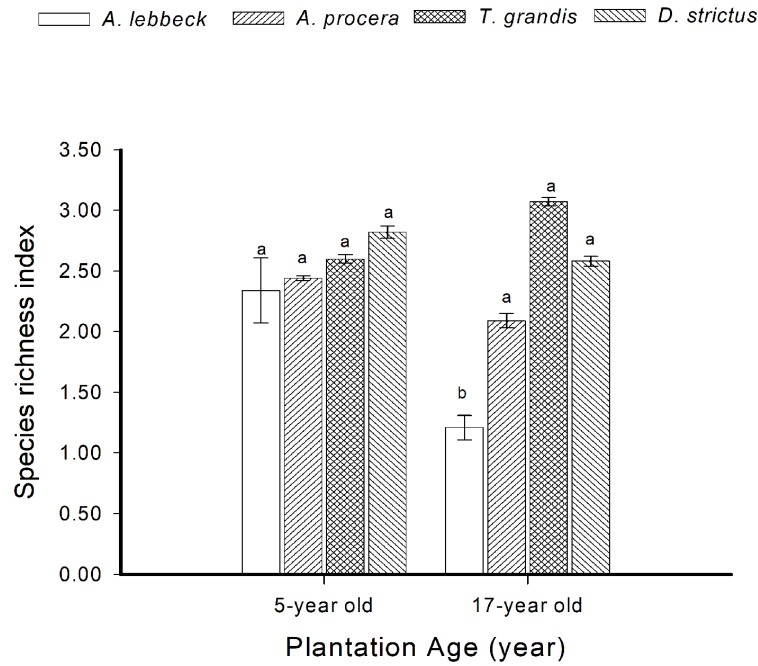


Figure 5. Species richness index of herb layer vegetation under plantations of woody species on coal mine spoil. Vertical bars are 1 SE. Values with different letters are significantly different with each other at $p < 0.05$

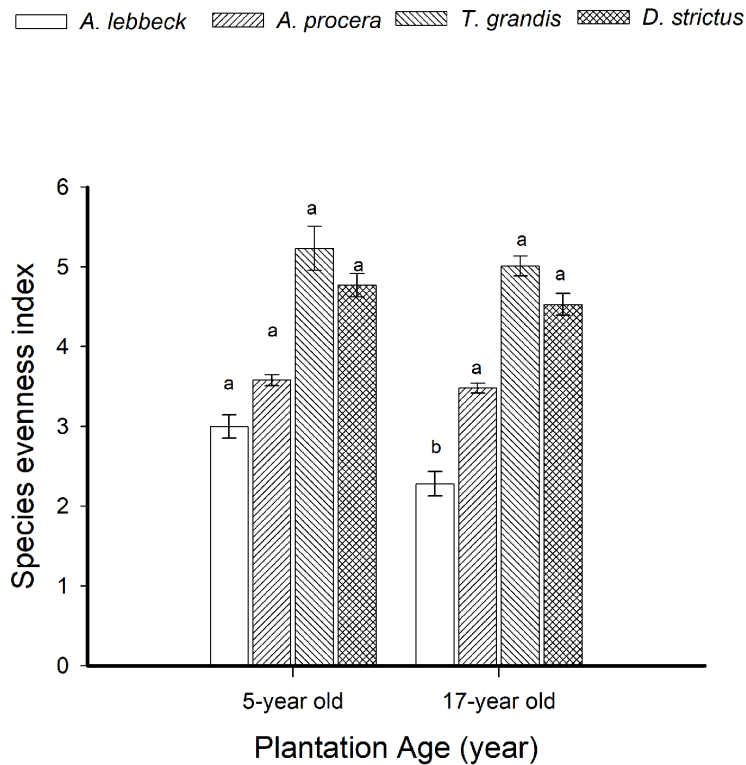


Figure 6. Species evenness of herb layer vegetation under plantations of woody species on coal mine spoil. Vertical bars are 1 SE. Values with different letters are significantly different with each other at $p < 0.05$

DISCUSSION

In the present study, the Poaceae family was the most commonly encountered with a maximum number of species (18) beneath all the plantation

stands followed by Fabaceae (11) and Asteraceae (10) (Fig. 2). However, a similar trend was observed by several researchers from different coal mined areas [Wade and Thomson, 1993; Ekka and Behera, 2011] in a dry tropical environment.

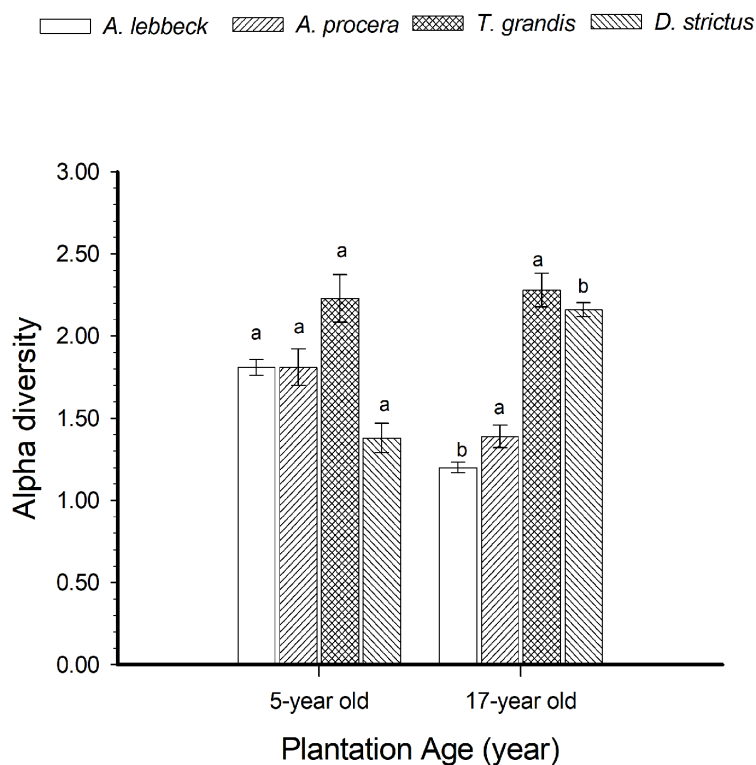


Figure 7. Alpha diversity of herb layer vegetation under plantations of woody species on coal mine spoil. Vertical bars are 1SE. Values with different letters are significantly different with each other at $p < 0.05$

The studies conducted across European countries on afforested reclaimed sites such as [Rawlik et al., 2018 (281 sp.); Pensa et al., 2008 (100 sp.) and Mudrak et al., 2010 (79 sp.)] exhibited a relatively higher number of species as compared to the present study. However, the studies concerned with herbaceous vegetation on un-reclaimed sites such as [Hodačova and Prach, 2003; Pensa et al., 2004; Deo and Panda, 2005; Ekka and Behera, 2011; Biswas et al., 2012] revealed a high number of species in contrary to reclaimed sites. Probably, the substrate heterogeneity [Frouz et al., 2008; Mudrak et al., 2010] and greater colonization for microhabitats

[Pensa et al., 2008; Mudrak et al., 2010] enhance the number of species on un-reclaimed sites.

A study was conducted by Singh [2012] on the same site area (19 months old naturally re-vegetated coal mine spoil) of the present study site revealed the occurrence of 17 herbaceous species. Limited entry of plant species in this study might be due to the slow rate of succession at young age of mined spoil, and the nature of growing tree species itself demanded a greater quantity of soil organic matter for further growth and development. However, in our study, a close taxonomic similarity was observed with the above-cited studies indicated

Table 3. Beta diversity index and Similarity index of herbaceous species under different plantation age of four native woody species on coal mine spoil. Values in the rows suffixed with different letters are significantly different with each other at $p < 0.05$

Plantation stand	Beta diversity index		Similarity index	
	Plantation age (Year)			
	5-	17-	5-	17-
<i>A. lebeck</i> vs. <i>A. procera</i>	1.46 ^a	1.50 ^a	31.72 ^a	19.40 ^b
<i>A. lebeck</i> vs. <i>T. grandis</i>	1.60 ^a	1.50 ^a	37.17 ^a	33.18 ^a
<i>A. lebeck</i> vs. <i>D. strictus</i>	1.53 ^a	1.44 ^a	28.53 ^a	22.47 ^a
<i>A. procera</i> vs. <i>T. grandis</i>	1.60 ^a	1.47 ^a	40.69 ^a	56.00 ^a
<i>A. procera</i> vs. <i>D. strictus</i>	1.66 ^a	1.56 ^a	31.34 ^a	24.14 ^a
<i>T. grandis</i> vs. <i>D. strictus</i>	1.41 ^a	1.35 ^a	47.67 ^a	47.76 ^a

that most of the taxon might be more or less in similar families [Holocomb and Bickford, 1952; Kozłowski, 1962; Leary et al., 1997 and Goel and Behl, 2004].

However, the studies from the European coal mined areas [Mudrak et al., 2010; Pensa et al., 2008 and Rawlik et al., 2018] reported that the herb layer flora hardly overlaps within the same geographic regions. Perhaps, the parent material, geology, and microclimatic conditions were favorable to the growth of more diverse vegetation in the plantation stands. Generally, low-temperature regime and shorter period of sunny days in the European climate which is absolutely temperate in nature act as a barrier to them.

In the present study, on the basis of IVI (> 50), several species which existed in 5th- and 17th-year-old planted stand of all species were: *Bothriochloa pertusa*, *Aristida adscensionis*, *Hyptis suaveolens*, *Ocimum basilicum*, *Oplismenus burmannii*, *Heteropogon contortus*, *Clitoria ternatea* and seedlings of *A. lebeck*. This occurrence under both planted ages of all species stands presumably depends upon the special characters of that herbaceous species. According to Bradshaw [1983] only those species which are adapted to the special conditions of the sites, or those species which can acclimatize to the extreme conditions of the sites, are selected in a very distinctive flora on drastically disturbed lands. Predominance of grasses in young spoil age indicated the colonizing and thriving ability in a nutrient impoverished environment [Ekka and Behera, 2011].

Grasses possess a network of the fibrous root system, which efficiently binds soil particles, slows down soil erosion, and retains the soil moisture level [Helm, 1995; Woźniak, 2010; Błońska et al., 2019]. Jha and Singh [1991] reported the mechanism of natural succession of coal mine spoil. This study was conducted on the series of mine spoil age (5-, 10-, 12-, 16- and 20- year old) near to the present research sites. They found that *Aristida adscensionis* was a highly successful grass species for the natural succession of coal mine spoil since from the earlier stage to late-successional stage. Another grass species *Bothriochloa pertusa* was one of the main successional species at 20-year-old coal mine spoil exhibited better participation for the community development.

However, in the present study, both species occurred in all planted stands but do not possess the ability to dominate the community structure. Thus, out of the total recorded species amongst

plantation stand, only three species (*Hyptis suaveolens*, *Clitoria ternatea* and *Desmodium triflorum*) were common and dominated in the all planted species, in both years of plantation age.

It appears that the biodiversity development (ground vegetation) in a rehabilitated coal mine spoil by desirable plant species is also one of the regulating factors. However, in the case of plant diversity development beneath, both planted stands were consistently similar (13 for *A. lebeck* and 13 for *A. procera*) at 5th-year age followed by *D. strictus* (17) and *T. grandis* (17) plantation (Fig. 4). Since, *Albizia lebeck* and *A. procera* both planted woody species are the member of same family (Fabaceae); therefore, many general characters might be similar but not all, because, *A. lebeck* had comparatively better restoration potential than *A. procera* [Singh et al. 2004b]. However, the biodiversity development, at age 17th of plantation stand, colonizing species under corresponding plantation were in the increasing order only in *T. grandis* (23) and *A. procera* (15) while decreasing in *D. strictus* (14) and *A. lebeck* (9) from earlier plantation age (5th-year) (Fig. 3).

Perhaps, due to the sprouting high density of seedlings at the ground surface in the *A. lebeck* plantation changed the pattern of herbaceous development in this study. However, this situation was also a trajectory in the *A. procera* stand due to the emergence of the own seedlings at ground level but the situation was quite better because the distribution of seedlings was sparse as compared to the plantation stand of *A. lebeck*. Therefore, the situation was somewhat better in the *A. procera* plantation and thus permitted higher number of herbaceous species underground surface from earlier plantation age.

The basal area (BA) of plantation stand in this study, however, increased with the plantation age in all planted stands; therefore, the effect of this parameter on the biodiversity development coincided significantly with the plantation age increases. However, the relationship between the stand basal cover and alpha-diversity was not promoting to each other; therefore, the relationship was not significant ($p > 0.1$ $r = 0.37$; Fig. 8a) at 5-year age, but negatively correlated ($p < 0.01$, $r = 0.72$; Fig. 8b) in the 17th-year old plantation stand of all planted species.

Perhaps, an increased basal area in the plantation stands negatively affects the entrance and development of herbaceous vegetation as well as animal diversity, at least in the developing young

forests. In conformity with our study, Harrington and Ewel [1997] found a declining diversity of underground species under 26–32-year-old plantation stands of *Flindersia brayleyana*, *Eucalyptus saligna* and *Fraxinus uhdei* at Hawaii, USA. Further, they reported a variable range of species richness (36, 42 and 39, respectively) under the same plantations. However, a lower range was found in the present study. Perhaps, in coal mine spoils, low concentration of nutrients and spoiled seed banks cannot attract a variety of vegetation in the young period [Singh and Singh, 2006].

The diversity of a developing community depends upon the species richness and their evenness. Negative significant relationships between the stand basal area with species richness were found at 5th-year ($p < 0.05$, $r = 0.66$; Fig. 9a) and 17th-year ($p < 0.01$, $r = 0.75$; Fig. 9b) of all planted species. However, when these data were

pooled across all ages and all planted species for developing the same relationship, no relationship was developed. Perhaps, it might be due to the range of species richness recorded at 17th-year old plantation stands of all species which showed a contrasting pattern.

Except *T. grandis*, other plantation stands (*A. lebeck* > *A. procera* > *D. strictus*) showed a slightly declining trend in species richness; furthermore, poor space and high competition between individuals for resources [Wilson, 1988; Spies and Franklin, 1991; Bingham et al., 1991; Jefferson, 2004] constrained the pace of vegetation development. Moreover, the plantation plots of *A. lebeck* and *A. procera* at 17th-year of age showed the self-regenerating efficiency which reduces the entry of other herbaceous species on the ground surface due to a profuse number of seedlings. In conformity with this, Parrotta [1992] and

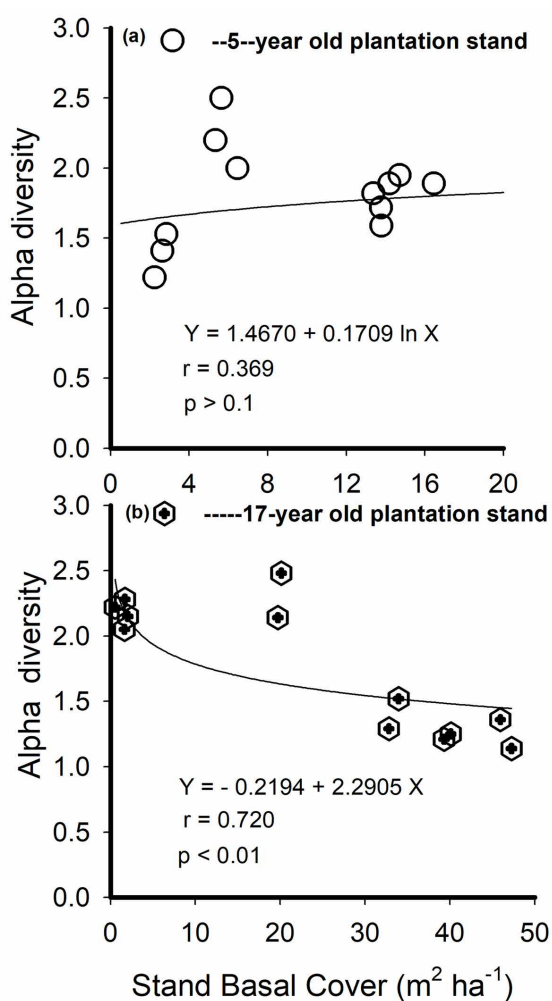


Figure 8. Relationship between stand basal cover with alpha-diversity under 5th-year old (A) and 17th-year old (B) plantations of all species on coal mine spoil

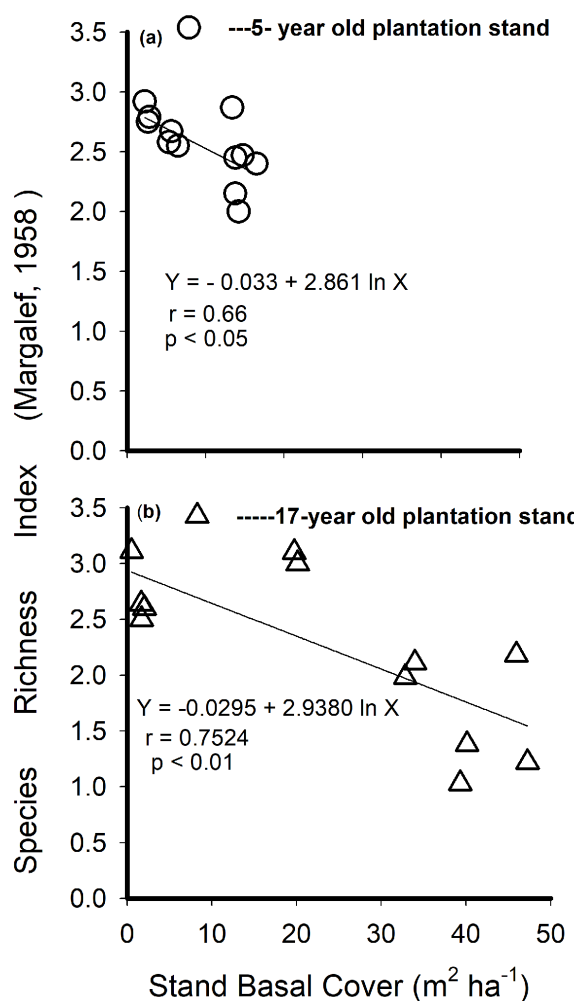


Figure 9. Relationship between stand basal cover of all planted woody species with species richness of herbaceous species at 5th-year old (A) and 17th-year old (B) plantation stand on coal mine spoil

Keenan et al. [1997] reported the same trend in their study.

In the present study, however, the effect of stand basal area on species evenness was also found. A strong negative relationship between the stand basal area with species evenness index for 5th-year ($p < 0.001$, $r = 0.84$; Fig. 10a) and 17th-year of age of all planted species ($p < 0.001$, $r = 0.83$; Fig. 10b) was found. Perhaps, the effect of the basal area is a strongly influential factor for the colonization of a new species on the ground surface of the planted species on the coal mine spoil.

In the present study, the relationship between basal area with species richness for all species of all ages was negatively correlated ($p < 0.0001$, $r = 0.76$; Fig. 11a) while evenness exhibited a positive correlation ($p < 0.01$, $r = 0.49$; Fig. 11b). Perhaps, each planted species had a specific effect on coal mine spoil; therefore, under increasing age, the plantation stands

significantly expanded their size in terms of structural parameters such as biomass and their height, and thus, light intensity and shrinking space of ground cover might reduce a significant number of herbaceous diversity.

Additionally, heliophytes (light loving plants) would be highly restricted in the shade areas of the plantation stands. However, developing young forests on the coal mine spoil are regulated by the better qualities of the physicochemical properties of soil as reported by Singh et al. [1995] and Singh et al. [2004a, b]. A detailed study of the impacts of these plantations on soil redevelopment of the coal mine spoil in chronosequence (3–6 year) is available in Singh [1999]; Singh and Singh [1999]; Singh et al., [2004a, b]; Singh et al., [2006] and Singh and Singh [2006].

On the basis of all those corresponding reports, it was found that except *T. grandis*, the plantations of *A. lebeck*, *A. procera* and *D. strictus*

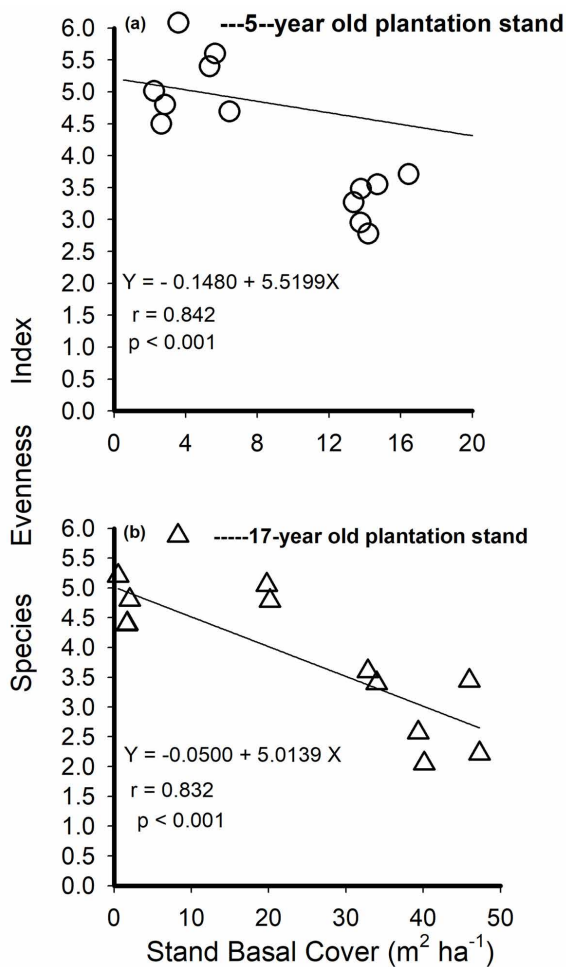


Figure 10. Relationships between stand basal cover of all planted woody species with species evenness index of herbaceous species at 5th-year old (A) and 17th-year old (B) plantation stands on coal mine spoil

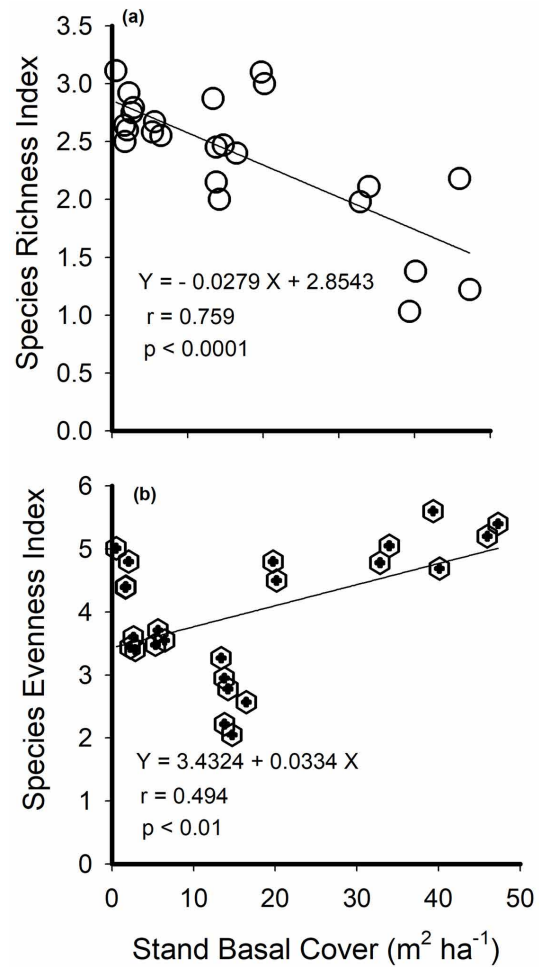


Figure 11. Relationships between stand basal cover of all planted species with species richness index (A) and species evenness index (B) of all age plantations on coal mine spoil

are much better for the restoration of a degraded coal mine spoil. Perhaps due to that reason, the canopy cover of all these plantations was substantially developed. Contrary to this, the canopy cover of *T. grandis* plantation was less spread and not in ovate shape that provided sufficient light to the undergrowth.

The plantations of *D. strictus* and *T. grandis* are non-leguminous in nature but *D. strictus* (a member of grass family: Poaceae) exhibited surprising better efficiency of restoring the coal mine spoil at least from the initial stage of the rehabilitation [Singh and Singh, 1999] as compared to *A. procera* (a legume) and non-legume *T. grandis*. Perhaps, the plantation of *T. grandis* could not attain the restoring efficiency due to low efficiency of biomass production rates and growth behavior; however, based on the socio-economical point, it has been recommended for planting in the degraded area because of the precious and valuable timber quality.

Moreover, the biodiversity development was substantially better in this plantation stand at both planted age as compared to the other planted stands of *A. procera*, *D. strictus* and *A. lebeck* suggesting that colonizing of herbaceous species under the plantation stands of a coal mine spoil was not regulated as a whole by the properties of the planted species. The species number found in these plantation stands was comparatively lower (9–23) than in the naturally vegetated coal mine spoils (19–45) under different ages at the adjoining sites of present research area. Jha and Singh [1991] indicates that the dominance of herbaceous species at the initial level of mine spoil restoration by own acclimatizing property but later on controlling by the governing system of over-story population of the plants

Wiryo and Siahaan [2013] reported lower species richness of herbaceous vegetation (17 species) under 1.5-year-old *Gmelina arborea* stand in Bengkulu coal mined land, Indonesia and they presumed that the lower species richness was due to the recent reclamation and low fertility of the mine soil. However, Woch et al. [2013] reported higher species richness (197 species) at Siersza hard coal mine, Poland wherein they inferred that high species richness in this small area is owing to the close proximity and ecological amplitude of a certain group of species.

Although the data concerning the restoration of coal mine spoil by natural succession is more exhaustive and available [Iverson and Wali, 1982;

Jha and Singh, 1991, 1992; Bradshaw 1997; Wali, 1999; Singh, 2004], there is insufficient amount of data on biodiversity development on coal mine spoil under planted woody species. In this research site, the parent materials, climate, rainfall or other edaphic factors are the same for all plantations. Therefore, the difference in the pattern of biodiversity development in each plantation species might be due to the nature of the specificity of species.

In agreement with this, the earlier study documented that the plantations of *A. lebeck* and *D. strictus* showed substantially better efficiency for biomass production, deposition of nutrients (C, N, and P) on the mine spoil surface by leaf litterfall followed by *A. procera* and *T. grandis* plantation [Singh et al., 2004a,b]. However, two planted species (*A. lebeck* and *A. procera*) are leguminous in nature but their restoring efficiency is different from each other [Singh et al., 2004b].

The species diversity is an important characteristic since variations in the diversity under different plantations of the present study are presumed to be the effect of plantation species only, because, the biotic and abiotic components of this degraded ecosystem are the same for all stands. Therefore, the variations that occurred in the plantation stand for such an important parameter of biodiversity is somewhat the impact of its own plantation stand. Our finding is in agreement with some studies [Pensa et al., 2008; Mudrak et al., 2010], but it is much more difficult to predict a uniform trend for all kinds of mining habitats across globe, as nature and properties of the mine spoils may be heterogeneous and physically, chemically as well as biologically vary from one site to another site.

Thus, in the case of *T. grandis* plantation, the species richness was increased from 5th- to 17th-year of age, while in other plantations, a decreasing trend appeared with plantation age indicating the species-specific tendencies. On the other hand, the space problems in the stands would be one of the key barriers for new species colonizing plantations [Jha et al., 1999].

CONCLUSION

The information regarding the reconstruction of biodiversity development under the planted woody species on coal mine spoil is scanty. In the present study, 44 species of herbaceous plants belonging to 14 families were recorder. In the

17th-year old plantation stand of *T. grandis*, the highest number of species was exhibited while the development of plant diversity under *A. lebbeck* was not pronounced. Across all ages of plantation stands, the Poaceae family was more dominant and contributed to the maximum allocation in the community development on ground surface. A declining trend was observed in the species richness in all the plantation stands except *T. grandis*, as the age increases. The environmental conditions were the same for all the plantation stands; thus, the fluctuation in herbaceous vegetation is the impact of individual species only. The competition between herbaceous species for space, nutrients, and light may constraint the community development. Since herbaceous vegetation regulates the production of organic matter, soil-biota, litter decomposition and nutrient channeling in the soil, the diversity and composition of herb layer must be taken into consideration while establishing restoration projects and making policies for the rehabilitation of mine-spoiled ecosystems.

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