PROBLEMS AND PROSPECTS OF AFFORESTATION ON SANDY TIN TAILINGS IN PENINSULAR MALAYSIA

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ANG, L.H. 1994. Problems and prospects of afforestation on sandy tin tailings in Peninsular Malaysia. Large tracts of unproductive tin tailings occur in Peninsular Malaysia. This paper surveys the problems of afforestation on sandy tin tailings, which comprise an estimated 80% of total tin tailings. High sand composition, low nutrients, low organic matter, low moisture and high ground temperature make sandy tin tailings unsuitable for tree planting. Solutions to the identified problems are suggested. These include improvement of the tailings' moisture and fertility, and the introduction of beneficial microorganisms. In addition, the legal and silviculture aspects of afforestation on sandy tin tailings are discussed.

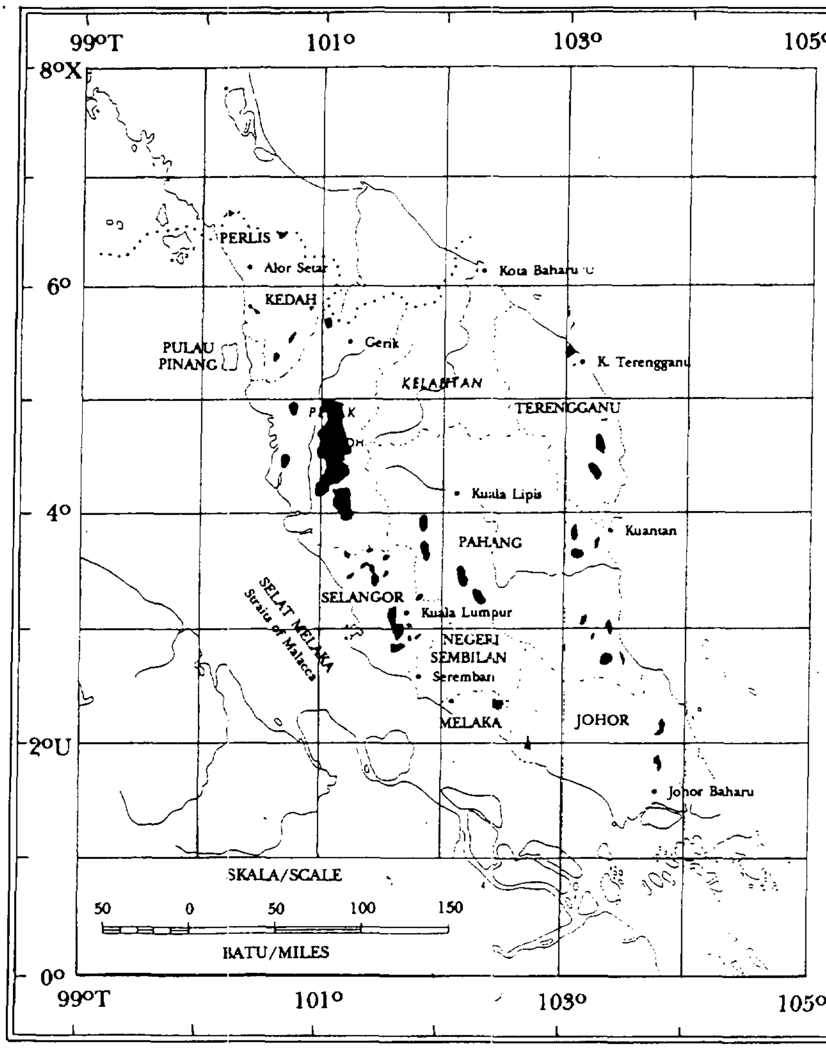
Key words: Rehabilitation - Malaysia - tin tailings - afforestation

ANG, L.H. 1994. Masalah dan prospek penghutanan semula pada hampas lombong timah yang berpasir di Semenanjung Malaysia. Terdapat banyak kawasan hampas lombong yang tidak produktif di Semenanjung Malaysia. Kertas kerja ini mengkaji masalah penghutanan semula di hampas lombong berpasir yang merangkumi 80% jumlah hampas lombong. Komposisi pasir yang tinggi, kandungan nutrien yang rendah, bahan organik yang sedikit serta lembapan yang rendah dan suhu tanah yang tinggi menjadikan hampas lombong berpasir tidak sesuai untuk penanaman pokok. Penyelesaian kepada masalah-masalah tersebut dicadangkan. Antaranya ialah memperbaiki kelembapan dan kesuburan hampas lombong serta menggunakan mikroorganisma yang berfaedah. Aspek-aspek dari segi undang-undang dan silvikultur penghutanan semula pada hampas lombong turut dibincang.

Introduction

Malaysia is one of the world's main tin producers. Most of the alluvial tin ore deposits are located on the western side of the main range in the peninsula (Figure 1), beginning in the north and stretching southward through Ipoh to Melaka. On the east coast, tin lodes are found at Sungai Lembing. Mining activities since the 1930s have resulted in about 113 700 ha of tin tailings throughout the peninsula, or about 2% of the total land area (Chan 1990). Tin tailing sites are most extensive in the state of Perak (63%), followed by Selangor (22%).

About 80% of tin tailings is sand and the rest is slime and sandy slime. Slime consists of clay and silt, is found in localities previously used as detention ponds for discharged tailings, and is a better ground for agriculture than sand as it has good drainage (Mitchell 1957). Sand is very infertile and is not suitable for cultivation. Only small pockets of such infertile sites are used for settlement, vegetable farming and fruit tree growing. Large amounts of fertiliser are required to reclaim this land for agriculture. The cost is prohibitive, and consequently large tracts of tin tailings remain idle. Tree planting on tin tailings is recognised to be an effective rehabilitation method (Abd. Rahman 1985). Mitchell (1957) reported promising afforestation on 20-year-old tin tailings, and recommended several forest tree species from preliminary species trials. From three of these plots established at three locations in the peninsula, some potential tree species for reclamation of sandy tin tailings were identified (Ang 1986). This paper identifies problems of afforestation of sandy tin tailings and discusses the prospects of such rehabilitation activities.



Tin deposit

Source: Mines Department, Malaysia

Figure 1. Tin mining areas in Peninsular Malaysia

Source of tailings

Most of Malaysia's tin production is obtained from alluvial tin deposits by gravel pump, dredging and opencast mines. In 1990, 86.6% of tin production came from these mines (Table 1).

These methods employ water for the mechanical separation of the tin ore from the tin-bearing soils. The top soil is normally not saved. Extraction using these methods results in sandy tin tailings because the clay and silt are washed away and deposited separately from the coarse sand and fine sand.

Table 1. Percentage of tin production in Peninsula Malaysia by various methods

Year	Gravel pumps	Dredging	Open cast	Under-ground	Other	Total
1970	55.2	32.4	3.4	3.1	5.9	100 (73 795t)
1980	56.2	29.7	4.4	1.8	8.0	100 (61 406t)
1988	33.9	45.5	9.5	0.4	10.8	100 (28 866t)
1989	41.4	37.3	9.1	0.3	11.8	100 (32 034t)
1990	42.9	36.1	7.6	0.4	13.0	100 (28 468t)

Source: Ministry of Primary Industries, Malaysia 1991.

Gravel pump mining

Gravel pump mining is most commonly practiced in smaller mines and is used to work tin deposits on uneven bedrock. The tin-bearing earth is excavated and separated by jets of water. The suspension is then raised to an elevated sluice box or *palong*. Here, a rough tin concentrate is deposited through gravity, and the tailings are usually discharged on sloping ground contoured on the lower end by a retaining bank. Gravel and coarse sand are therefore found near the point of discharge, with a continuous gradation to a fine clay at the lower end of the slope.

Dredging

Large mines in Malaysia employ dredging for alluvial mining. In this method, the overburden from 20 to 40 m is stripped and discharged behind the dredge. The underlying ore-bearing material is then excavated and broken up by water jets in the dredge. During this process, the soil structure is broken down and a great portion of the soil organic matter and nutrient content is removed. Gravel, stones and unbroken clay balls are discharged behind the dredge. Fine sand, silt, clay and mineral ores are passed through jigs from which a rough tin concentrate is obtained. The sand fraction is discharged via a sand chute. Sand tailings are estimated to occupy an average of 80% of the tailing surfaces (Lim *et al.* 1981). The presence of water holes depend largely on the elevation of the mining area. The finer silt and clay particles in suspension are pumped into a slime retention area for settlement. It is estimated that the slime fraction occupies an average of 20% of the original ground. In the case of dredge mining it is common practice to ensure that much of the coarse sand and gravel is subsequently covered with silt clay, a practice known as sliming. This type of land is much more amendable to reclamation by forestry (Mitchell 1957).

Opencast mining

Opencast tin mining accounts for about 7.6% of total tin ore production in the peninsula. Opencast mining involves removal of tin ore rich alluvium by mechanical means rather than by water. The excavation of the alluvium is carried out by shovel, dragline or hydraulic excavators. The alluvium is transported to the *palong*. Tin from the alluvium is extracted by water, similar to the gravel pump method.

Properties of tin tailings

Certain physical and chemical properties of sandy tin tailings make afforestation of these tailings difficult.

Physical properties: particle size distribution

Mitchell (1957) reported a high percentage of sand in the texture of tin tailings, independent of age (Table 2). This implies that weathering and vegetation have little influence on the texture of tin tailings even after 20 years. The study also indicated that tin tailings continue to lose clay content to erosion for a prolonged duration after dumping, e.g. 6.3% clay in five-year-old tin tailings compared to only 2.4% found in 20-year-old tin tailings. The low percentage of clay in tin tailings makes the establishment of seedlings more difficult because it reduces the cation exchange capacity (CEC) and water holding capacity of the tin tailings.

Table 2. Particle size distribution (%) of sandy tin tailings resulting from gravel pump method (adapted from Mitchell 1957)

Age (years)	5				10				15			
Composition depth (cm)	C	S	FS	CS	C	S	FS	CS	C	S	FS	CS
0 - 15.0	6.7	3.0	26.7	63.6	2.6	2.6	17.4	77.4	2.2	5.8	20.9	71.1
15.0 - 30.0	8.0	4.4	25.7	61.9	3.6	3.6	20.4	72.4	2.4	6.8	19.4	70.4
45.0 - 60.0	6.6	5.2	21.2	67.0	4.0	4.5	26.3	65.0	2.4	7.3	19.4	70.9
Average	6.3	4.5	22.6	66.0	3.4	3.6	21.9	70.9	2.4	6.4	20.6	70.2
Forested area	40.0	10	19.1	30.9								

Note: C = clay (< 0.002 mm), S = silt (0.002-0.05 mm), FS = fine sand (0.05-2.00 mm) & CS = coarse sand (> 2.00 mm).

Forested area: Muchong soil series from Pasoh Forest Reserve, Negri Sembilan, Malaysia (AllBrook 1973).

Temperature

The high temperature of tin tailings is another limiting factor for tree planting. Table 3 shows the temperature regime of tin tailings at various depths (Mitchell 1957). The high temperatures of tin tailings approach or exceed the 50% heat killing temperature of primary rainforest species, which ranges from 43.9 °C to 51.7 °C (Levitt 1972). This indicates that most of the high value timber tree species from natural forest are not suitable for planting on sandy tin tailings.

Table 3. Diurnal changes in temperature (°C) of sandy tin tailings at the surface and at depth

Depth (cm)	Time									
	9.30	10.30	11.30	12.30	13.30	14.30	15.30	16.30	17.30	18.30
Surface	34.4	39.4	44.4	47.7	48.3	48.8	49.4	45	38.3	31.7
10	28.9	30.0	32.2	35.6	36.7	38.3	38.9	38.3	37.2	35.6
20	27.2	27.5	27.7	28.9	30.0	31.1	32.2	33.9	34.4	35.0

Source: Mitchell 1957.

Moisture content

The prevalent moisture status of the tin tailings is dry. Palaniappan (1972) observed that the field moisture content of the sand was only one ml per 100 g of dry sand. The high porosity of sand particles in tin tailings reduces the water retention capacity. Mitchell (1957) reported that the low water table level in the sloping terrain of tin tailings also contributed to its low moisture content. If the mined-over site has a high water table, depressions among the tin tailing slopes may have high moisture content.

Chemical properties

Natural restoration of site fertility of sandy tin tailings is very slow. A 20-year-old area of tin tailings has only about one-twentieth the fertility of a 20-year-old plantation (Mitchell 1957). The fertility of the site is very much dependent on the availability of nutrients, which is affected by the pH.

Organic matter

Sandy tin tailings are infamous for low organic matter, which ranges from 0.1 to 0.2% in a newly mined site (Palaniappan 1972). The organic matter content increases with the age (year after dumping) of tin tailings. This is due to the establishment of vegetation on the older tin tailings. However, the organic content of 20-year-old tin tailings is only about 35% that of an undisturbed lowland forest (Table 4). The low organic content of tin tailings indicates that extra input is required to restore fertility to facilitate any tree planting activities.

Table 4. The nutrient status of sandy tin tailings. Figures in brackets indicate percentage of value for forested area

	Age (years)				Forested area
	5-10	10	15-20	20	
% Organic matter					
Soil depth (cm)					
0 - 15	0.13	0.18	0.62	0.63	1.77
	(7)	(10)	(35)	(36)	(100)
15 - 30	0.08	0.07	0.13	0.07	-
% Nitrogen					
Soil depth (cm)					
0 - 15	0.02	0.02	0.03	0.05	0.13
	(15)	(15)	(23)	(38)	(100)
15 - 30	0.01	0.01	0.01	0.01	-
Available P (p.p.m.)					
Soil depth (cm)					
0 - 15	0.4	0.6	0.9	1.3	4.3
	(9)	(14)	(21)	(30)	(100)
15- 30	0.3	0.4	0.5	1.2	-
Available K (meq/100 g)					
Soil depth (cm)					
0 - 15	0.03	0.02	0.05	0.05	0.27
	(11)	(7)	(19)	(19)	(100)
15- 30	0.03	0.02	0.03	0.03	-

Sources: Mitchell 1957, Wan Razali & Ang 1991.

Nitrogen content

The nitrogen content of sandy tin tailing is very much lower than that of forested areas (Table 4). Low nitrogen content of tin tailings is expected because of the low organic content.

Available phosphorous

The phosphorous content is very much lower in tin tailings compared with forested areas (Table 4). The low level of available phosphorous in the tin tailings could be due to the low pH and low clay content (Thompson & Troch 1972).The shortage of available phosphorous in the tin tailings could be a nutritional problem for the trees because added phosphate fertiliser tends to react with the tin tailings to form low solubility materials such as iron and aluminium phosphates which are unavailable to plants.

Potassium

The available potassium (K) of tin tailings is less than that of forested areas (Table 4). Potassium solubility is not affected by the pH but potassium is highly susceptible to leaching. A high leaching rate could be expected in the tin tailings because of the tailings' high porosity and low clay content.

pH

Mitchell (1957) reported that most sandy tin tailings were acidic (pH 5-6), while (Lim *et al.* 1981) reported that tailings from peaty and acid sulphate areas could be extremely acidic (pH <3.5).

Toxic compounds

Knabe *et al.* (1965) and Fox (1984) reported that a high content of heavy metals such as cadmium, manganese, and aluminium compounds made the mining spoils more difficult to reclaim by afforestation. Reclamation is further aggravated by the low content of organic matter in sandy tin tailings; some of these elements, e.g. aluminium and manganese, are rendered harmless by combination with humus (Knabe 1965).

From this review of chemical properties, it is clear that tin tailings are a problem soil for tree growing. In addition, erosive forces such as water in surface erosion, leaching and gully erosion are common to sloping tin tailings (Figure 2). These make sandy tin tailings more difficult to stabilise.

Natural regeneration

The sporadic patches of vegetation in sandy tin tailings (Figure 3) are low in diversity (Table 5). The life-forms that colonise the tin tailings are creeper and shrub species and unmarketable secondary tree species (Table 6). The trend of succession is dependent on the site properties of tin tailings. The properties of sandy tin tailings improve with age and become more favourable for succession. This could be due to higher nutrient content and lesser heavy metal toxicity in the older tin tailings (Down& Stocks 1977). Hence, more shrub and tree species are found in the older sandy tin tailings. *Pinus caribaea* was observed to grow significantly faster on six-year-old sandy tin tailings than on a current mined-over area (Ang 1986).

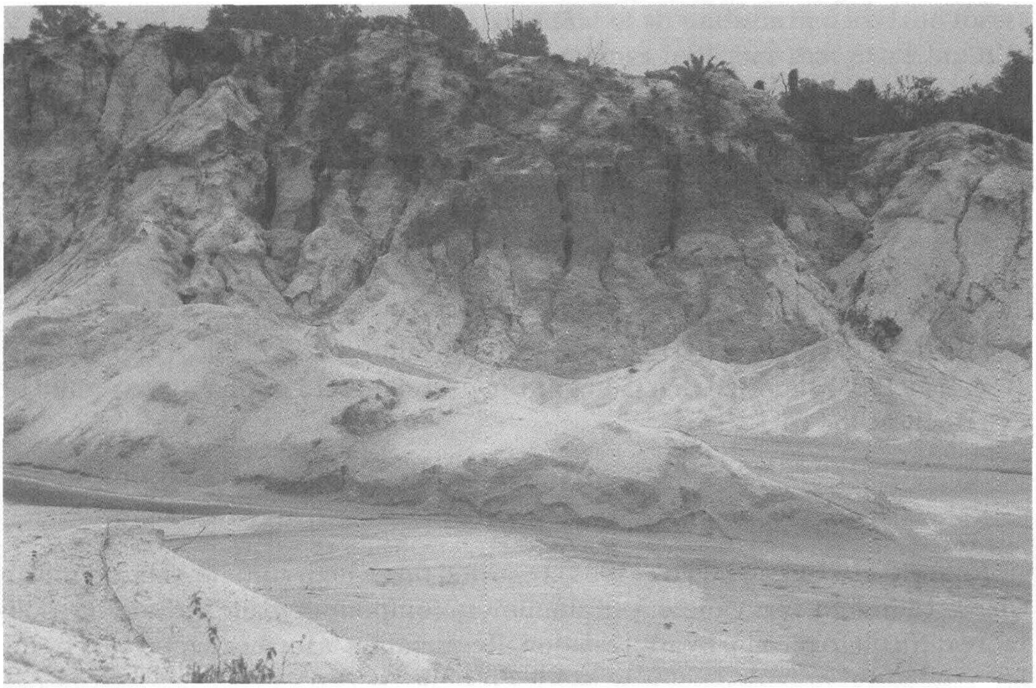


Figure 2. Erosion of sandy tin tailings often slows down the colonization of vegetation(Kundang, Selangor)

Table 5. Number of species at selected tin tailings sites

Site	Pond	Sand	Sandy slime	Slime
Shrubs/small trees	0	9	7	19
Others	24	38	54	56
Total	24	47	61	75

Source: Derived from Palaniappan 1974.

Table 6. Species diversity at various ages of sandy tin tailings

Age (y)	Current	3	5	10	15	20
Creepers	0	2	3	8	8	12
Shrubs	0	1	1	1	7	9
Total	0	3	4	9	15	21

Source: Derived from Appendix II, Mitchell 1959.

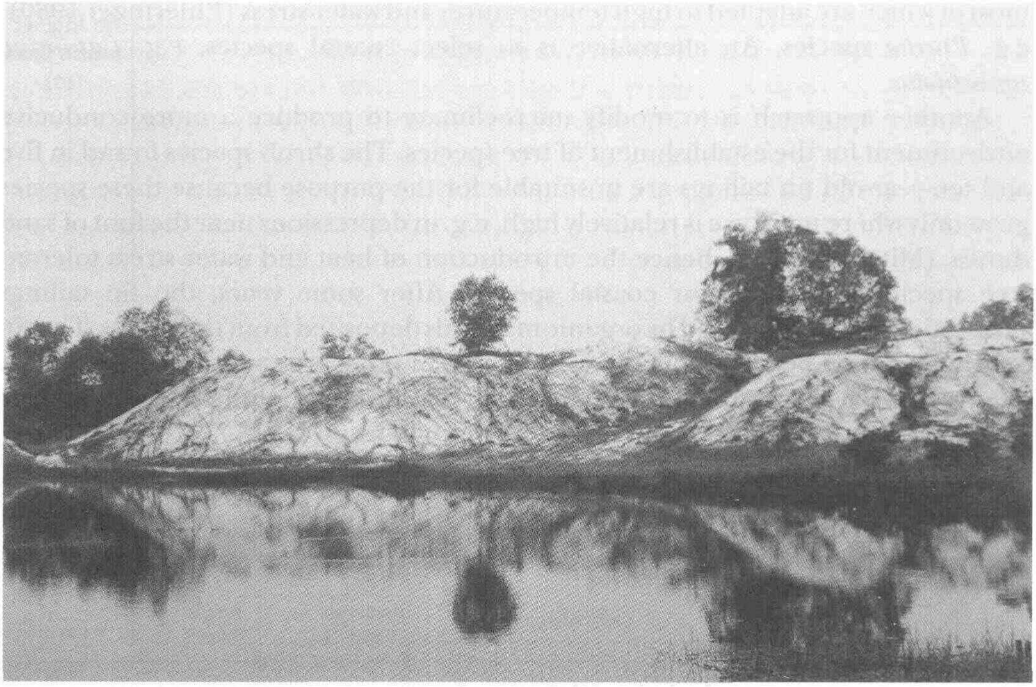


Figure 3. Sporadic patches of vegetation colonize the sandy tin tailings (Kundang, Selangor)

Implications of succession on tin tailings

Reliance on the natural succession to restore sandy tin tailings without any human aid will take a long period, during which the tin tailings will remain economically barren. Hence, afforestation with suitable multipurpose tree species is more desirable than solely depending on succession for reclamation of tin tailings. The benefits of afforestation on tin tailings are obvious. Species trials in various tin tailings in Peninsular Malaysia were initiated by Mitchell (1957). Preliminary results showed that several nitrogen fixing and most probably heat and water tolerant tree species adapt themselves very well on sandy slime tin tailings.

Species selection

A habitat oriented approach should be taken when screening species for afforestation of tin tailings. The selection of high quality indigenous timber tree species for afforestation of tin tailings will only lead to failure because of the harsh environmental conditions and poor site properties. None of the tree species with important timber values can colonise pure sandy tin tailings (Mitchell 1959, Palaniappan 1974). However, several late pioneer species, viz. *Sapium baccutum* and *Alstonia scholaris* ,were observed to grow on sandy slime tin tailings, which have better site properties (Ang 1986). Another option is to utilise desert or semi-arid species, most of which are adapted to high temperatures and water stress (Ehleringer 1980), e.g. *Encelia* species. An alternative is to select coastal species, e.g. *Casuarina equisetifolia.*

Another approach is to modify microclimate to produce a more conducive environment for the establishment of tree species. The shrub species found in five and ten-year-old tin tailings are unsuitable for the purpose because these species grow only where moisture is relatively high, e.g. in depressions near the foot of sand dunes (Mitchell 1963), hence the introduction of heat and water stress tolerant tree species, e.g. desert or coastal species. After some years, the tin tailings properties may be improved by organic materials deposited from the plants. The tin tailings will then be more suitable for planting of other tree species. However, for sites where the water table is high, species trials showed that nitrogen fixing tree species could yield timber 30 to 40 years after planting (Table 7).

Table 7. Growth of some tree species on sandy tin tailings

Species	Stand age (y)	n	DBH (cm)	Height (m)	MAI diameter (cm y^{-1})	MAI height (m y^{-1})	Site
Acacia aulacocarpa	27	14	22.9	17.3	0.85	0.64	FRIM
A. auriculiformis	32	6	24.9	21.4	0.78	0.67	FRIM
Casuarina equisetifolia	30	39	23.4	30.0	0.78	1.00	Mantin
*Pinus caribaea**	26	33	15.1	17.7	0.58	0.68	FRIM
*P. caribaea**	26	42	19.8	19.2	0.76	0.74	FRIM
P. elliottii	33	7	19.5	16.5	0.59	0.50	FRIM

* Different stands.
Source: Ang 1986.

Site improvement of tin tailings before tree planting

Improvement of tailings moisture

The uneven water table of sandy tin tailings is due to unplanned deposition of tailings during mining activities. Figure 4 illustrates a cross section of a hypothetical tin tailings site. Water-logged depressions covered with densely marshy vegetation, small trees and shrubs are found near the mining pool. The rationale is to level the sand hill so that the water table rises. A probe was conducted to assess the validity of this hypothesis. A total of 12 seedlings of four-month-old *A. mangium* were planted at a moist site on sandy tin tailings (10 cm above water table level), and another 10 seedlings were planted on sand dunes. At 10 months after planting, the probe showed that the average top height increment of *A. mangium* planted at the moist site was greater than that of the seedlings planted in raised sand (Figure 5).

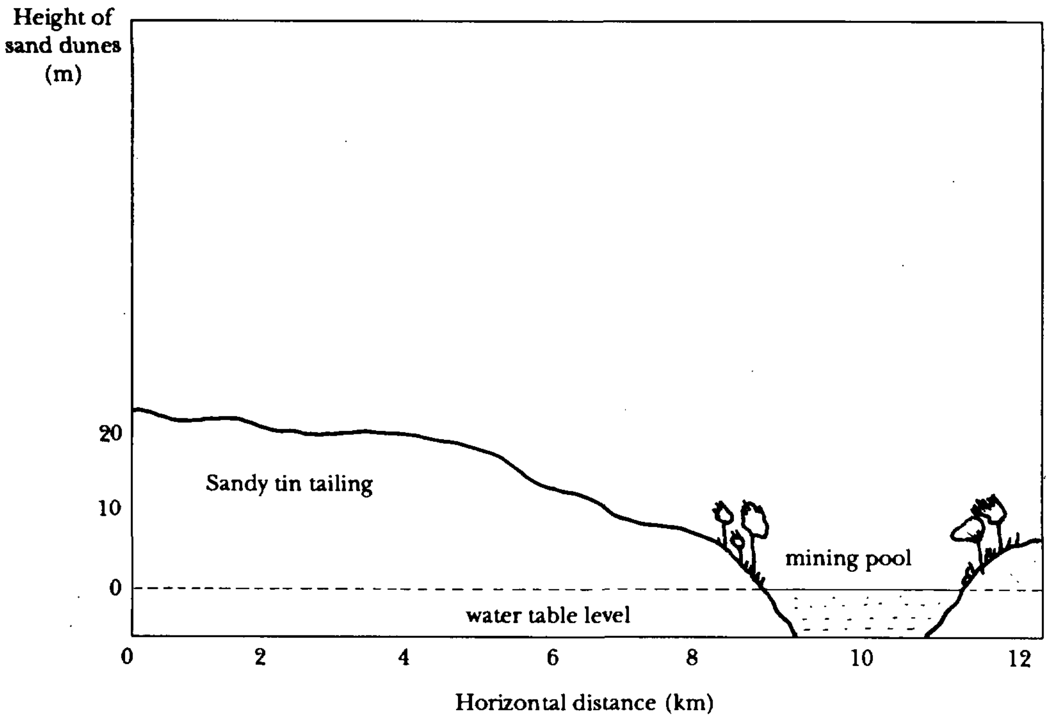


Figure 4. Hypothetical profile diagram of tin tailings

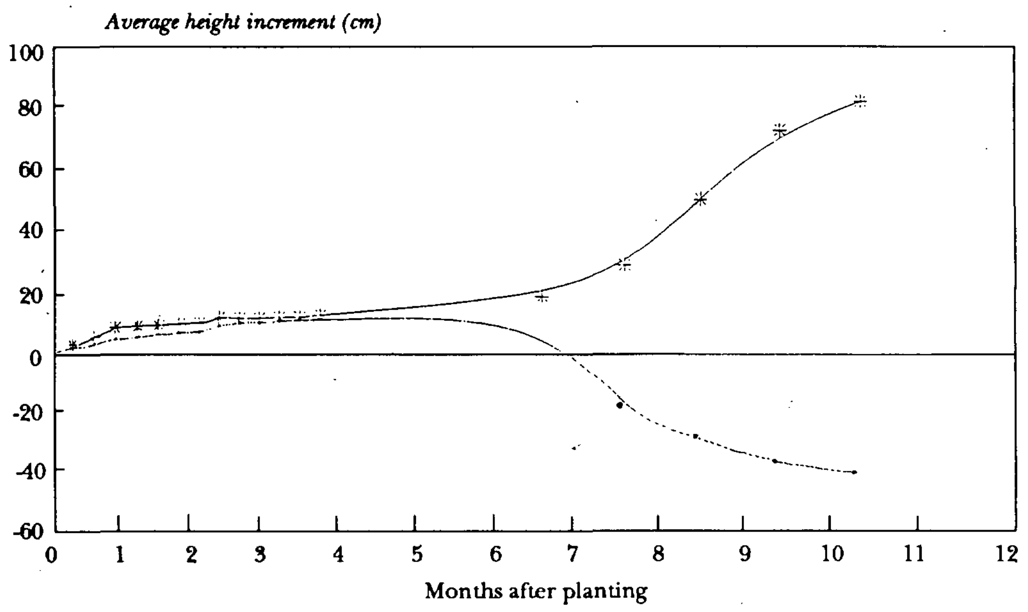


Figure 5. Height increments of *A. mangium* planted at sandy tin tailings

Raising the water table level by levelling the sand dune can be an expensive but rewarding practice in afforestation activities. To reduce cost, Kho (1977) developed an underground plastic basin technique for vegetable cultivation on sandy tin tailings. However, the technique may not be effective for tree planting because the rooting system of forest tree species is more extensive than that of vegetables. In addition, it is difficult to install a plastic basin slightly greater than the maximum capillary rise of water in sand dunes which are usually situated 10-15 m above the water table. This means that an insufficient reserve of free water will be stored in the bottom of the basins (Lim *et al.* 1981). Dripping and sprinkling systems are employed by some vegetable farmers (Figure 6). The constraints are that the site must be located near the water body, and it is costly to employ this irrigation system. Other methods such as top soil enrichment and mulching can be employed to improve water retention properties of sandy tin tailings.

Figure 6. The sprinkling system employed for vegetable farming on sandy tin tailings (Selayang, Kuala Lumpur)

This discussion shows that practical methods of improving the moisture content of sandy tin tailings are available, and hence, afforestation activities are feasible on these areas.

Improvement of site fertility

For relatively gentle sites, the texture can be improved by the use of agriculture waste, e.g. oil palm husk, and slime generated from mining activities. Dumping of tin tailings must be properly planned so that each dump varies in composition (slime/sand) in order to provide a better site for reclamation after mining activities (Mitchell 1957). Manuring and mulching improve the growth of *Pinus merkusii, Paraserianthes falcataria* and *Sesbania rostrata* planted on sandy tin tailings where the water table level reaches the root zone (Mitchell 1957, Rodziah & Zulkifli 1990).

Microbial associations

Actynomycetes, mycorrhiza and nitrogen fixing bacteria which are associated with plants in fixing nitrogen or improving nutrient uptake should be introduced to the species planted on tin tailings. The beneficial effects of such organisms on the plants have been noted (Anonymous 1963), e.g. association of *Telephora ramariodes* with *Casuarina equisetifolia.* Ang (1986) noted that all the tree species successfully established on tin tailings have this symbiotic association with nitrogen fixing micro-organisms. The commercial production of microbial inoculums has made introduction of such micro-organisms possible in large afforestation projects.

Silvicultural practices

The rainy season is recognised to be the best time for planting (Anonymous 1963). Planting must be carried out before 10 a.m. to avoid poor establishment. Routine checking of the planting site is very important because fire is often a hazard in afforestation sites on tin tailings during the dry season; a major fire in the 1963 dry spell, for example, destroyed the establishment of *Casuarina equisetifolia* on sandy tin tailings (Anonymous 1963, Mitchell 1963).

Legal aspects

Ex-mining lands are state-owned. In the past, tin tailings were frequently reworked, but the development of improved mining technology to maximise the extraction of tin ores has discouraged remining activities. The Mining Enactment F.M.S. Cap. 147 does not specifically deal with the rehabilitation of mining land. Miners are only required under section 5(i) of the mining enactment to fill and level with no rise of ground steeper than 1 vertical to 18 horizontal and without standing water (Abd. Rahman 1985, Yeong 1985). In some cases escape clauses provide for minimal unfilled areas upon completion of mining. The agreement normally carries a provision whereby performance is guaranteed by individuals or companies by way of monetary commitment (Abd. Rahman 1985,Yeong 1985). Usually this rehabilitation practice is not carried out by the miners; e.g. in most cases the tenure of the mining lease is too short for any proper planning by the mining companies (Abd. Rahman 1985). Hence, most of the tin tailings require modification for afforestation purposes (Johson & Bradshaw 1979, Fox 1984). However, Yeong (1985) discouraged filling and levelling activities for tin tailings which are located near major cities because these can be converted to other land uses, e.g. construction and recreational sites. This further implies that afforestation projects on tin tailings should be implemented at least 40 km radius away from a major city.

To further enhance the rehabilitation of mining land, other conditions could be included which require the planting and maintenance of vegetation for a fixed period after expiry of mining activities on the mined-over sites (Abd. Rahman 1985). Yeong (1985) suggested that a fund for the rehabilitation of mining land should be established for Government projects as and when the need arises.

Recently, the Government of Malaysia embarked on a compensatory forest plantation project that is to cover about 188 000 ha. The objective is to supplement the forecasted wood shortage in the year 2000. Two of these forest plantation species have the potential to grow well on tin tailings. *Acacia mangium* and *A. auriculiformis* were observed to grow well in sand dunes where the water table reaches the root zone (Table 8) and *Paraseriathes falcataria* was observed to perform well on slimy and sandy slime tin tailings (Mitchell 1957, Ang 1986). Hence, afforestation on sandy tin tailings has an important role in the rehabilitation of mined-over lands.

Table 8. Growth of some tree species planted at degraded sites in Peninsular Malaysia

Degraded sites	Species	Stand age (y)	MAI diameter at b.h. (cm y^{-1})	MAI top height (m y^{-1})
Tin tailings				
1. Sandy				
	Acacia aulacocarpa	27	0.85	0.64
	A. auriculiformis	32	0.78	0.67
*	*A. mangium*	4	2.87	2.95
	Pinus caribaea	26	0.76	0.74
	P. elliottii	33	0.59	0.50
	Casuarina equisetifolia	30	0.78	1.00
2. Sandy slime				
	A. auriculiformis	30	1.24	0.80
	A. richii	28	1.02	0.68
	P. merkusii	32	0.87	0.98
	P. caribaea	30	1.22	1.00
3. Slime				
	A. auriculiformis	32	0.99	0.83
	Paraserianthes falcataria	30	1.63	0.91
	Fagraea fragrans	30	0.47	0.41
4. BRIS soils				
	Acacia mangium	8	2.60	1.86
	Hopea odorata	6.5	0.72	0.54
	Araucaria cunninghamii	29	0.65	0.45
	Pinus caribaea	30	0.92	0.71
	P. merkusii	24	0.92	0.56
	P. oocarpa	24	0.91	0.71
	Casuarina equisetifolia	8	2.74	2.45

*Based on a trial at Kundang.
Source: Ang 1986.

Conclusion

The prospect for reclamation of tin tailings through afforestation is bright. However, the technology of afforestation still needs to be further developed through practical research activities.

Future afforestation research

Based on the problems identified for sandy tin tailings, several areas of research for afforestation of sandy tin tailings in the peninsula have been identified.

Species trials: Species trials should be made of heat and water stress tolerant species, with preference for marketable fast-growing tree species which are site improvers.

Site preparation: Factors that will be investigated are: overcoming water stress of sandy tin tailings, improving the site properties, modifying microclimatic conditions of sandy tin tailings, and improving site fertility.

Stand maintenance: Research on stand maintenance will be carried out after the establishment of plantations on the sandy tin tailings.

Economics of afforestation: Economic studies should be conducted together with other research activities. The feasibility of the project depends on its economic viability. Establishment of short rotation (< 7 y) timber plantations for chipwood and pulpwood productions is encouraged. Ang (1986) suggested agroforestry practices for the rehabilitation of sandy tin tailings.

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Appendix 1. Plant distribution at various tin tailings sites

Species	Pond	Sandy	Sandy-clay	Clay
Herbs/creepers/ferns				
1. *Borreria stidents*	-	/	/	/
2. *Tricholaena rosea*	-	/	/	/
3. *Eclipta prostrata*	-	/	-	-
4. *Paspalum scrobiculatum*	-	/	/	-
5. *Eragrostis unioloides*	/	/	/	/
6. *Fimbristylis miliacea*	/	/	/	/
7. *Bulbostylis barbata*	-	/	/	-
8. *Mimosa pudica*	-	/	/	/
9. *Cyperus rotundus*	/	/	/	/
10. *Hedyotis herbaceus*	-	/	/	/
11. *Hedyotis pinifolia*	-	/	/	-
12. *Bridelia tomentosa*	-	-	/	/
13. *Emilia sonchifolia*	-	/	/	/
14. *Fimbristylis pauciflora*	-	/	/	-
15. *Desmodium triflorum*	-	/	/	/
16. *Alycicarpus vagnalis*	-	/	/	-
17. *Tridax procumbens*	-	/	/	-
18. *Hyptis suaveolens*	-	/	/	/
19. *Crotolaria striata*	-	/	/	/
20. *Eupatorium odoratum*	/	/	/	-
21. *Chloris barbata*	-	/	-	/
22. *Imperata cylindrica*	-	/	/	/
23. *Paspalum conjugatum*	/	/	/	/
24. *Eleusine indica*	-	-	/	-
25. *Erechthetis valerianifolia*	-	-	/	/
26. *Scoparia dulces*	-	-	/	/
27. *Cyperus brevifolius*	-	-	/	/
28. *Sporobolus indicus*	-	/	/	-
29. *Desmodium ovalifolium*	-	-	/	/
30. *Cassytha filiformis*	-	-	/	-
31. *Dryopteris linearis*	-	-	/	/
32. *Scleria multifoliata*	-	-	/	/
33. *Lygodium microphyllum*	-	-	/	/
34. *Vitis trifolia*	-	-	/	/
35. *Lycopodium cernuum*	-	-	/	/
36. *Pteris vittata*	-	-	/	/
37. *Stenochlaena palustris*		-	/	/
38. *Cyperus iria*	/	-	/	-
39. *Hyptis capitata*	-	-	/	/
40. *Vernonia cinerea*	-	-	/	/
41. *Mimosa sepiara*	-	-	/	/
42. *Uncaria acide*	-	/	-	-
43. *Mikania cordata*	/	/	/	/
44. *Nephrolepis biserrata*	-	-	-	/
45. *Hydrocotyle asitica*	-	-	-	/
46. *Spathoglottis plicata*	-	-	-	/
47. *Meloobia corchorifolia*	-	/	-	/
48. *Cordia cylindristachya*	-	/	-	/
49. *Borreria laevicaulis*	-	/	/	/
50. *Centrosema pubescens*	-	/	-	-
51. *Pueraria phaseoloides*	-	/	/	/
52. *Rhynchospora aurea*	/	-	-	/
53. *Isachne globosa*	/	-	-	/
54. *Tetracera scandens*	-	-	-	/
55. *Premna corymbosa*	-	-	-	/
56. *Vitis gracilis*	-	-	-	/

Species	Pond	Sandy	Sandy-clay	Clay
57. *Bridelia stipularis*	-	-	-	/
58. *Acrosticum aureum*	-	-	-	/
59. *Rhynchospora corymbosa*	/	-	-	-
60. *Panicum amplexicaule*	/	-	-	-
61. *Limnocharis flava*	/	-	-	-
62. *Merremia umbellata*	-	/	/	/
63. *Ischaemum mutiecm*	-	/	/	/
64. *Eragrostis amabilis*	-	/	/	-
65. *Echinochlea colona*	-	/	/	-
66. *Chrysopogon aciculatus*	-	/	-	/
67. *Borreria latifolia*	-	/	/	/
68. *Lindernia crustacea*	-	/	-	-
69. *Premna foetida*	-	-	-	/
70. *Stachytarpheta indica*	-	/	-	-
71. *Monochoria vaginalis*	/	-	-	-
72. *Axonopus compressus*	-	-	/	/
73. *Amaranthus spinosus*	-	-	/	-
74. *Cyperus polystachyus*	/	-	/	-
75. *Ludwigia hyssopifolia*	/	-	/	/
76. *Scirpus mucronatus*	/	-	/	-
77. *Nelumbium nelumbo*	/	-	/	-
78. *Typha angustata*	/	-	/	-
79. *Phragmites karka*	/	-	-	/
80. *Cyclosorus unitus*	/	-	-	/
81. *Leersia hexandra*	/	-	-	/
82. *Fuirena umbellata*	/	-	-	/
83. *Cyperus compressus*	-	-	-	/
84. *Eichbornia crassipes*	/	-	-	-
85. *Polygonum barbatum*	/	-	-	-
Total	24	38	54	56
Shrubs/small trees				
1. *Macaranga javonica*	-	-	/	/
2. *Melastoma malabarthricum*	-	/	/	/
3. *Eugenia elongata*	-	-	/	/
4. *Psidium guajava*	-	-	/	/
5. *Commersonia platyphylla*	-	/	-	-
6. *Glochidion laevigatum*	-	/	-	/
7. *Lantana aculeata*	-	/	-	/
8. *Alstonia angustiloba*	-	/	/	/
9. *Croton hirtus*	-	/	-	-
10. *Vitex pubescens*	-	/	/	/
11. *Morinda umbellata*	-	/	-	/
12. *Acacia auriculiformis*	-	/	-	/
13. *Muntinga calabura*	-	-	/	/
14. *Ficus globosa*	-	-	-	/
15. *Fagraea crenulata*	-	-	-	/
16. *Eugenia spicata*	-	-	-	/
17. *Phyllantus niruri*	-	-	-	-
18. *Randia anisophylla*	-	-	-	/
19. *Macaranga griffithiana*	-	-	-	/
20. *Leea indica*	-	-	-	/
21. *Elaeocarpus petiolatus*	-	-	-	/
22. *Mallotus barbatus*	-	-	-	/
Total	0	9	7	19

/ denotes present, - denotes absent.
Source: adapted from Palaniappan 1972.

Appendix 2. Species succession on tin tailings of various ages (Mitchell 1959)

Age (y)	current	3	5	10	15	20
Species: Herbs/creepers						
1. *Borreria hispida*	N	N	N	*	N	*
2. *Desmodium capitum*	N	N	N	N	N	*
3. *Eragrostis elongata*	N	N	N	N	*	*
4. *Glechenia linearis*	N	*	N	N	*	*
5. *Imperata cylindrica*	N	N	N	N	*	*
6. *Lypodium cernum*	N	N	N	N	*	*
7. *Merremia umbellata*	N	N	N	N	N	*
8. *Nepenthes gracilis*	N	N	N	N	*	*
9. *Oldenlandia dichotoma*	N	N	N	N	*	*
10. *Oldenlandia herbacea*	N	N	*	*	*	*
11. *Tricolaenea rosea*	N	N	N	*	N	*
12. *Spathoglottis plicata*	N	N	N	*	N	*
13. *Bulbostylis barbata*	N	N	N	*	N	N
14. *Ischaemum muticum*	N	N	N	*	N	N
15. *Mimosa pudica*	N	N	N	*	N	N
16. *Hyptis sauveolens*	N	N	N	*	N	N
17. *Themeda villosa*	N	N	*	*	N	N
18. *Adenosma capitatum*	N	N	N	*	N	N
19. *Puspulam scorbiculatum*	N	*	N	N	N	N
20. *Leucas zeylanica*	N	N	N	N	N	N
Shrubs/small trees						
1. *Dillenia suffruticosa*	N	N	N	N	N	*
2. *Eugenia spicata*	N	N	N	N	*	*
3. *Euphotorium odoratum*	N	N	N	N	N	*
4. *Glochidion superbum*	N	N	N	N	N	*
5. *Melastoma malabathricum*	N	N	N	*	*	*
6. *Ixonanthes reticulata*	N	N	N	N	*	*
7. *Rhodomnia trinerva*	N	N	N	N	*	*
8. *Vitex pubescens*	N	N	N	N	*	*
9. *Norrisia malaccansis*	N	N	N	N	*	N

Note: N - absent, * - present.
Source: Mitchell 1959.