The influence of fast-growing species composition on natural regeneration of coal mine reclamation

T Yunanto¹, F Amanah² and I Z Siregar³

¹ Bandung Polytechnic of Energy and Mines, Ministry of Energy and Mineral Resources, Jl. Jenderal Soedirman No. 623, Bandung 40211, Indonesia
² Directorate General Mineral and Coal, Ministry of Energy and Mineral Resources, Jl. Prof. Dr. Soepomo, S.H. No. 10, Jakarta 12870, Indonesia
³ IPB University, Jl. Raya Dramaga, Babakan, Bogor 16680, Indonesia

E-mail: tedi.yunanto@esdm.go.id

Abstract. Natural regeneration on mine reclamation can be an indicator of reclamation success. *Enterolobium cyclocarpum*, *Samanea saman*, *Senna siamea*, and *Paraserianthes falcataria* are mostly planted fast-growing species at the beginning of reclamation. Those species bind and enrich nitrogen to improve the natural regeneration of ex-mined land. This research aims to determine fast-growing species and the growth rate of natural regeneration development in the ex-mined site. The research was conducted in mine reclamation areas with different ages: 1 (125.14 ha), 4 (323.76 ha), 6 (199.44 ha), 9 (285.18 ha), and 11-year-old plantation (75.39 ha). The statistical analysis of Multivariate Analysis showed that biological species were mostly grouped with *P. falcataria* than *E. cyclocarpum* and *S. siamea* in the 11-year-old plantation area as well as in the 9-year-old plantation area. Most natural species were grouped with *C. cyclocarpum* rather than *S. saman* and *S. siamea* in a 6-year-old plantation area. In contrast, the biological species had no groups with *E. cyclocarpum* and *S. siamea* as fast-growing species in the 1-year-old plantation area. Generally, the most dominant planted fast-growing species were *E. cyclocarpum* (with the mean total number ± standard deviation, 35 ± 17.1) and *P. falcataria* (28 ± 8.3). The number of natural regeneration species and individuals in areas dominated by *P. falcataria* (5 ± 1.7 and 25 ± 10.5) was greater than in areas with predominance of *E. cyclocarpum* (4 ± 2.6 and 11 ± 4.8). Thus, species selection is necessary to increase natural regeneration. However, further research is required to measure the tolerability of fast-growing species on other natural regeneration species.

1. Introduction

Mine reclamation is an endeavour to rehabilitate the environmental function of the ex-mined site. It aims to organize, restore and improve the quality of the environment and ecosystem of the ex-mined sites to its designation. It is also to maintain land stabilization, improve land productivity and land function. There are different approaches of mine reclamation, namely “Guide for Surface Coal Mine Reclamation Plans” in Canada [1]; the “Forest Reclamation Approach (FRA)” in the US by the Virginia Tech Powell River Project [2]; mine reclamation model in Australia [3]; and European model [4, 5].

In Indonesia, revegetation is a form of mine reclamation which is initiated by fast-growing pioneers and cover crop plantation. Most planted fast-growing pioneer species are *Enterolobium cyclocarpum*,
Samanea saman, Senna siamea, and Paraserianthes falcata from the family of Fabaceae. They can associate with azotobacter bacteria for nitrogen fixation as pioneer species [6, 7]. In addition, pioneer plants perform to increase soil fertility by removing root exudates that attract certain bacteria, create a microclimate, and prevent erosion because of the root system’s ability to hold the soil from scouring water [8].

Furthermore, local long-lived species are also mandatory in Indonesian mine reclamation guidelines due to species richness. However, the number and species of planted local long-lived plants and their number are very limited information, hence the number and species of planted local long-lived development are highly dependent on natural regeneration [11]. Natural regeneration species can appear from stored seeds in the soil or carry them by animals, wind, water, etc. Planted pioneer species are also a factor to influence the growth of natural regeneration. Important characteristics such as the tree architecture, the root growth, the presence of allelopathic substances, and the decomposition ability of plant parts such as leaves, twigs, and branches may affect the growth of natural regeneration. This study aims to compare the number and species of natural regeneration as the result of pioneer plant plantation in ex-mined reclamation areas of different ages.

2. Methodology
This research was conducted at coal company, PT Mahakam Sumber Jaya (PT MSJ), in Kutai Kartanegara Regency and Samarinda City, East Kalimantan Province, Indonesia. The company has approximately 20,380 ha, consisting of forest (79.69%) and non-forest areas (20.31%). The forest area is also a concession of a logging company, PT Sumalindo Hutani Jaya. The land cover of the study area is mostly dominated by shrubs or pioneer plants, covering 18,142 ha or about 89% of the total area of the mining concession. The rainfall ranged from 1,787 to 2,634 mm/year between 2001 and 2010, with the highest rainfall occurring in March (268 mm), and the lowest was recorded in August (95 mm).

PT MSJ has been carrying out the mine reclamation since 2005 with a planting space of 4 m x 4 m. The planted fast-growing pioneer species are P. falcata, S. siamea, E. cyclocarpum, S. saman, etc., and planted local long-lived species from the Dipterocarpaceae family on the availability of the seedlings in the nursery. The vegetation inventory was taken using a modified circular plot of radius \( r = 17.8 \) m or about 0.1 ha [9]. A total of 10 plots (1 ha), which is the minimum size of plot that can be used for silvicultural research [10], were made for each of the vegetation/stand types in the different ages of reclamation areas, namely 1, 4, 6, 9 and 11-year-old-plantation. The circular plot was divided into three compartments, namely compartment “a” with a radius of 2 m, compartment “b” with a radius of 5 m, and main plot or compartment “c” with a radius of 17.8 m. The compartment differentiation was made for counting and measuring the different stages of trees, namely: compartment “a” was a subplot for calculating the seedling stage with the characteristics of a total height (h) of 30 cm ≤ h ≤ 1.30 m; compartment “b” was a subplot for measuring trees (sapling stage) that had a diameter at breast height (DBH, 1.3 m h), 1 cm ≤ DBH <10 cm; and compartment “c” was the main plot for measuring trees with a DBH ≥ 10 cm.

Species data recorded in this study are all plants that live and grow naturally and fast-growing pioneer species. The total number of individual species were summed up from all stages and plots. The summed data was then analyzed using Multivariate Analysis with the STATISTICA version 12 program.
3. Result

3.1. Natural regeneration growth in 11-year-old plantation
The most planted pioneer species in 11-year-old plantation was *P. falcataria*, followed by *S. siamea* and *E. cyclocarpum*, with individual total numbers from all stages and plots were 212, 78, and 35, respectively (figure 1). The natural regeneration found dominantly were *Monocarpia eunera*, *Mezzettia parviflora*, and *Macaranga tanarius* with the total number of 63, 59, and 14, respectively.

![Figure 1. The individual number of planted pioneer species and natural regeneration species in 11-year-old plantation.](image1)

![Figure 2. Multivariate analysis of planted pioneer species and natural regeneration species in 11-year-old plantation.](image2)
The multivariate analysis showed that *P. falcataria* dan *S. saman* were grouped with the natural regeneration more than *E. cyclocarpum* and *S. siamea* in the 11-year-old plantation. *P. falcataria* and *S. saman* were grouped with *Vitex pinnata, Bridelia glauca, Leucaena leucocephala, Trema orientalis, Macaranga tanarius, Mezzetta parviflora, Monocarpia eunera* and *Polyalthia sumatrana*. In addition, *E. cyclocarpum* was grouped with *Ficus obscuro, and S. siamea* was grouped with *Gliricidia sepium*. Some natural regeneration species were ungrouped with the pioneer species, such as *Nauclea subdita, Clerodendrum sp, Actinodaphne glabra, and Nothaphoebe sp.* (figure 2).

### 3.2. Natural regeneration growth in 9-year-old plantation

In 9-year-old plantation, there were two dominant pioneer species groups: *E. cyclocarpum* and *P. falcataria* with individual total numbers from all stages and plots were 182 and 172, respectively (figure 3). The natural regeneration found dominantly were *Macaranga gigantea* with an individual total number of 30.

![Figure 3](image)

**Figure 3.** The individual number of planted pioneer species and natural regeneration species in 9-year-old plantation.

The multivariate analysis in figure 4 showed that *P. falcataria* was grouped with more natural regeneration species than *E. cyclocarpum*. In detail, *P. falcataria* was grouped with *Ficus obscuro, Macaranga gigantea, Artocarpus odoratissimus, Cananga odorata, Actinodaphne glabra, Pterospermum javanicum, Mezzetta parviflora, Ficus albipila, Xanthophyllum sp. and Vernononia arborea*. In addition, *E. cyclocarpum* was grouped with *Neonauclea excelsa, Dillenia indica, Glochidion calospermum, Anthocephalus cadamba, and Macaranga tanarius* (figure 4).
Figure 4. Multivariate analysis of planted pioneer species and natural regeneration species in 9-year-old plantation.

3.3. Natural regeneration growth in 6-year-old plantation

In 6-year-old plantation area, *S. saman* (189) was found higher in total individual number than *E. cyclocarpum* (134) and *S. siamea* (69). Moreover, *Baccaurea lanceolata* was planted as a long-lived local species with a total individual number 5 (figure 5). However, the total individual numbers of natural regeneration in this area were still under 10, with the most dominant being *A. cadamba*.

Figure 5. The individual number of planted pioneer species and natural regeneration species in 6-year-old plantation.
The multivariate analysis in the 6-year-old plantation area showed that *E. cyclocarpum* was grouped with *Macaranga trichocarpa*, *Bridelia glauca*, *Ficus albipila*, *Ficus obscura*, and *Alstonia Scholaris*. While the species of *B. lanceolata* was grouped with *Macaranga tanarius*, *Acacia mangium*, and *Cratoxyllum sumatranum* (figure 6).

![Figure 6](image)

**Figure 6.** Multivariate analysis of planted pioneer species and natural regeneration species in 6-year-old plantation.

### 3.4. Natural regeneration growth in 4-year-old plantation

In the 4-year-old plantation area, *E. cyclocarpum* led the total individual number in all plots with 204 (figure 7). Its presence was the highest among *S. saman* (48) and *S. siamea* (14). Thus, only one natural regeneration species in three plots, namely *A. cadamba*, with the total individual number of 8.

![Figure 7](image)

**Figure 7.** The individual number of planted pioneer species and natural regeneration species in 4-year-old plantation.

The multivariate analysis in 4-year-old plantation showed that the planted pioneer species were ungrouped with any natural regeneration species (figure 8). Therefore, *A. cadamba* grew separately from the planted pioneer species.

![Figure 8](image)

**Figure 8.** Multivariate analysis of planted pioneer species and natural regeneration species in 4-year-old plantation.
3.5. Natural regeneration growth in 1-year-old plantation

In the first year after plantation, the most dominant pioneer species was *E. cyclocarpum* with individual total number from all stages and plots 18, followed by *Hibiscus tiliaceus* (9) and *S. siamea* (6). After that, however, *T. orientalis* growth was rapidly (16) as natural regeneration species (figure 9).

Nevertheless, as the dominant pioneer species, *E. cyclocarpum* was ungroup with any natural regeneration species. Instead, the natural regeneration species such as *T. orientalis*, *Macaranga trichocarpa*, and *Geunsia petandra* were grouped with *H. tiliaceus* (figure 10).

3.6. Number of natural regeneration species

According to figure 11, two dominant planted fast-growing pioneer species were *E. cyclocarpum* and *P. falcataria*. The mean total individual number for all stages and plots of *P. falcataria* was 25 in the mine reclamation area. It is higher than *E. cyclocarpum* (11). Moreover, the mean total number of natural regeneration species grouped with *P. falcataria* (5) was also higher than *E. cyclocarpum* (4).

![Figure 9](image1.png)  
**Figure 9.** The individual number of planted pioneer species and natural regeneration species in a 1-year-old plantation.

![Figure 10](image2.png)  
**Figure 10.** Multivariate analysis of planted pioneer species and natural regeneration species in a 1-year-old plantation.

![Figure 11](image3.png)  
**Figure 11.** Relationship of dominant planted pioneer trees species with natural regeneration.
4. Discussion

Mine reclamation rehabilitates the ex-mined sites for succession [11, 12]. Therefore, the soil monitoring results in the study area suggested the importance of species selection. Some parameters such as pH, moisture content, soil texture, and nutrient availability may be considered to define appropriate species [13].

Generally, *P. falcata* had the highest total individual number among all planted fast-growing pioneer species in the study area. Moreover, *P. falcata* was also grouped with many natural regeneration species such as *V. pinnata, B. glauca, L. leucocephala, T. orientalis, M. tanarius, M. parviflora, M. eunera, P. sumatrana*, etc. However, *P. falcata* was only found in 9 and 11-year-old plantation areas. Natural regeneration species invaded under pioneer species in the 10-year-old plantation area [14, 15]. In addition, *E. cyclocarpum* was the second pioneer species that had a high total individual number and was found in all mine reclamation areas. It was grouped with *F. obscura, N. excelsa, D. indica, G. calospermum, A. cadamba, M. tanarius*, etc.

Based on a previous study in the same area, the correlation analysis between the number of species and the reclamation ages showed a positive relationship in all growth stages [16]. The total number of natural regeneration species and families for seedling were 16 species and 11 families; sapling: 24 species and 13 families; and a tree: 15 species and 12 families. However, the numbers of natural regeneration species in the study area were still insufficient. The soil condition may affect the vegetation growth due to the topsoil thickness of 40 cm and high clay content and compaction. In addition, high clay content and reduction also may prohibit the root penetration and inhibit germination of N, P, and K [17, 18, 19, 20].

Mine reclamation in Indonesia starts by covering crop plantations to enrich soil nitrogen and reduce erosion [21]. Based on the study in 11-year-old plantation, vegetation structure growth still needed time to achieve its climax. Moreover, natural succession in the mine reclamation area, particularly in forest areas, may advance by planting the local long-lived species in the first plantation [22]. In this approach, species selection of local long-lived species is prioritized by intolerant species, so the reclamation success may also be achieved. Local long-lived species are a key to restore the forest [23] and increase the understory species [11, 24]. As the age of reclamation increases, the site converts into a self-sustaining forest [25, 26, 27, 28].

As the most planted pioneer species in mine reclamation, *P. falcata* had the highest survival rate compared to *H. brasilienensis* and *A. mangium* [29]. The plant height increment also shows its capability to grow faster. Planting time in a rainy season is also essential to enhance the survival rate [30]. The canopy cover model of *P. falcata* enables the light to penetrate the forest floor for understory natural regeneration species growth [31]. The succession is also supported by the distance of the nearest reclamation area and forest area.

As the natural regeneration species in the study area, *T. orientalis* was also advised as a fast-growing species and occurred in nickel and tin mine reclamation areas [32]. Therefore, it also could form colonization with natural regeneration species, especially in ex-mined nickel areas.

5. Conclusion

Based on the study, planting fast-growing pioneer species in mine reclamation creates ecological conditions; thus, natural regeneration tends to grow invasively. Moreover, *P. falcata* showed a higher total number and total individual number of natural regeneration species than other fast-growing pioneer species. Therefore, to enhance the reclamation success, species selection is necessary to increase natural regeneration. However, further research is required to measure the tolerability of fast-growing pioneer species on other natural regeneration species.

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