REVEGETATION OF TIN-MINED LAND USING VARIOUS LOCAL TREE SPECIESIN BANGKA ISLAND, INDONESIA[1]

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Abstract: Bangka is the largest tin producing island in Indonesia. Sand tin tailing may have 95% sand, C-organics less than 2%, cation exchange capacity less than 1.0, and its soil temperature may reach 45^{o}C. The objective of this research was to study the growth of ten selected local tree species in various planting densities and soil treatments on a barren tin-mine. The study aimed to identify agricultural techniques which the improved microclimate for those species, and enhanced natural recolonisation. A planting density of 10,000 seedlings ha^{-1} and legume cover crops gave the highest survival rate, cover, and litter production. It was suggested that higher planting density improved the microclimate faster. As *Hibiscus tiliaceus*, *Ficus superba*, *Calophyllum inophyllum*, and *Syzygium grande* had the highest individual survival and cover, and therefore show potential for revegetating sandy tin tailings.

Additional Key Words: revegetation, sand tin tailings, local tree species

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Introduction

Reliance on natural succession to restore sand tin tailings without any human aid can be very slow (Mitchell 1959; Nurtjahya *et al.* 2007a). Natural regeneration of 7-year old tin-mined land was initiated by plants from the Cyperaceae, Poaceae, and Melastomaceae; and followed by herb species at 11-years old; then by shrub species by 38-years. The vegetation structure of 38-year old tin-mined land was less than 2% similar to the vegetation structure of a forest (Nurtjahya *et al.* 2007a).

Sand tin tailings need to be amendment before planting. The un-mined C/N ratio was higher than forest. Concentrations of Ca, Mg, K, and Na were lower than undisturbed land, where older tin-mined land had higher concentrations than the younger ones. The cation exchange capacity of all tin-mined lands was very low, and the total base concentration was much higher than in forest and abandoned farmed-land (Nurtjahya *et al.* 2007a). No toxicity, however, was reported and heavy metal concentrations were still below those of the undisturbed land (Kusumastuti 2005).

A number of exotic species are widely used in rehabilitation programs but ecological caution suggests it is unwise to continue to rely on such a limited species mix for all future rehabilitation efforts (Lamb and Tomlinson 1994). The use of native tree species will accelerate natural succession. Xerophytic (Khemnark and Sahunalu 1988) and catalytic species, and some belong to sandy soil (Norisada *et al.* 2005), Padang vegetation, and *Barringtonia* formation seems to be suitable for revegetating tin-mined lands. Lists of plant invaders in revegetated tin-mined land (Latifah 2000; Setiawan 2003) may be considered.

Besides species selection, cultivation methods are another important factor in accelerating sand tin tailing restoration. Although much work has been carried out, there is a lack of systematic scientific studies on suitable site amelioration techniques (Ang *et al.* 2003). Besides standard soil amendment practices in Bangka (Nurtjahya 2001), various organic and non-organic materials, including microorganisms have been examined (Puryanto 1983; Awang 1988: Sastrodihardjo 1990; Madjid *et al.* 1994; Naning *et al.* 1999; Nurtjahya 2001; Setiadi 2002; CBR 2002).

To improve microclimate, a suitable planting method is needed (Rachmawati *et al.* 1996). Parrotta and Knowles (2001) reported thag high density 2 m x 2 m (2,500 tree ha^{-1}) planting with high plant species richness (80 – 100 species) proved to be successful in bauxite mines in Brazil.

A combination of soil amendments together with appropriate species and planting methods would be expected to successfully revegetate tin-mined land quickly and cheaply.

To evaluate the success of a revegetation program, various indicators can be applied: survival rate, plant growth rate, vertical and horizontal root growth, plant cover, litter production, local species recolonisation, and habitat improvement (Setiadi 2002); tree composition and size, integrity of rip-lines, nutrient cycling index, and habitat complexity (Ludwig *et al.* 2003), landscape function analysis (Tongway *et al.* 2001), bacterial functional redundancy (Yin *et al.* 2000), ant (Andersen and Sparling 1997), and bird (Passell 2000).

The aim of this study was to study the growth of ten selected local tree species in amended sand tin tailings, and to identify cultivation practices which support the best growth of local tree species and encourage natural colonization.

Materials and Methods

Study Site

The two hectare barren tin-mined land was operated by PT Tambang Timah until 4 years prior to this study is located at Riding Panjang, at an elevation of 30 m in Bangka Island, in the Province of Bangka Belitung Indonesia (01^{o} 59' 53.46"S and 106^{o} 06' 45.32"E) (Fig. 1). The island has 2,408 mm mean annual rainfall with 200 rainy days, with its mean daily temperature ranges 23.8^{o}C – 31.5^{o}C (Pangkalpinang Meteorology Station 2006). The site was firstly exploited around 1941 during the Dutch colonial period, before re-mining from 1997 until 2000. The premining vegetation was a swamp (Kusmah 2005).

Species Selection

To assist natural regeneration, potential tree species were selected by choosing species which grow in an environment similar to tin-mined land i.e. dry, porous, and infertile soil, high day time temperature, and prone to hot winds. Species were selected which were pioneers in lowland forest and abandoned farmed-land, or had strong catalytic characteristics. Information was obtained from conservationists and from the literature.

Ten local tree species were selected: *Calophyllum inophyllum* L. (Clusiaceae) (11.7%) and *Hibiscus tiliaceus* L. (Malvaceae) (9.9%) represented the *Barringtonia* formation (Backer and van den Brink 1965) which is tolerant to salt spray, nutrient-deficient soil, and seasonal drought (Whitten *et al.* 2000). *Macaranga* sp. (Euphorbiaceae) (3.1%) and *Mallotus paniculatus* (Lmk)

M.A. (Euphorbiaceae) (3.1%) were early pioneers. *Schima wallichii* (DC) Korth. (Theaceae) (6.3%) and *Vitex pinnata* (Verbenaceae) (20.6%) were late pioneers. *Ficus superba* Miq. (Moraceae) (15.2%) and *Syzygium grande* (Wight) Walp. (Myrtaceae) (17.9%) are adapted to sandy and rocky areas and sea winds. *Aporosa* sp. (Euphorbiaceae) (3.1%) commonly dominates in open and relatively dry areas. *Syzygium polyanthum* (Wight) Walp. (Myrtaceae) (9.0%) is considered a catalytic species.

Seeds from all species, mostly collected from Bangka Island, were germinated in sieved-white sand in 1 m x 1 m germination boxes in a 5 m x 5 m green house. Each box was contained one species. Seeds were dipped in 1% (v/v) humic acid liquid for about 2 – 6 hours to accelerate germination. The outer layer of *V. pinnata* seeds were peeled off in water. When seedlings reached the 3 leaf stage they were transplanted in to 10 cm x 20 cm polyethylene bags filled with soil. When their height reached at least 35 cm, they were acclimatized at the mine site for three weeks prior to planting.

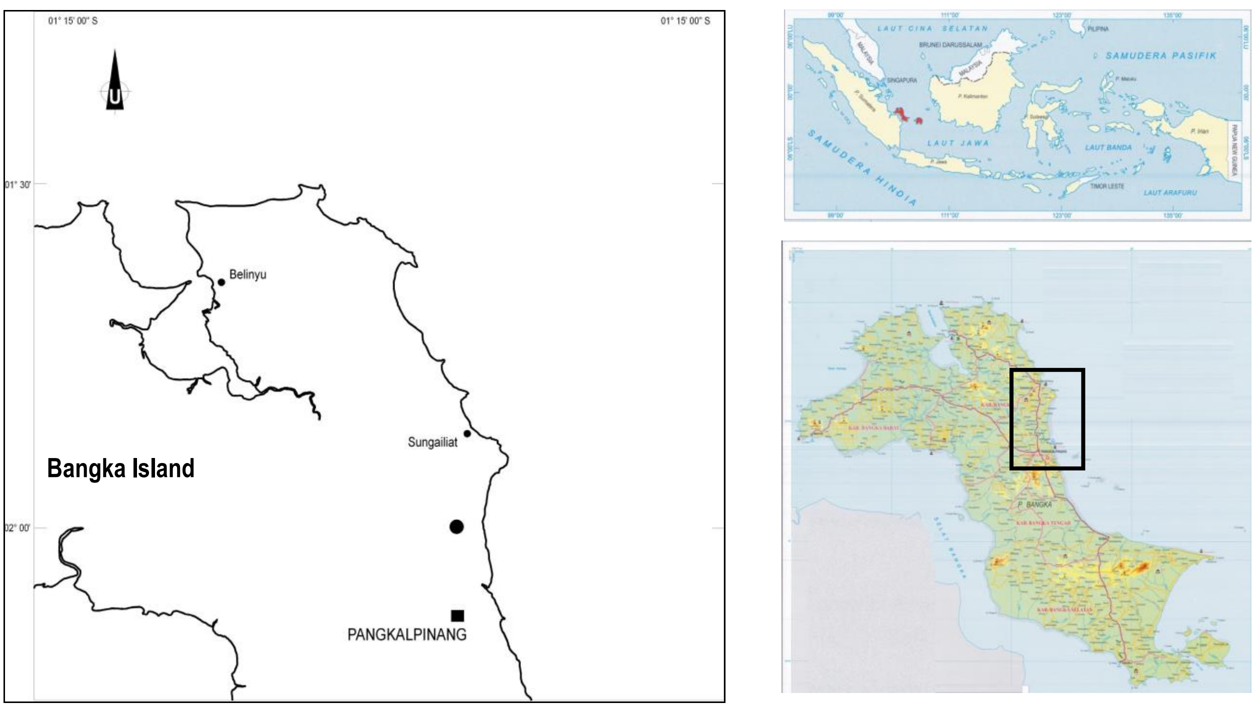

Figure 1. Bangka Island and site location (●)

Site Preparation

The tailing site was leveled (Fig. 2) and mapped. The local youth soccer club dug 30 cm x 30 cm x 30 cm planting holes and 40 cm width x 30 cm depth small ditches and installed individual fences in every 12 m x 12 m plot to support the edge of the sand tailing. Thirty liters of mineral soil, and 7 liters of sawdust-cow dung fermented compost were placed into each planting hole.

Figure 2. Study site after leveling (top-left), plot I J1T1 at fourteen months after planting (top-right), name board (bottom-left), and the study site from a different angle at 14 month after planting (bottom-right).

Experimental Design

The experiment consisted of a factorial randomized complete block design with two factors: planting distance and soil treatment, and three replicates. The three planting distance levels were 1 m x 1 m (J1), 2 m x 2 m (J2), and 4 m x 4 m (J3). The number of plants of each species in each planting distance treatment was 163 at 1 m x 1 m (J1, 10,000 seedlings ha^{-1}), 46 at 2 m x 2 m (J2, 2,500 seedlings ha^{-1}), and 14 at 4 m x 4 m (J3, 625 seedlings ha^{-1}), a total of 3,345 plants in 45 plots. Each planting distance treatment plot had ten species.

The five soil treatments were: (T1) control, (T2) the application of 500 grams powdered slime tailing under *Lepironia articulata* Rich. at three, seven, and eleven months after planting, (T3) an equal composition (1:1) 30 kg ha^{-1} of legume cover crops (LCC) *Calopogonium mucunoides* Desv. and *Centrosema pubescens* Bth., (T4) LCC and the application of 2.5% (v/v) humic acid at three, seven, and eleven months after planting, and (T5) LCC and top soil. To supply organic material, all individual plants all five soil treatments were given 1 liter cow dung solution – 20 liters of fresh cow dung in 200 liters of water – at three, seven, and eleven months after planting.

Planting

Planting was conducted by mostly local women on April 19, 2005 and replacement of dead plants (7.2%) was carried out 3 weeks after planting. Around the root collar of each plant, 3 – 4 pieces of coconut shell were placed at planting to improve the microclimate. The plants were watered with about one liter each by hoses in the afternoon from a nearby ex mined pond every day unless it rained. The water quality fluctuated seasonally but still fell in an acceptable range; the highest electrical conductivity in the dry season was 1.9 dS m^{-1} with no detectable concentration of heavy metals. Several fish species lived in the pond indicating that the water quality was high.

Data Collection and Analysis

Soil temperature at 3 cm depth and soil humidity at about 5 cm depth, inside and outside the coconut shells, was measured at nine months (wet season) and twelve months after planting (dry season). Survival and cover diameter of all individuals in each plot was measured at three, six, nine, and twelve months after planting. Fallen litter in each of the 45 plots was collected and weighed 12 months after planting. Population density of ants and *Collembola* spp. was determined using pitfall traps (Suhardjono 2004) at three, six, nine, and twelve months after planting. The number of plant species which invaded in each plot was determined at the end of the experiment. Analysis of variance ($p<0.05$) of the data was performed using one-way

ANOVA and Duncan Multiple Range Test. F values and significance levels were analyzed using the statistical package SAS 9.1.

Results

Microclimate beneath coconut shells was improved (Nurtjahya *et al.* 2007b). The shell significantly reduced soil temperature 4.3^{o}C inside the coconut shell at late dry season (month 9) and 2.1^{o}C at wet season (month 12), and significantly increased soil humidity between 7.6% – 12.2% at inside the coconut shell at dry season and mostly between 0.8% – 7.8% at wet season except at control (T1) and plots treated with slime tailing powder (T2).

Survival of all individuals in all 45 plots went down from 98.8% at three months after planting to 87.9% at six months after planting, and to 71.8% at nine months after planting and this percentage did not change at the end of the experiment (Table 1). There was significant effect of interaction between planting distance and soil treatment to survival rate. At planting distance 1 m x 1 m, all soil treatments gave high survival rate (a). At planting distance 2 m x 2 m all soil treatments also gave the same survival rate (b). At planting distance 4 m x 4 m, soil treatment with 500 g slime powder (T2) and soil treatment with LCC and humic acid (T4) gave survival rate lower (c) than the other three soil treatments (Table 2). The other three soil treatments i.e. control (T1), LCC (T3), and LCC and top soil (T5) had similar survival to those of planting distance 2 m x 2 m (b) although both planting distance treatments had different planting density. The combination treatment of highest planting density and LCC and top soil (J1T5) gave the highest survival rate at 78.7% although there was no different among five treatments at planting distance 1 m x 1 m. The overall survival at the end of the experiment was 2,395 individuals or 71.6%. The survival of individual species above 90% at the end of the experiment was belonged to *H. tiliaceus* (100%), *F. superba* (99.9%), *C. inophyllum* (99.3%), and *S. grande* (90.2%).

Table 1. Plot survival (%) and plot cover (m^2) at three, six, nine, and twelve months after planting

Plot	month 3		month 6		month 9		month 12		
	S (%)	Cover (m^2)	S (%)	Cover (m^2)	S (%)	Cover (m^2)	S (%)	Cover (m^2)	Cover (%)
J1T1	99.4	7.1	91.8	6.9	74.6	19.2	73.6	24.1	16.7
J1T2	95.7	8.1	91.4	7.3	72.8	16.5	73.2	19.5	13.5
J1T3	99.4	10.4	90.2	10.0	75.3	26.6	75.1	31.4	21.8
J1T4	99.6	9.2	91.8	8.7	77.5	22.3	77.3	25.9	18.0
J1T5	98.2	10.2	91.0	10.4	77.3	26.2	78.7	30.5	21.2
J2T1	98.6	2.1	79.0	2.2	60.9	3.7	60.1	5.1	3.5
J2T2	97.1	2.7	81.2	2.3	65.2	5.6	65.2	6.9	4.8
J2T3	96.4	2.1	79.0	2.7	63.8	4.7	63.0	5.6	3.9
J2T4	97.8	1.9	73.9	1.9	62.3	3.9	61.6	5.0	3.4
J2T5	99.3	2.0	81.9	2.0	58.0	4.4	57.2	5.4	3.7
J3T1	97.6	0.7	83.3	0.7	61.9	1.4	61.9	2.0	1.4
J3T2	100.0	0.7	78.6	0.8	52.4	1.3	52.4	1.7	1.2
J3T3	97.6	0.7	76.2	1.1	64.3	2.3	64.3	3.2	2.2
J3T4	100.0	0.6	81.0	0.6	52.4	1.1	52.4	1.4	0.9
J3T5	100.0	0.8	76.2	0.6	59.5	1.4	61.9	1.9	1.3

Note: J1 = planting density 1 m x 1 m (10,000 seedlings ha^{-1}), J2 = planting density 2 m x 2 m (2,500 seedlings ha^{-1}), and J3 = planting density 4 m x 4 m (625 seedlings ha^{-1}), T1 = control, T2 = the application of 500 grams powdered slime tailing under *L. articulata* at three, seven, and eleven months after planting, T3 = an equal composition (1:1) 30 kg ha^{-1} of legume cover crops (LCC) *C. mucunoides* and *C. pubescens*, T4 = LCC and the application of 2.5% (v/v) humic acid at three, seven, and eleven months after planting, and T5 = LCC and top soil.

Table 2 Duncan multiple range test on the effect of planting distance and soil treatment interaction to survival (%) at twelve months after planting

Soil Treatment (T)	Planting distance (J)		
	1 m x 1 m	2 m x 2 m	4 m x 4 m
control (T1)	73.62 [a]	60.15 [bc]	61.91 [b]
slime powder (T2)	73.21 [a]	65.22 [b]	52.38 [c]
LCC (T3)	75.05 [a]	63.04 [b]	64.29 [b]
LCC + humic acid (T4)	77.30 [a]	61.60 [b]	52.38 [c]
LCC + top soil (T5)	78.73 [a]	57.24 [bc]	61.90 [b]

Note: T1 = control, T2 = the application of 500 grams powdered slime tailing under *L. articulata* at three, seven, and eleven months after planting, T3 = an equal composition (1:1) 30 kg ha^{-1} of legume cover crops (LCC) *C. mucunoides* and *C. pubescens*, T4 = LCC and the application of 2.5% (v/v) humic acid at three, seven, and eleven months after planting, and T5 = LCC and top soil.

Similar superscript letters (a, b, c) within a column indicate that means were not significantly different between treatments (*P<0.05*).

There was significant interaction between planting distance (J) and soil treatment to cover of month 12. At planting distance 1 m x 1 m, T3 – legume (31.4 m^2) and T5 – top soil plus legume (21.2 m^2) gave the same high (a). T5 and T4 – humic acid plus legume were similar (b). At planting distance 2 m x 2 m, and planting distance 4 m x 4 m, soil treatments gave low (e) (Table 3). The average cover of planting distance 2 m x 2 m (2,500 seedlings ha^{-1}) and planting distance 4 m x 4 m (625 seedlings ha^{-1}) were not different despite different planting density. The highest cover were J1T3 (31.4 m^2) and J1T5 (30.5 m^2). Planting distance 2 m x 2 m (2,500 seedlings ha^{-1}) showed 4%, and planting distance 4 m x 4 m (625 seedlings ha^{-1}) gave the least at less than 1.5%. The highest cover of four individual species at the end of the experiment, twelve months after planting was belonged to *H. tiliaceus* (0.42 m^2), *S. grande* (0.25 m^2), *F. superba* (0.18 m^2), and *C. inophyllum* (0.13 m^2).

Table 3. Duncan multiple range test on the effect of planting distance and soil treatment interaction to cover (m^2) at twelve months after planting

Soil treatment (T)	Planting distance (J)		
	1 m x 1 m	2 m x 2 m	4 m x 4 m
control (T1)	24.08 ^{cd}	5.07 ^{e}	1.99 ^{e}
slime powder (T2)	19.47 ^{d}	6.86 ^{e}	1.71 ^{e}
LCC (T3)	31.40 ^{a}	5.64 ^{e}	3.20 ^{e}
LCC + humic acid (T4)	25.93 ^{bc}	4.96 ^{e}	1.36 ^{e}
LCC + top soil (T5)	30.50 ^{ab}	5.39 ^{e}	1.90 ^{e}

Note: T1 = control, T2 = the application of 500 grams powdered slime tailing under *L. articulata* at three, seven, and eleven months after planting, T3 = an equal composition (1:1) 30 kg ha^{-1} of legume cover crops (LCC) *C. mucunoides* and *C. pubescens*, T4 = LCC and the application of 2.5% (v/v) humic acid at three, seven, and eleven months after planting, and T5 = LCC and top soil.

Similar superscript letters (a, b, c, d, e) within a column indicate that means were not significantly different between treatments ($P<0.05$)

The average of litter production was 119 kg $ha^{-1}year^{-1}$. There was interaction between planting distance (J), and soil treatment (T) to litter production. Treatment with highest density and LCC (J1T3) had the highest litter production (459.7 kg $ha^{-1}year^{-1}$) although was not significantly different to highest density and LCC and the application of humic acid (J1T4) that was 233.8 kg $ha^{-1}year^{-1}$, to highest density and LCC and top soil (J1T5) that was 293.3 kg $ha^{-1}year^{-1}$, and to least density and LCC and top soil (J3T5) that was 124.5 kg $ha^{-1}year^{-1}$. Treatment with least density and the application of slime tailing powder (J3T2) had the least litter production (3.1 kg $ha^{-1}year^{-1}$). Highest density (1 m x 1 m) that was 212.5 kg $ha^{-1}year^{-1}$ was higher than middle density (2 m x 2 m) that was 90.9 kg $ha^{-1}year^{-1}$, and least density (4 m x 4 m) was the least that was 53.6 kg $ha^{-1}year^{-1}$. Soil treatment with LCC (T3) that was 208.6 kg $ha^{-1}year^{-1}$, LCC and the application of humic acid (T4) that was 145.8 kg $ha^{-1}year^{-1}$, and LCC and top soil (T5) that was 207.1 kg $ha^{-1}year^{-1}$ gave high litter production compared to control (T1) that was 19.1 kg $ha^{-1}year^{-1}$ and the application of slime tailing powder (T2) that was 14.4 kg $ha^{-1}year^{-1}$. Regardless the planting density, the use of LCC supplied a major percentage of litter production. In fact, the litter was majority (about 90%) came from *C. mucunoides*. *C. pubescens* showed poor adaptation to sand tin tailing environment.

There was no interaction between planting distance and soil treatments to ants and Collembolan population, but the time factor showed it (Nurtjahya *et al.* 2007c). The average of ant population density at month 9 was the highest (11,909 ind. m^{-2}) and not siginificantly different with month 6 (7,243 ind. m^{-2}), while the density of month 6 was not significantly different to month 12 (3,849 ind. m^{-2}). On the other hand, the average density of *Collembola* spp. at month 12 was the highest (375 ind. m^{-2}) although was not siginificantly different with month 9 (301 ind. m^{-2}), while the density of month 6 was the least (40 ind. m^{-2}). There was a tendency of higher population at more densed planting distance. The average density at planting distance 1 m x 1 m (3,514 ants and 4,820 *Collembola* spp.) was higher than planting distance 2 m x 2 m (2,872 ants and 341 *Collembola* spp.), and higher than planting distance 4 m x 4 m for *Collembola* spp. (301 individuals) but not for ants (5,161 individuals). The number of Collembolan species either at tin-mined lands or at the yard at Bangka was much lower than 76 species reported by Suhardjono (1992) at some forests in Bali and Lombok islands. The number of ant species either at tin-mined lands and the yard at Bangka was also much lower than 216 species of 61 genera reported at Bogor Botanic Garden (Ito *et al.* 2001).

There was 41 species belonged to at least 8 families found at study sites at month 12, 18 species of Poaceae, 7 species of Cyperaceae, 3 species of Asteraceae, 2 species of Leguminosae, 2 species of Melastomataceae, 1 species of Euphorbiaceae, 1 species of Orchidaceae, 1 species of Myrtaceae, and 6 species of other families. Four highest frequencies were recorded at species belong to Cyperaceae (88.9%), Melastomataceae (33.3%), Leguminosae (24%), and Poaceae (22%). There was no significantly different among plots, but soil treatments showed the differences. Top soil plus legume cover crops was the highest (7.4 species) and significantly different to others.

Discussion

It is suggested that the higher planting density, the faster plant cover covered the barren unfavourable area. The establishment of vegetative cover quickly should be emphasized during the early years of land rehabilitation at coal-mined rehabilitation (Wali 1999). The interaction between planting distance and soil treatment seemed to be determined by planting density and species composition in each plot. As the majority of individuals at planting density 10,000 seedlings ha^{-1} was more adaptive species, the overall survival was higher that other two. Comparing the composition of four highest survival and cover species (*H. tiliaceus*, *F. superba*, *C. inophyllum*, and *S. grande*) at three different planting densities, the total percentage of those species was not significantly different. This data showed that other six species might be also responsible to the difference. Other study (Nurtjahya and Juairiah 2006) showed that *S. grande* seemed to have more morphology, anatomy, and physiological adaptations on tin-mined land than *V. pinnata* seedlings by examining stomata density, and root conductivity ratio. Higher density and top soil gave the highest survival rate at 78.7%. Higher density might supply more organic matter, might support more suitable soil and air temperature, and soil humidity. Highest planting density also gave highest cover. These four species showed higher adaptability to sand tin tailing.

The combination of higher planting density and legumes, and the combination of higher planting density, legumes and top soil would increase the organic matter, and improve the microclimate by covering the bare ground faster. The efficiency of choosing high density with ecological benefits, however, might be also evaluated from the economic point of view. It seems that choosing a combination of middle planting density and legumes and combined with the use of four best local tree species may work. Litter production was significantly influenced by legumes mostly *C. mucunoides* leaf. Litter accumulation is the first visible sign of soil recovery (Setyawan *et al.* 2003).

Collembolan population significantly increased along with the age of study site although their average number at month 12 was only 8.3% of those at undisturbed land. The tendency of higher ants and Collembolan population at higher plant density may due to improved microclimate especially humidity. Collembolan population which increased from month 6, month 9, and month 12 reflected the increasing soil fertility and higher litter as the plant grew, and better microclimate. Ants population on the other hand showed different trend and seemed it failed to agree with Andersen and Sparling (1997) that ants as indicator of restoration process following disturbance. Probably it was affected by dynamics among the community over the time and possible hot spots at few plots due to man activities nearby, and one or two dogs from nearby hamlet was sometimes passing the study area. *Collembola* as a potential bioindicator for revegetation on tin-mined land success was suggested (Nurtjahya *et al.* 2007c). A similar study was reported that there was a quadratic four-morphospecies Collembolan population increase ($y = 33.352x^2 - 91.189x + 179.56$; $R^2 = 0.9817$) at 0, 3, 7, 9, 12, and 13-year revegetated tin-mined soil under *Acacia mangium* Willd. (Fabaceae) although there was not significant difference among the 3, 7, 9, 12, and 13 year revegetated areas (Nurtjahya *et al.* 2008 *unpublished*).

Soil treatment with top soil plus legume cover crops had the highest invading species among four soil treatments. It seemed that the top soil showed the function as source of seeds. Zhang *et al.* (2001) reported that 1-cm layer of top soil provided sufficient seeding density as thick top soil did at lead/zinc mine tailing. The good management of top soil for soil fauna, nutrient cycle, and biodiversity development on tailing was mentioned (Parrotta 2003, *pers. comm.*). The least invaders at tailing slime powder (T2) was probably due to a relatively acidic slime powder which did not support germination. The only woody species found was *A. mangium*, which most probably dispersed by birds as the source plant was a relatively far, about 1 km as the nearest from the site. Almost half of the site was surrounded by water, and the other part was peat swamp dominated by *Melaleuca leucadendron* and barren sand tin tailing. Birds as possible *A. mangium* seed disperser are reported (Starr *et al.* 2003).

Conclusion

Although it needs further verification, higher planting density played role in improving microclimate as more mineral soil and organic material added at the same area, faster soil coverage, might reduce hot and strong wind and high evapotranspiration. Alternating rips planting model faster minimized the open area. Species selection and composition seemed to be responsible for high survival and cover. Combination high planting density 10,000 seedlings ha^{-1} with legume, or with legume *C. mucunoides* plus top soil might be the choice. A combination of middle planting density (2 m x 2 m) and legume *C. mucunoides* and the use of four best local species i.e. *H. tiliaceus*, *F. superba*, *C. inophyllum*, and *S. grande* may be further studied to lower the cost.

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References

Andersen A. N., Sparling G. P. (1997). Ants as Indicators of Restoration Success: Relationship with Soil Microbial Biomass in the Australian Seasonal Tropics. Rest. Ecol., 5, 109-114. http://dx.doi.org/10.1046/j.1526-100X.1997.09713.x.

Ang L-H., Ho W-M., Najib L. A. (2003). *Soil Amendment of Ex-Mining Land for Growing Multipurpose Tree Species*. Proceedings of the AKECOP International Workshop, August 6-8th 2003, Thailand.

Awang K. (1988). *Tin Tailings and Their Possible Reclamation in Malaysia in* Adisoemarto S (ed.). Regional Workshop on Ecodevelopment Process for Degraded Land Resources in Southeast Asia, Bogor 23-25 August 1988.

Backer C. A., van den Brink R. C. B. (1965). *Flora of Java*. Vol. II. Angiospermae, Families 111 – 160. Groningen: NV P Noordhoff.

[CBR] Centre for Biotechnology Research. (2002). *Effect of Bio-organic on Soil and Plant Productivity Improvement of Post Tin Mine Site at PT Koba Tin Project Area, Bangka*. Bogor Agricultural University, October 2002.

Ito F., Yamane S., Eguchi K., Noerdjito W. A., Kahono S., Tsuji K., Ohkawara K., Yamauchi K., Nishida T., Nakamura K. (2001). Ant Species Diversity in the Bogor Botanic Garden, West Java, Indonesia, with Descriptions of Two New Species of the Genus Leptanilla (Hymenoptera, Formicidae). Tropics, 10(3), 379-404. http://dx.doi.org/10.3759/tropics.10.379

Khemnark C., Sahunalu P. (1988). *Revegetation trials for tin mine tailings reclamation in Thailand in* Adisoemarto S (ed.). Regional Workshop on Ecodevelopment Process for Degraded Land Resources in Southeast Asia, Bogor 23-25 August 1988.

Kusmah. (2005). *Rona Awal TB 1.2*. STIPER Bangka: Laporan Tugas Matakuliah Ekologi Tanaman (*unpublished*).

Kusumastuti E. (2005). Rehabilitasi Lahan Pasca Penambangan Timah di Pulau Bangka dengan Amelioran Bahan Organik dan Bahan Tanah Mineral dengan Tanaman Indikator Jati (*Tectona grandis*) [tesis]. Bogor: Sekolah Pascasarjana Institut Pertanian Bogor.

Lamb D., Tomlinson M. (1994). *Forest Rehabilitation in the Asia-Pasific Region: Past Lessons and Present Uncertainties*. J. of Trop. For. Sci., 7, 157-170.

Latifah S. (2000). *Keragaan Pertumbuhan Acacia mangium Willd. Pada Lahan Bekas Tambang Timah (Studi Kasus di Areal Kerja PT Timah Tbk.)* [tesis]. Bogor: Institut Pertanian Bogor, Program Pascasarjana.

Ludwig J. A., Hindley N., Barnett G. (2003). Indicators for Monitoring Minesite Rehabilitation: Trends on Waste-Rock Dumps, Northern Australia. Ecol. Indicators, 3, 143-153. http://dx.doi.org/10.1016/S1470-160X(03)00038-4.

Madjid N. M., Hashim A., Abdol I. (1994). *Rehabilitation of Ex-Tin Mining Land by Agroforestry Practice*. J. of Trop. For. Sci., 7, 113-127.

Mitchell B. A. (1959). *The Ecology of Tin Mine Spoil Heaps. Part I Sand and Gravel Tailings*. Malay. Forester, 22, 111-132.

Naning M. I, Diha M. A., Gofar N. (1999). *Perbaikan Sifat Kimia Bahan Tailing Asal Lahan Pasca Penambangan Timah dan Pertumbuhan Tanaman Jagung dengan Pemberian Bahan Organik dan Zeolit in* Prosiding Seminar Hasil Penelitian Universitas Sriwijaya, Maret 1999.

Norisada M., Hitsuma G., Kuroda K., Yamanoshita T., Masumori M., Tange T., Yagi H., Nuyim T., Sasaki S., Kojima K. (2005). *Acacia mangium, A Nurse Tree Candidate for Reforestation on Degraded Sandy Soils in the Malay Peninsula*. Forest Science, 51(5), 498-510.

Nurtjahya E., Setiadi D., Guhardja E., Muhadiono, Setiadi Y. (2007a). *Succession On Tin-mined Land in Bangka Island*. The Seventh International Flora Malesiana Symposium, Leiden 17 – 22 June 2007, the Netherlands.

Nurtjahya E., Setiadi D., Guhardja E., Muhadiono, Setiadi Y. (2007b). *Sabut Kelapa sebagai Mulsa pada Revegetasi Tailing Timah di Pulau Bangka*. Eugenia, 13(4), 366-382.

Nurtjahya E., Setiadi D., Guhardja E., Muhadiono, Setiadi Y. (2007c). *Potensi Collembola sebagai Indikator Revegetasi Tailing Timah di Pulau Bangka*. Jurnal Ilmu-ilmu Pertanian Indonesia, 9(2), 113-123.

Nurtjahya E., Juairiah L. (2006). *Struktur Anatomi dan Karakter Fisiologi Tanaman Pionir di Lahan Pasca Penambangan Timah di Riding Panjang, Bangka*. Sungailiat: Universitas Bangka Belitung.

Nurtjahya E. (2001). *Revegetation on Tin Post Mining Area in Bangka Island (Bibliographical Review)*. Indonesian Mining Journal, 7(3), 32-37.

Pangkalpinang Meterology Station. (2006). Data Iklim Bangka 1996 – 2005.

Parrotta J. A., Knowles O. H. (2001). Restoring Tropical Forests on Lands Mined for Bauxite: Examples from the Brazilian Amazon. Ecol. Eng., 17, 219-239. http://dx.doi.org/10.1016/S0925-8574(00)00141-5.

Passell H. D. (2000). Recovery of Bird Species in Minimally Restored Indonesian Tin Strip Mines. Restoration Ecology, 8(2), 112-118. http://dx.doi.org/10.1046/j.1526-100x.2000.80017.x.

Puryanto E. (1983). *Rehabilitasi Tanah Pasir Kuarsa eks Tambang Timah Pulau Bangka dengan Bahan-bahan Alamiah untuk Budidaya Tanaman Jambu Monyet (Anacardium occidentale L.)* [skripsi]. Bogor: Institut Pertanian Bogor, Fakultas Pertanian.

Rachmawati I., Karyawan K. A., Sinaga M. (1996). *Pengaruh Model Tanam terhadap Pertumbuhan Beberapa Jenis Pohon Serba Guna*. Buletin Penelitian Kehutanan BPK Kupang, 1, 102-108.

Sastrodihardjo S. (1990). *Pengaruh Pemberian Bahan Organik dan Polimer Alam serta Sintetik terhadap Beberapa Sifat Fisik dan Kimia Tanah Tailing Tambang 25 Wilasi Pangkalpinang Unit Penambangan Timah Bangka (UPTB)* [skripsi]. Bogor: Institut Pertanian Bogor, Fakultas Pertanian.

Setiadi Y. (2002). *Forest Restoration Program* (*unpublished*).

Setiawan I. E. (2003). *Evaluasi Tingkat Keberhasilan Revegetasi pada Lahan Bekas Tambang Timah PT Koba Tin, Koba, Bangka Belitung* [skripsi]. Bogor: Institut Pertanian Bogor, Fakultas Kehutanan.

Setyawan D., Gilkes R. J., Jasper D. A., Tongway D. J., Hindley N. (2003). *Nutrient cycling index in relation to organic matter and soil respiration of rehabilitated mine sites in Kelian, East Kalimantan*. Proceedings of the International Seminar on The Organic Farming and Sustainable Agriculture in The Tropics and Subtropics: Science, Technology, Management and Social Welfare. Palembang October 8-9, 2003, Vol. I, 123-126.

Starr F., Starr K., Loope L. (2003). *Acacia mangium, mangium wattle, Fabaceae. United States Geological Survey – Biological Resources Division Haleakala Field Station, Maui, Hawai'i*. (http://www.hear.org/starr/hiplants/reports/html/acacia_mangium.htm, visited March 3, 2007).

Suhardjono Y. R. (2004). *Buku Pegangan Belajar Collembola (Ekor Pegas)*. Bogor: Museum Zoologicum Bogoriense.

Suhardjono YR. 1992. Fauna Collembola Tanah di Pulau Bali dan Pulau Lombok [disertasi]. Jakarta: Program Pasca Sarjana, Universitas Indonesia.

Tongway D., Hindley N., Setyawan D. (2001). *Indicators of Ecosystems Rehabilitation Success – Stage Two Verification of Indicators*. Kelian Equatorial Mining (*unpublished*).

Wali M. K. (1999). Ecological Succession and the Rehabilitation of Disturbed Terrestrial Ecosystems. Plant and Soil, 213, 195-220. http://dx.doi.org/10.1023/A:1004475206351.

Whitten A. J., Damanik S. J., Anwar J., Hisyam N. (2000). *The Ecology of Sumatra*. Singapore: Periplus Editions (HK) Ltd.

Yin B., Crowley D., Sparovek G., De Melo W. J., Borneman J. (2000). Bacterial Functional Redundancy along A Soil Reclamation Gradient. Appl. and Env. Microbiol., 66, 4361-4365. http://dx.doi.org/10.1128/AEM.66.10.4361-4365.2000.

Zhang Z-Q. , Shu W-S., Lan C-Y., Wong M-H. (2001). Soil Seed Bank as An Input of Seed Source in Revegetation of Lead/Zinc Mine Tailings. Rest. Ecol., 9, 378-385. http://dx.doi.org/10.1046/j.1526-100X.2001.94007.x.