# Establishment of Four Native Tree Species for Potential Revegetating of Tin-Mined Land in Bangka Island, Indonesia

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## Abstract

*A research study was conducted to investigate revegetation of tin-mined land using mixed native tree species on Bangka Island, Indonesia. Natural plant succession on these sites is very slow. Consequently, the objective of this study was to evaluate ten native tree species for their suitability, and develop protocols for the rapid restoration of sand tin tailings. An experiment evaluated three levels of planting distance (4 x 4 m, 2 x 2 m, 1 x 1 m), five levels of soil treatment (control, plus slimes tailings powder, legume cover crops (LCC), LCC and humic acid, and LCC and topsoil) with each treatment replicated three times. A total of 3345 seedlings were planted in 45 plots, each 12 x 12 m. Four species i.e. Hibiscus tiliaceus L. (Malvaceae), Ficus superba Miq. (Moraceae), Calophyllum inophyllum L. (Clusiaceae), and Syzygium grande (Wight) Walp. Myrtaceae showed highest survival rates (90.2–100%) and canopy (0.13–0.42 $m^2$) at twelve months after planting. These four species are believed to possess better anatomical, morphological, and physiological adaptations than the other six species. H. tiliaceus, F. superba, C. inophyllum, and S. grande appear to be the most promising species to use for revegetating tin-mined lands.*

## 1 Introduction

Reliance on natural succession to restore sand tin tailings without any human intervention is impractical as it will take a long time before an effective cover is established (Mitchell, 1959; Ang, 1994; Nurtjahya et al., 2007a). Studies of natural regeneration on seven year old tin-mined land showed a dominance of species belonging to the families Cyperaceae and Poaceae; species belonging to Poaceae were dominant after 11 years, while shrub species of the family Myrtaceae were common on 38-year old tin-mined land (Nurtjahya et al., 2007a). The older tin-mined land tended to have soil with less sand and more silt and clay, a lower C/N ratio, higher $P_2O_5$, $K_2O$, Ca, Mg, K, Na, cation-exchange capacity (CEC), lower base saturation, and higher $Al^{3+}$ (Nurtjahya et al., 2007a). No chemical toxicity to plants was reported (PPTA, 1996; E. Kusumastuti 2002, pers. comm.).

Standard sand tin tailings rehabilitation procedures practiced on the island involved planting with predominantly exotic Acacia mangium (Nurtjahya, 2001). Various sources of organic and inorganic matter to ameliorate the soil were examined (Siagian and Harahap, 1981; Puryanto, 1983; Sastrodihardjo, 1990; Naning et al., 1999; Nurtjahya, 2001) to increase CEC (especially in young tailings, Bendfeldt et al., 2001), water holding capacity, aggregate stability, and nutrient availability (Schroeder, 1996). The use of living mulch (Madjid et al., 1994; CBR, 2002) and the application of arbuscular mycorrhizal fungi were reported. A number of exotic tree species, widely used in rehabilitation programmes, were considered undesirable for all future rehabilitation efforts (Lamb and Tomlinson, 1994) as they may inhibit natural recolonization, although recent study showed that A. mangium was used successfully as a nurse-tree for reforestation on degraded sandy soils (Norisada et al., 2005). Selection of native tree species has been guided by information from natural succession observation (Nurtjahya et al., 2007a), vegetation types (Roemantyo et al., 2004), lists of plant invaders in revegetated tin-mined land (Latifah, 2000; Setiawan, 2003), and heath forest species (Norisada et al., 2005).

Various indicators have been used to evaluate the success of revegetation. These include survival rate, plant growth, vertical and horizontal root growth, canopy, litter production, native species recolonization, and habitat improvement (D.J. Tongway et al., 2001, pers. comm.; Y. Setiadi, 2002, pers. comm.; Ludwidg et al., 2003), and the measurement of flora and fauna (Andersen and Sparling, 1997; Passel, 2000; Yin et al., 2000; Nurtjahya et al., 2007b). Survival rate is viewed as the most critical indicator (Lamb and Tomlinson, 1994).

The aim of this experiment was to identify the potential native tree species and amelioration amendments that are most useful in revegetating sand tin tailings. Results will aid the development of planting strategies that are effective for the re-establishment diverse native forests in as short a time as possible at places where the expense and high level of technical and professional supervision might be limited.

## 2 Methodology

### 2.1 Study site

The two hectares zero-year-old barren tin-mined land selected for the trial is located at Riding Panjang, Bangka Island, Indonesia (lat. 01°59'53.46"S; long. 106°06'45.32"E; 30 m asl.) (Figure 1). Mean annual rainfall (1996–2005) was 2408 mm, and temperature ranges from 23.8–31.5°C with an average of 26.8°C (Pangkalpinang Meteorology Station, 2006). Each site was fenced and a 40 cm wide, 30 cm deep trench dug around the perimeter. Planting holes were a 30 cm cube filled with 30 L mineral soil, and 7 L saw dust-cow dung compost.

### 2.2 Species selection

A total of ten species with different percentages were selected for use in the trial. Calophyllum inophyllum L. (Clusiaceae) (11.7%) and Hibiscus tiliaceus L. (Malvaceae) (9.9%) are found in the Barringtonia formation (Backer and van den Brink, 1965) which is tolerant of salt spray, nutrient-deficient soil, and seasonal drought (Whitten et al., 2000). Calophyllum sp. and Syzygium sp. are common in padang vegetation, which is regarded as natural regeneration of degraded heath forest (Whitten et al., 2000). Macaranga sp. (Euphorbiaceae) (3.1%) and Mallotus paniculatus (Lmk) M.A. (Euphorbiaceae) (3.1%) are early pioneer species. Schima wallichii (DC) Korth. (Theaceae) (6.3%) and Vitex pinnata (Verbenaceae) (20.6%) are late pioneer species and seedlings of both species were recorded at 38-year old tin-mined land (Nurtjahya et al., 2007a). Syzygium grande (Wight) Walp. (Myrtaceae) (17.9%) is common in the foothill coastal areas. Ficus superba Miq. (Moraceae) (15.2%) is adapted to sandy and rocky coastal areas. Aporosa sp. (Euphorbiaceae) (3.1%) commonly dominates in open and relatively dry areas. Syzygium polyanthum (Wight) Walp. (Myrtaceae) (9.0%) is a nurse tree.

### 2.3 Seedling preparation

Seeds were germinated in sieved white sand in a green house with an average humidity of 76% and an air temperature of 30.4°C. Seeds were dipped in 1% (v/v) humic acid solution for about 2–6 hours, or a hot sand dip for 20 minutes for V. pinnata seeds. Seedlings with at least three leaves were transplanted into polythene bags, and sprayed with leaf fertilizer Hyponex (red) (0.25 g/L) every three weeks. Seedlings with a height of 35 cm were transferred to the environs of the study site for three weeks of acclimatization prior to planting.

### 2.4 Experimental design

The experiment consisted of a factorial randomized complete block design with two factors (planting density and soil treatment) and three blocks as replications. Each plot was 12 x 12 m with 2 m spacing between plots and blocks. Three planting density levels were 1 x 1 m (10,000 seedlings/ha), 2 x 2 m (2500 seedlings/ha), and 4 x 4 m (625 seedlings/ha), comprising a total of 3345 plants of ten species while the species composition among the three planting density treatments was similar. The planting arrangement was diamond or alternating one (Rachmawati et al., 1996; Parrotta and Knowles, 2001).

Five soil treatments were (i) control (T1), (ii) 500 g slime tailing powder under Lepironia articulata Rich. (T2), (iii) equal composition (1:1) of legumes Calopogonium mucunoides Desv. and Centrosema pubescens Bth. with 30 kg/ha (T3), (iv) legumes and the application of 2.5% (v/v) humic acid (T4), and (v) legumes and topsoil (T5). Legumes were fertilized with compost applied at rates of 200 kg/ha and 5 tons/ha. The compost

was a medium quality one with its pH 7.8, C-organic 10.2%, N-total 0.45%, P-total 0.23%, and K-total 0.32%. Slimes tailings powder was prepared by crushing dried tin slime tailings which were available near the study site. It had 44% silt and 49% clay, pH = 2.9, C/N = 23, Ca = 1.26, Mg = 2.03, K = 0.11, and Na = 0.63 cmol(+)/kg, and CEC = 17.2. Humega humic acid (6% liquid humic acid extract) was applied at three, seven, and eleven months after planting. Its pH was 8.9, C/N = 26, Na = 0.93, Ca = 0.05, and Mg = 0.02 ppm. All plants were given 1 Lof 48-hour fermented cow dung (10% v/v) at three, seven, and eleven months after planting. Topsoil was collected from nearby lowland forest and the nearest Padang vegetation.

## 2.5 Planting

Seedlings were acclimatized in palm leaf-roofed green houses for three weeks before planting. Replacement of dead plants took place over three weeks after planting, and involved 241 plants or 7.2% of the total number of seedlings. Three to four pieces of coconut shell were placed around the collar of each seedling in the field. This reduces soil temperature by 2.1–4.3°C and significantly increases soil humidity between 0.8–12.2% (Nurtjahya et al., 2007c). Every two weeks over the first three months, the plants were sprayed with leaf fertilizer Hyponex at a concentration of 0.25 g/L. The plants were watered every afternoon using water extracted from a nearby ex-mining pond (kolong) (Figure 2). The water quality fluctuated seasonally but remained within the normal range for plants with the highest reading of electric conductivity (EC) in the dry season (1.9 mmhos/cm). Its pH was 3.8 in dry season and 4.1 in rainy season, total cations 21.45 me/L in the dry season and 0.94 me/L in the rainy season, total anion 19.44 me/L in dry season and 1.04 me/L in the rainy season, silt 0 ppm in the dry season and 115 ppm in the rainy season, and no detected concentration of Pb, Cd, Co, Ni, and Cr cations except 0.03 Pb and 0.01 ppm Ni in the dry season. Several fish species live in the pond.

## 2.6 Data collection and analysis

Survival and sapling canopy diameter (maximum) of all individuals were measured at three, six, nine, and twelve months after planting.

# 3 Results

## 3.1 Survival

Survival of all individuals in all 45 plots declined from 98.8% at three months after planting, to 87.9% at six months, and to 71.8% at nine months, after which it remained the same until the end of the experiment, twelve months after planting. This mortality was mainly a result of poor survival of the pioneer species S. wallichii, Macaranga sp. and M. paniculatus, and the non-pioneer species Aporosa sp. Only a small percentage of seedling mortality was attributed to human disturbance. Survival rates above 90% at the end of the experiment was recorded for H. tiliaceus (100%), F. superba (99.9%), C. inophyllum (99.3%), and S. grande (90.2%) (Figure 3). Four species with the highest survival rates at three months were also the highest survivors at the end of the 12-month study. Species showing survival rates below 20% at the end of experiment included S. wallichii, Macaranga sp. M. paniculatus, and Aporosa sp.

## 3.2 Tree canopy

The four species with the highest canopy cover at the end of the experiment were H. tiliaceus (0.42 m$^2$), S. grande (0.25 m$^2$), F. superba (0.18 m$^2$), and C. inophyllum (0.13 m$^2$) (Figure 4). The four plant species with the highest canopy cover at three months also had the highest canopy cover at the end of the experiment. Figure 4 shows the cover development of each species from three months after planting to twelve months. At six months after planting, the cover remained low, but increased thereafter.

The four species with the highest survival and canopy cover were H. tiliaceus, F. superba, C. inophyllum, and S. grande. This appears to be explained by the morphological adaptability to the environmental conditions of these species such as thicker cuticle and/or suberin. Some adaptations were reported in other study (Nurtjahya and Juairiah, 2006). Stomatal density of S. grande planted in tin tailing (609.8/mm$^2$) was significantly greater than that of planted in undisturbed land (539.1/mm$^2$), while stomatal density of

V. pinnata showed the opposite. Leaf tissue ratio of V. pinnata planted in tin tailings (0.10) was greater than that of planted in undisturbed land (0.09), while S. grande showed the opposite. Root conductivity ratio of S. grande planted in tin tailing (0.09) was significantly less than that of planted in undisturbed land (0.10) (Nurtjahya and Juairiah, 2006). Sonibare et al. (2006) reported that heavy lignification, multiple epidermis and the presence of hypodermis in some Ficus species from Nigeria were probable anatomical features of adaptation to xerophytic environments. Specific leaf area probably plays a significant role in effective assimilation and maintenance of heath forest productivity under stressful conditions (Miyamoto et al., 2007). On the other hand, some pioneer, nurse tree, or non-pioneer species were not adapted to barren sand tin tailings. Early or late pioneer (Cheah, 1995; M. Kanzaki, 2004, pers. comm.) is not always suitable to revegetate at any stages of abandoned tin-mined lands, although seeding early-successional shrubs may be an inexpensive strategy to accelerate recovery (ITTO, 2002). Macaranga spp. and Mallotus spp. were absent as colonizers in padang vegetation in Bangka Island (Whitten et al., 2000). Only species with heat tolerance or avoidance capacities may survive the heat stress in sand tailings (Ang and Ang, 1997).
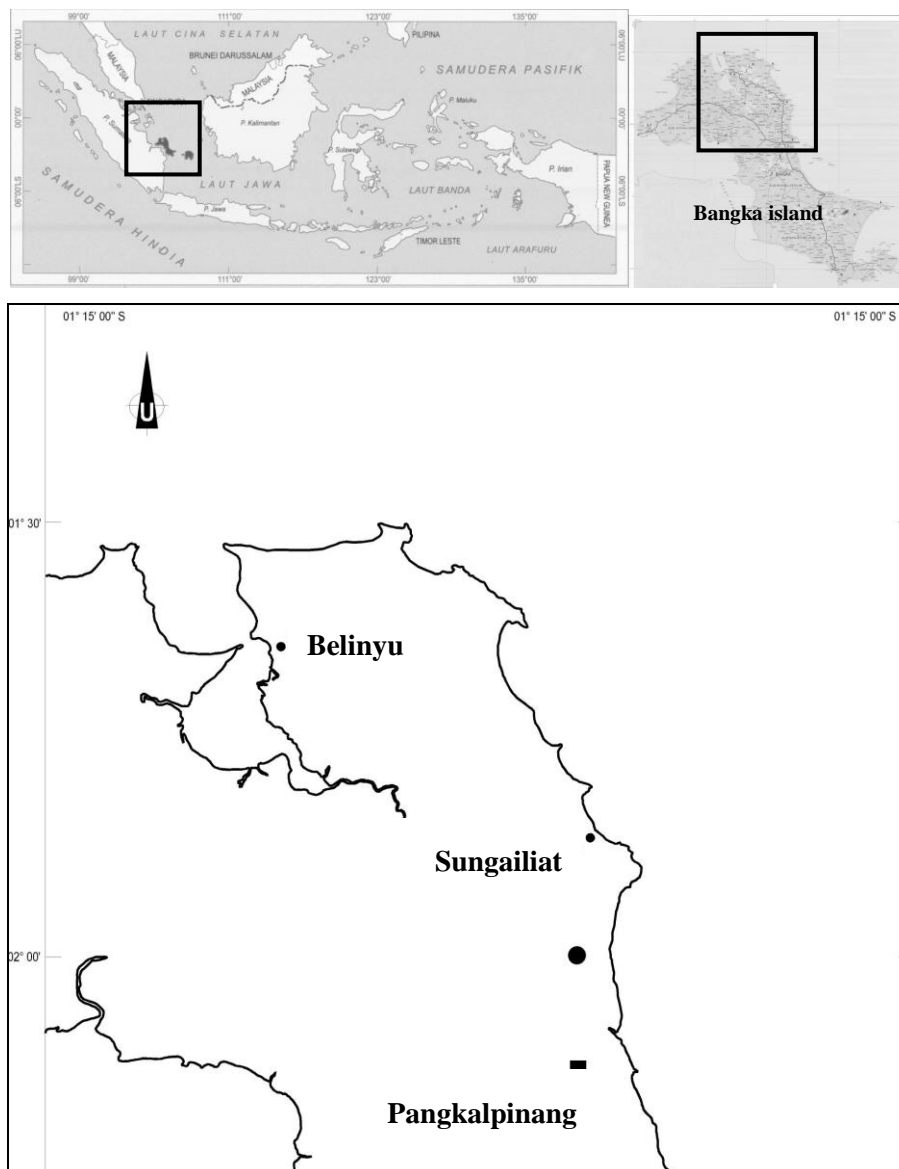


**Figure 1    Study site (●) in the north-east of Bangka Island, Indonesia**

**Figure 2**    **Barren sand tin tailing before planting (top); highest planting density (1 x 1 m) and no soil treatment at the end of experiment (bottom)**
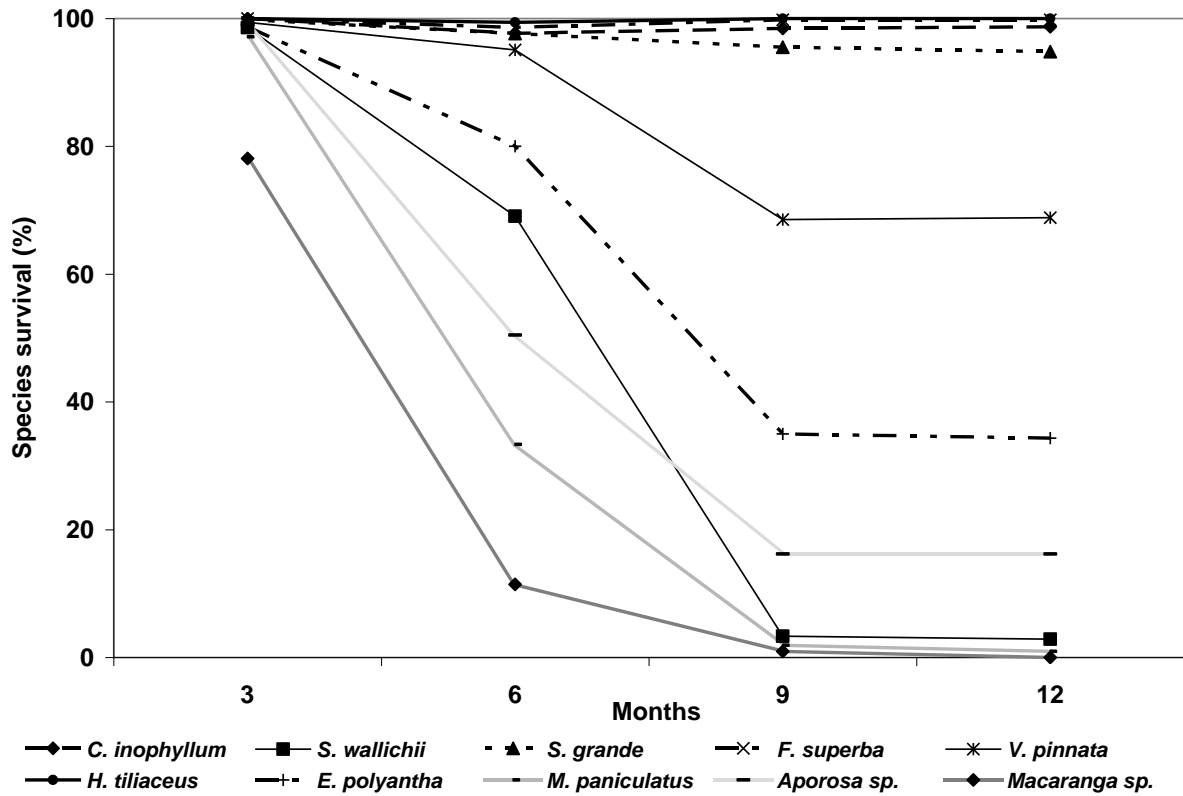
**Figure 3** The average species survival at three, six, nine, and twelve months after planting
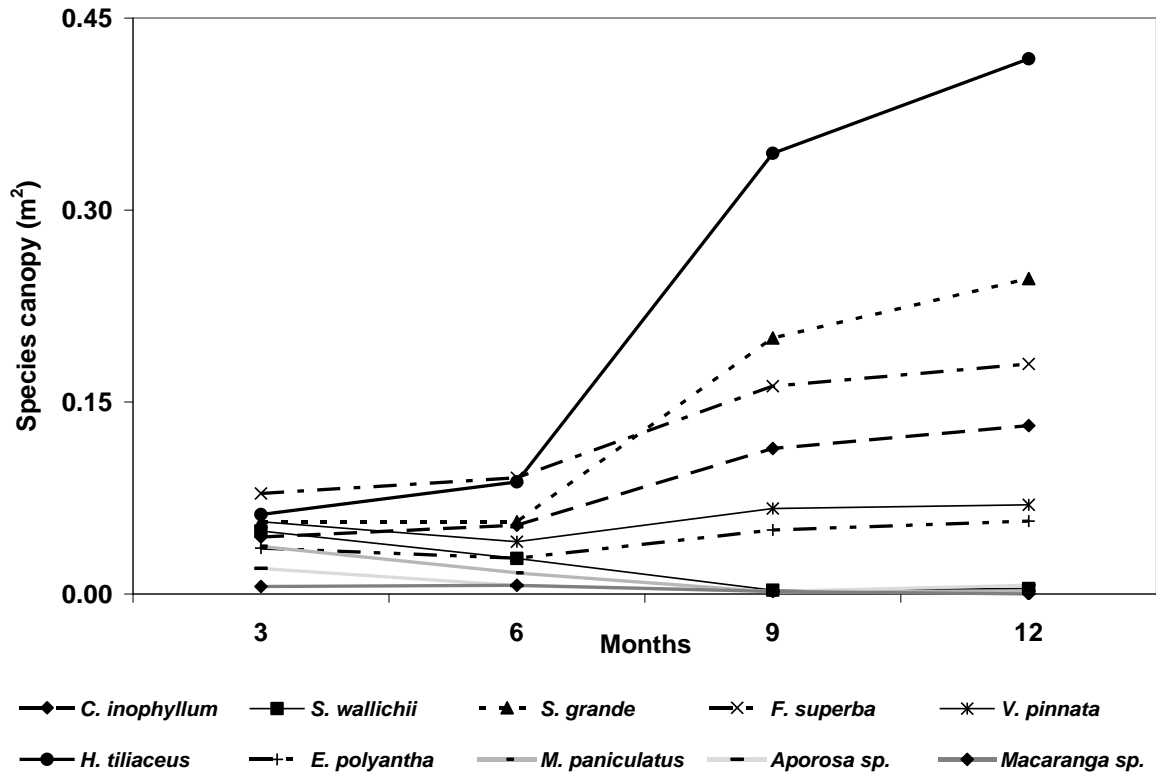


**Figure 4** The average species canopy area at three, six, nine, and twelve months after planting

# 4    Conclusions

Four of ten native tree species i.e. H. tiliaceus, F. superba, C. inophyllum, and S. grande showed highest survival rates (90.2–100%) and highest cover development (0.13–0.42 m$^2$) at twelve months after planting. Evidence suggests that these four species have better anatomical, morphological, and physiological adaptations than the other six species and are therefore the most promising of the ten native tree species for revegetating tin-mined lands. Based on different adaptation among native trees planted in the experiment, minimal water demand and evapotranspiration should be measured in further selections of native tree species as candidates for revegetating sand tin tailing. These should be sought within the Barringtonia formation of coastal mixed forest, and Padang vegetation.

# Acknowledgements

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