

ARTICLE

Implementation of Conservation through the Use of Native Tree Species for Enrichment Planting in Revegetated Post-Coal Mining Sites

Kissinger ^{1*} , Pamela Yvonne Scheffler ² , Rina Muhayah Noor Pitri ¹ , Wirawan Noor Hadi ¹ 

¹ Faculty of Forestry, Universitas Lambung Mangkurat, Banjarbaru 70714, Indonesia; rina.muhyah@ulm.ac.id (R.M.N.P.); wirawanhadi@ulm.ac.id (W.N.H.)

² Tropical Ecosystem and Agroforestry Management Program and Natural Sciences Program, Math and Natural Sciences Department, Hawaii Community College, Hilo, HI 96720, USA; pamelays@hawaii.edu

ABSTRACT

The low diversity of vegetation on revegetated post-coal mining sites presents an ecological problem that can restrict forest structure and biodiversity recovery. Native tree species were evaluated for enrichment planting using social, economic, ecological and field-survival criteria in five-year-old revegetation plots with roughly 70%–80% canopy cover. Initially, ten native species were screened and planted in field trials. The revised four-class screening framework classified *Anisoptera marginata* as High, whereas *Aleurites moluccana*, *Alstonia scholaris*, *Aquilaria malaccensis*, *Ficus benjamina*, *Shorea balangeran*, *Anthocephalus cadamba*, and *Syzygium* sp. were Moderate, and *Combretocarpus rotundatus* and *Melaleuca cajuputi* were Low. Field survival exceeded 50% for *A. malaccensis*, *F. benjamina*, *A. scholaris*, *A. marginata*, *A. moluccana*, and *A. cadamba*. *A. marginata* was selected as the major recommended species, since it coupled a High preliminary screening class with adequate field survival. The remaining surviving species were kept as conditional candidates, whereas species with reduced survival were interpreted in connection to the studied microsite circumstances and probable silvicultural restrictions. The sensitivity analysis indicated that the restriction of the advice was greater with an increase in the survival criterion. These results highlight the need to use both feasibility screening and field confirmation, rather than just one of them. The recommendations are particular to the partially shaded reclamation settings that were evaluated and require further validation across contrasting microsites and with longer monitoring periods.

*CORRESPONDING AUTHOR:

Kissinger, Faculty of Forestry, Universitas Lambung Mangkurat, Banjarbaru 70714, Indonesia; Email: kissinger@ulm.ac.id

ARTICLE INFO

Received: 8 June 2026 | Revised: 15 July 2026 | Accepted: 14 August 2026 | Published Online: 10 October 2026

DOI: <https://doi.org/10.30564/re.v8i5.13608>

CITATION

Kissinger, Scheffler, P.Y., Pitri, R.M.N., et al., 2026. Implementation of Conservation through the Use of Native Tree Species for Enrichment Planting in Revegetated Post-Coal Mining Sites. *Research in Ecology*. 8(5): 175–191. DOI: <https://doi.org/10.30564/re.v8i5.13608>

COPYRIGHT

Copyright © 2026 by the author(s). Published by Bilingual Publishing Group. This is an open access article under the Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (<https://creativecommons.org/licenses/by-nc/4.0/>).

Keywords: Post-Coal Mining; Enrichment Planting; Native Tree Species; Species Adaptability; Biodiversity Conservation

1. Introduction

The mining industry plays a significant role in supporting Indonesia's economic development, and still supplies vital resources and energy for national development^[1]. Coal mining in particular is still closely linked to power generating and industrial expansion. Open pit coal mining causes considerable ecological disruption via loss of vegetation, disturbance of soil horizons, modification of surface hydrology, increased potential for erosion and fragmentation of habitat^[2,3]. Such impacts may endure for a long time after the cessation of mining activities, particularly when the reconstructed substrates are characterized by low organic matter content, poor soil structure, high bulk density, low biological activity and poor chemical properties. Reclamation should not just be viewed as a regulatory requirement but also as an ecological restoration process that aims to recreate functional landscapes after mining damage

In Indonesia, reclamation after mining is executed through land reshaping, erosion control, revegetation, maintenance and monitoring. Among these components, revegetation is one of the most evident reclamation initiatives since it immediately contributes to soil stabilization, microclimate enhancement, carbon storage and progressive restoration of habitat services^[4-7]. However, tree cover or planting density should not be the exclusive measure of success for revegetation. Early revegetation in many coal mining sites is often characterized by fast-growing species intended to accelerate canopy development and stabilize substrates. The natural regeneration processes may then be impacted by the original species^[8]. These species are useful as early colonizers in restoration but extended dominance may limit the regeneration of natural forest structure and variety if no enrichment planting is undertaken.

Enrichment planting is a restoration method when species are introduced into an existing revegetated or regenerated stand^[9]. Enrichment planting in post-coal mining sites can change the development of vegetation from a plantation structure dominated by pioneers to a more diversified forest-like community. The ecological benefit of the species selected for enrichment planting is critical. Species should

be able to resist the stress of a post-mining site, flourish under partial canopy circumstances, play a role in soil protection, sustain biodiversity. They also should be socially acceptable and economically possible for implementation. Restoration projects depend on community support, seedling availability and operational costs^[10,11]. Evidence from reclaimed coal-mining landscapes in East Kalimantan further shows that enrichment planting of native species can achieve high early survival and growth, while also contributing to the recovery of vegetation succession when assessed together with natural regeneration, carbon, microclimate, and soil indicators^[12].

The adoption of native species is very important for reclamation for conservation. Native plants are more likely than foreign species to support local food webs, provide habitat resources for wildlife, and support regional floristic identity. Recent restoration studies have underlined the need to utilize the correct species in the right place and that species selection should be based on ecological features and site conditions^[10,11]. Trait-based and regionally grounded selection approaches can reduce trial-and-error planting, increase survival and promote the ecological legitimacy of reclamation in damaged tropical mining settings^[11]. This site-specific principle is also supported by mine-rehabilitation research showing that plant establishment and biodiversity are strongly conditioned by substrate properties and geochemical gradients, reinforcing the need to match species with the physical and chemical characteristics of individual microsites^[13].

Despite these advances, two practical problems remain common in enrichment planting studies. First, preliminary scoring systems are often used to select candidate species, but their function in the final recommendation is not always made explicit. A scoring system may act as an elimination filter, a weighting factor, a risk-diagnosis tool, or simply a descriptive summary. If this position is not made clear, the recommendation process becomes difficult to duplicate. Second, field survival statistics may be utilized as the only basis for recommendation without any justification of why some species with identical survival values are included and others excluded. Thus, a transparent decision framework is needed to link preliminary screening, field trial results and the final recommendation of species.

Studies on revegetation following coal mining in Kalimantan have revealed that the diversity of vegetation might be minimal, even after several years of reclamation^[7,14]. This suggests the need to consider enrichment planting in reclamation planning at an earlier stage, especially if mining permits, maintenance commitments and post-mining responsibilities constrain the time periods for operations. Native tree species must be examined in terms of both their biological potential and their practical feasibility in the context of mining reclamation. This study intends to analyse and select native tree species for enrichment planting in revegetated post-coal mining areas through a clearer choice framework by incorporating social, economic, ecological and field survival concerns. In East Kalimantan, integrated monitoring of 9- and 17-year-old reclaimed sites likewise found that vegetation succession remained substantially different from pre-mining conditions and concluded that enrichment planting of native trees was necessary to accelerate biodiversity recovery^[12].

2. Materials and Methods

2.1. Study Location and Object

The research was conducted in the revegetated post-coal mining sites at Pengaron Subdistrict, Banjar Regency, South Kalimantan, Indonesia (**Figure 1**). The research site represents a reclaimed landscape where the primary revegetation trees had been established prior to the enrichment planting trial. The existing stand of vegetation was about five-year-old and consisted mainly of fast-growing trees used in the early stage of reclamation. The enrichment planting trial was placed under this developing canopy to evaluate the early establishment capacity of native species under partial overstorey influence. The study site was located on red-yellow podzolic soil with a clay loam texture. Soil pH ranged from 5.95 to 6.24, indicating slightly acidic to near-neutral conditions. The revegetation stand had approximately 70%–80% canopy cover, with light intensity ranging from 3,900 to 4,500 lux under the canopy. During the field observation period, air temperature averaged 27.2 °C, ranging from 26.5 °C to 28.8 °C, while relative humidity averaged 85.5%, ranging from 80% to 89%.

The field environment was treated as an operational reclamation site rather than a controlled greenhouse exper-

iment. The site consisted of recontoured post-mining substrates with a heterogeneous surface, mine-soil characteristics, and partial canopy cover from the primary revegetation trees. Field observations indicated that the site had gentle to moderate slopes, partial shading from overstorey trees, limited natural litter accumulation, and a substrate condition typical of early post-coal mining reclamation. Exact plot-level soil chemical variables were not treated as experimental factors in this study; therefore, they are reported qualitatively as part of the site description and acknowledged as a limitation for cross-site transferability.

The research object consisted of native tree species proposed for enrichment planting, including species associated with lowland forest vegetation in Kalimantan^[15]. Seedlings were selected from species known by local communities, seedling suppliers, or forestry practitioners and considered relevant to native vegetation development in South Kalimantan and degraded-land rehabilitation in Indonesia^[16]. The materials used included seedlings of *Aleurites moluccana*, *Alstonia scholaris*, *Anisoptera marginata*, *Anthocephalus cadamba*, *Aquilaria malaccensis*, *Combretocarpus rotundatus*, *Ficus benjamina*, *Melaleuca cajuputi*, *Shorea balangeran*, and *Syzygium* sp. The equipment consisted of a phiband to measure the stem diameter, questionnaires for the interview-based assessment, tools for field documentation and planting tools.

2.2. Data Collection

Data were acquired thru interviews, field observations and field planting attempts. Informants were gathered from local communities and from tree seedling providers. At least five informants were employed to get information relevant to social acceptance, availability of seedlings, supply continuity, pricing of seedlings and local knowledge of the candidate species. Expert reasoning was collected from forestry references, previous reclamation research, and species habitat and adaptation ecology information. The seedlings were planted at 3 m × 3 m spacing. As a basic planting-hole amendment, each hole was amended with 1 kg organic matter. This modification was applied to all seedlings and was not considered as a separate experimental element.

The data collection procedure consisted of four steps. First, candidate native species were identified from community knowledge, seedling supplier information, and literature

on local forest species and post-mining rehabilitation. Second, each species was assessed using social, economic, and ecological indicators. Third, all ten species were planted in the field trial. All species were purposely included in the study since the preliminary screening was intended as a weighing and diagnostic stage rather than an elimination

stage. This method allowed species with low first scores to be scientifically verified and avoided the premature exclusion of species based on perception or seedling market information alone. Fourth, survival rate was measured at the last field observation to determine early establishment beneath the canopy of primary revegetation trees.

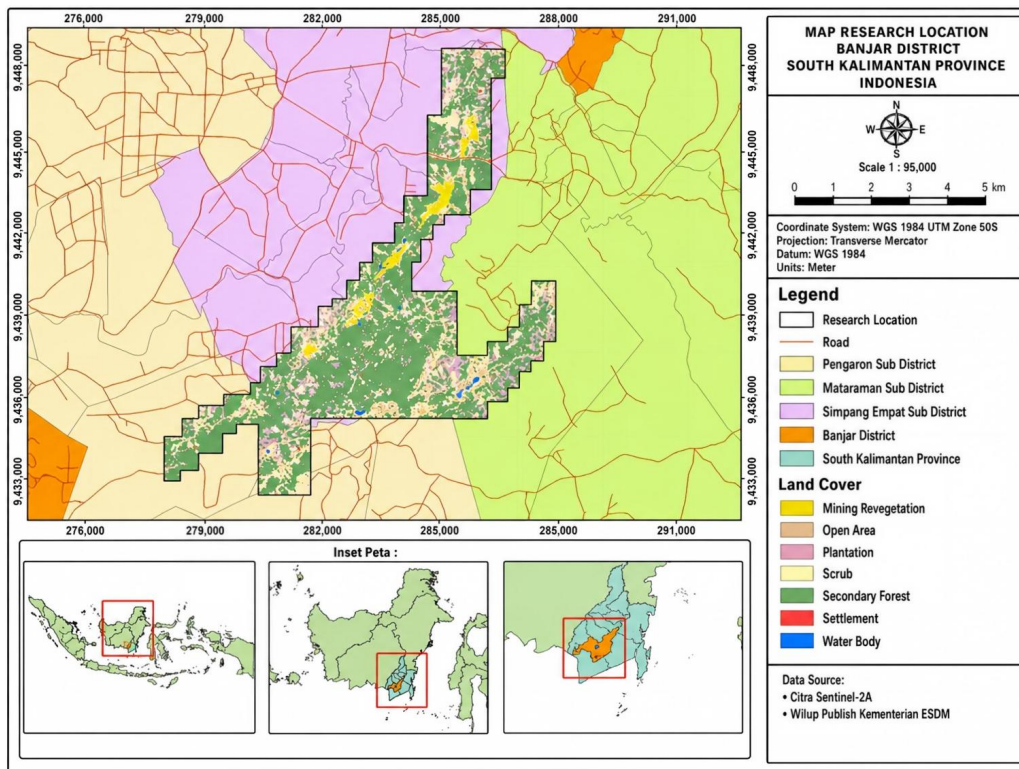


Figure 1. Research location map of the revegetated post-coal mining area.

The field trial was carried out in 5-year-old revegetation plots. Planting was done in accordance with operational reclamation procedures: land preparation, making planting holes, putting seedlings, backfilling and care after planting. The initial revegetation stand generated partial canopy conditions in which the seedlings were planted. Maintenance involved routine operating activities including weeding around seedlings and examination of field. No intensive irrigation or artificial shading treatment was introduced as a separate

experimental treatment because the objective was to evaluate operational adaptability under realistic reclamation conditions. Although each planting hole received 1 kg of organic matter as a standard operational amendment, the trial did not include replicated or contrasting soil-amendment treatments. Therefore, differences among species were interpreted as early operational field performance rather than as responses to controlled soil-treatment factors. The field-trial conditions used to interpret seedling survival are summarized in **Table 1**.

Table 1. Field-trial conditions and interpretation basis for enrichment planting survival assessment.

Field-Trial Component	Description Used in the Revised Interpretation
Revegetation age	Five-year-old primary revegetation stand
Soil type	Red-yellow podzolic soil
Soil texture	Clay loam texture
Soil pH	5.95–6.24
Planting position	Under partial canopy of established revegetation trees
Canopy cover	Approximately 70%–80%
Light intensity	3,900–4,500 lux under canopy conditions

Table 1. *Cont.*

Field-Trial Component	Description Used in the Revised Interpretation
Air temperature	Mean 27.2 °C; range 26.5–28.8 °C
Relative humidity	Mean 85.5%; range 80%–89%
Planting spacing	3 m × 3 m
Planting-hole amendment	1 kg organic matter per planting hole, applied uniformly to all seedlings
Site condition	Recontoured post-coal mining substrate with heterogeneous mine-soil conditions
Maintenance	Basic operational maintenance, including field inspection and weeding around seedlings
Measured response	Survival rate at the final field assessment
Transferability note	Canopy cover, soil pH, light intensity, air temperature, and humidity were recorded as site-context variables; future replicated trials should evaluate their direct effects on seedling survival

2.3. Data Analysis

2.3.1. Preliminary Screening of Candidate Species

The preliminary screening was based on three dimensions: social, economic and ecological compatibility. Social indicators were: prohibition or cultural restriction of species; community support; and expert rationale. Economic parameters were: ease of seedling acquisition, continuity of seedling supply and seedling pricing. The ecological indicators were the capacity to grow in the natural environment, ability to thrive under site stress and the ability to maintain the soil surface. The scores for each indicator ranged from 1 to 3, with 1 representing low suitability, 2 representing moderate suitability, and 3 representing great suitability. The total preliminary screening score ranged from 9 to 27 and was divided into four classes with equal intervals: Very Low (9–13), Low (14–18), Moderate (19–23) and High (24–27)^[17].

In the redesigned framework, the preliminary screening was not used as an *a priori* filter for elimination. Instead, it was a phase of risk diagnosis and weighing. Species with high preliminary scores were regarded as socially, economically and ecologically feasible but required confirmation of survival in the field. Species with modest preliminary scores were not immediately removed, since field survival can indicate adaptive potential not fully reflected by interview-based or literature-based grading. This clarification explains the decision logic between the initial screening and the planting trial.

The discriminating power of the 1–3 scoring system was taken with a grain of salt. Since most of the species were native or locally relevant, major disparities in preliminary rankings were not expected. Thus, the purpose of the screening was not to statistically rank species with great precision, but rather to set feasible limits prior to field testing. Final

recommendations were based not just on preliminary score, but on the agreement between a high preliminary score and adequate field survival, to strengthen interpretation.

2.3.2. Field Planting Trials

The field trial was conducted in a 5-year-old revegetation stand with 70–80% canopy cover and under-canopy light intensity of 3,900–4,500 lux. The soil of the site was red-yellow podzolic with clay loam texture. The soil pH was 5.95 to 6.24. Seedlings were transplanted at a spacing of 3 m × 3 m and each planting hole was amended with 1 kg of organic matter as a routine operational adjustment. Field observations were made at an average air temperature of 27.2 °C and an average relative humidity of 85.5%. Data analysis included survival rate assessments. Plant survival rate was determined by the following formula:

$$T = \left(\frac{h_i}{N_i} \right) \times 100\% \quad (1)$$

where T is the plant survival rate (%), h_i is the number of surviving plants in plot i , and N_i is the number of plants initially planted in plot i . Survival was classified into four categories: Very Low = 1 (survival <25%), Low = 2 (25%–<50%), Moderate = 3 (≥50%–<75%), and High = 4 (≥75%). The 50% threshold was adopted as an operational early-establishment benchmark rather than a universal ecological standard. Its use is supported by a tropical restoration experiment in Sumatra that explicitly used a minimum 50% survival threshold to distinguish successful species–microhabitat combinations^[18]. Because restoration survival varies among species, microsites, monitoring periods, and management regimes, the threshold was evaluated through sensitivity analysis at >50%, >60%, >65%, and ≥75% rather than treated as an absolute criterion of restoration success.

The final recommendation was made using a transparent decision rule. Primary recommended species were

those that (i) reached the High preliminary screening class (24–27) and (ii) achieved field survival >50%. Conditional candidates were species that met only one of these criteria or required additional silvicultural intervention. Species

with zero survival were considered unsuitable only under the tested operational condition and were assigned to targeted microsite testing rather than being interpreted as universally unsuitable. The decision logic is given in **Figure 2**.

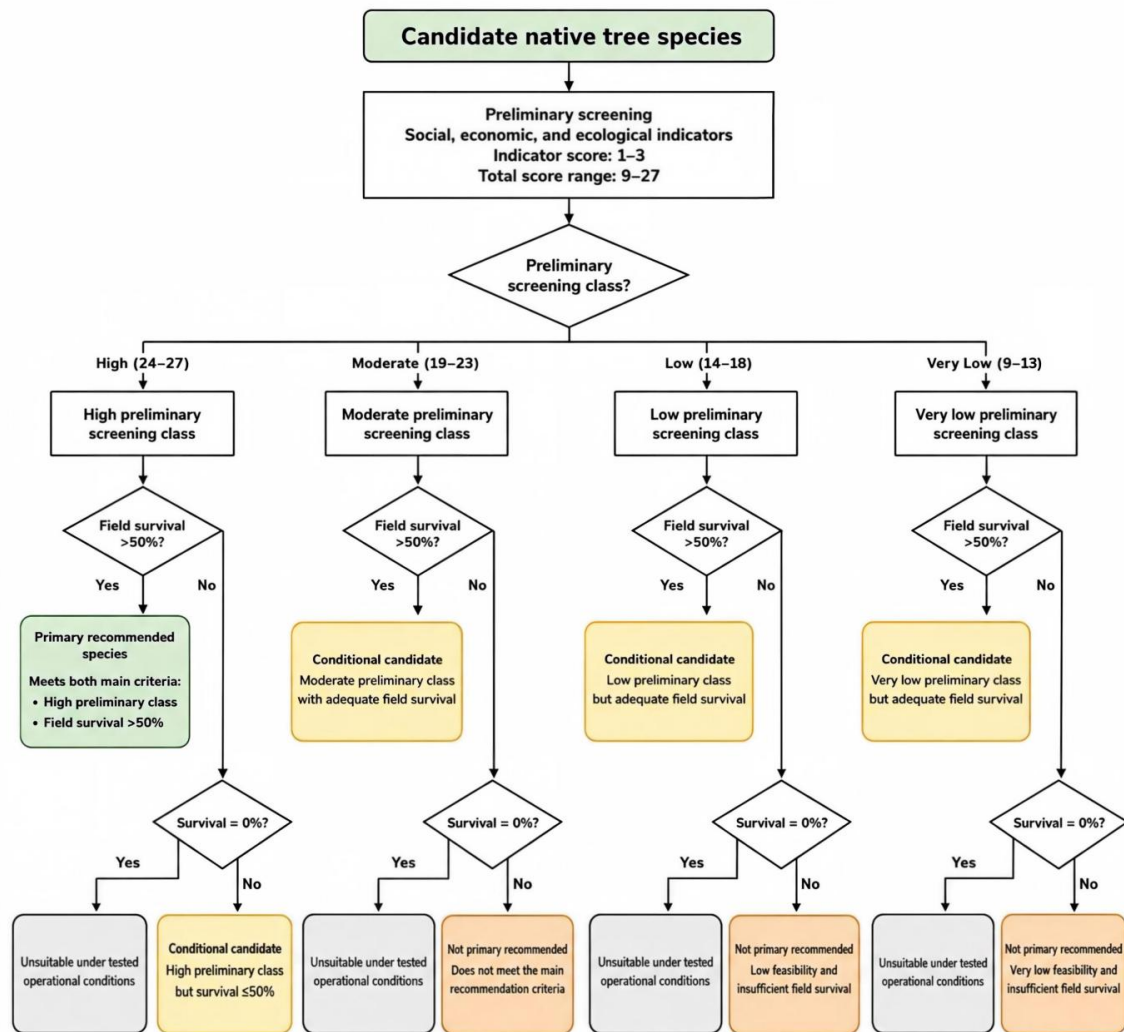


Figure 2. Decision logic linking preliminary screening, field survival, and final species recommendation.

3. Results

A prospective species list for enrichment planting consisted of ten native tree species (**Table 2**). The preliminary screening results are reported for the social, economic, and

ecological categories, the combination score, and the field survival data. The modified presentation differentiates the role of preliminary screening from the final field-based suggestion, so that each step has a distinct role in the decision process.

Table 2. Social criteria scores of native tree species for enrichment planting in revegetated post-coal mining sites.

Plant Species	Social Criteria			Score
	Prohibition on Species	Community Support	Expert Justification	
<i>Aleurites moluccana</i>	3	3	2	8
<i>Alstonia scholaris</i>	3	2	2	7
<i>Anisoptera marginata</i>	3	2	3	8
<i>Anthocephalus cadamba</i>	3	2	2	7
<i>Aquilaria malaccensis</i>	3	3	2	8

Table 2. Cont.

Plant Species	Social Criteria			Score
	Prohibition on Species	Community Support	Expert Justification	
<i>Combretocarpus rotundatus</i>	3	2	1	6
<i>Ficus benjamina</i>	3	2	3	8
<i>Melaleuca cajuputi</i>	3	1	1	5
<i>Shorea balangeran</i>	2	2	3	7
<i>Syzygium</i> sp.	3	2	2	7

Note: Social criteria were assessed using a scoring approach based on prohibition on species, community support, and expert justification. Each indicator was scored from 1 to 3, where 1 = Low, 2 = Moderate, and 3 = High. The total score was obtained by summing the scores of the three social criteria. Higher scores indicate greater social acceptance and suitability of the species for enrichment planting in post-mining land revegetation.

From the social assessment viewpoint, most species were not culturally bound by local populations. Both *Aleurites moluccana* and *Aquilaria malaccensis* were supported well by the community due to their known economic and cultural values. The original text used *Aquilaria moluccana* for candlenut; this version has corrected the species name to *Aleurites moluccana* throughout the document. Community support for *Melaleuca cajuputi* was lower because respondents perceived it to have lower economic value and less known growth potential in the post-coal mining environment.

Economic feasibility differed mostly in terms of

seedling availability and continuity of supply. The greatest economic rankings (Table 3) were given to *Aleurites moluccana*, *Alstonia scholaris*, *Anisoptera marginata*, *Melaleuca cajuputi* and *Shorea balangeran*, because seedlings were reasonably abundant, supply was judged more consistent, and pricing was operationally feasible. In this study, *Anthocephalus cadamba* had a lower economic score as seedlings were not more reliably available from suppliers. The reduced economic feasibility was essential in the final judgment since the species had enough survival but did not qualify for the high category of preliminary screening.

Table 3. Economic criteria scores of native tree species for enrichment planting in revegetated post-coal mining sites.

Plant Species	Economic Criteria			Score
	Easily Obtainable Species	Continuously Available	Seedling Price	
<i>Aleurites moluccana</i>	3	3	3	9
<i>Alstonia scholaris</i>	3	3	3	9
<i>Anisoptera marginata</i>	3	3	3	9
<i>Anthocephalus cadamba</i>	2	2	2	6
<i>Aquilaria malaccensis</i>	3	2	2	7
<i>Combretocarpus rotundatus</i>	2	2	3	7
<i>Ficus benjamina</i>	2	2	3	7
<i>Melaleuca cajuputi</i>	3	3	3	9
<i>Shorea balangeran</i>	3	3	3	9
<i>Syzygium</i> sp.	3	2	3	8

Note: Economic criteria were assessed using a scoring approach based on seedling availability, continuity of supply, and seedling price. Each criterion was scored from 1 to 3, where 1 = Low, 2 = Moderate, and 3 = High. The total score was obtained by summing the scores of the three economic criteria. Higher scores indicate greater economic suitability and feasibility of the species for enrichment planting in post-mining land revegetation.

Anisoptera marginata and *Ficus benjamina* obtained the highest ecological scores (Table 4). *A. marginata* is a native dipterocarp species found in lowland forests of Kalimantan^[19,20], whereas *F. benjamina* is known for its wide ecological tolerance, dense canopy structure and soil protection potential^[21–23]. *Anthocephalus cadamba*, *Aquilaria malaccensis* and *Shorea balangeran* also received relatively high ecological scores but their final recommendation was based on whether field survival supported their preliminary suitability. Overall, preliminary screening scores of native

tree species based on social, economic, and ecological criteria are as follows (Table 5).

The combined preliminary screening showed that one species was categorized as High, seven species were categorized as Moderate, and two species were categorized as Low. No species was categorized as Very Low. This revised four-class scoring system reduced overclassification into the High category and provided a stricter basis for final recommendation. Therefore, the initial score alone was insufficient to justify a final recommendation. The revised framework

uses preliminary screening as a weighting component and requires field survival confirmation for primary recommendation. The initial screening results for species selection in enrichment planting are shown below (Figure 3).

Table 4. Ecological criteria scores of native tree species for enrichment planting in revegetated post-coal mining sites.

Plant Species	Ecological Criteria			Score
	Growth Capability	Thrive Capability	Ability to Protect Soil	
<i>Aleurites moluccana</i>	2	2	2	6
<i>Alstonia scholaris</i>	2	2	2	6
<i>Anisoptera marginata</i>	2	3	3	8
<i>Anthocephalus cadamba</i>	2	2	3	7
<i>Aquilaria malaccensis</i>	2	2	3	7
<i>Combretocarpus rotundatus</i>	1	2	2	5
<i>Ficus benjamina</i>	3	2	3	8
<i>Melaleuca cajuputi</i>	1	1	1	3
<i>Shorea balangeran</i>	3	2	2	7
<i>Syzygium</i> sp.	2	2	2	6

Note: Ecological criteria were assessed using a scoring approach based on growth capability, thrive capability, and ability to protect soil. Each criterion was scored from 1 to 3, where 1 = Low, 2 = Moderate, and 3 = High. The total score was obtained by summing the scores of the three ecological criteria. Higher scores indicate greater ecological suitability of the species for post-mining land revegetation.

Table 5. Preliminary screening scores of native tree species based on combined social, economic, and ecological criteria.

Plant Species	Social	Economic	Ecology	Score/Class
<i>Aleurites moluccana</i>	7	9	6	22 (M)
<i>Alstonia scholaris</i>	7	9	6	22 (M)
<i>Anisoptera marginata</i>	8	9	8	25 (H)
<i>Anthocephalus cadamba</i>	7	6	7	20 (M)
<i>Aquilaria malaccensis</i>	8	7	7	22 (M)
<i>Combretocarpus rotundatus</i>	6	7	5	18 (L)
<i>Ficus benjamina</i>	8	7	8	23 (M)
<i>Melaleuca cajuputi</i>	5	9	3	17 (L)
<i>Shorea balangeran</i>	7	9	7	23 (M)
<i>Syzygium</i> sp.	7	8	6	21 (M)

Note: The initial screening score was obtained by summing the scores of social, economic, and ecological criteria for each plant species. Higher scores indicate greater suitability and potential for use as enrichment planting species in post-mining land revegetation.

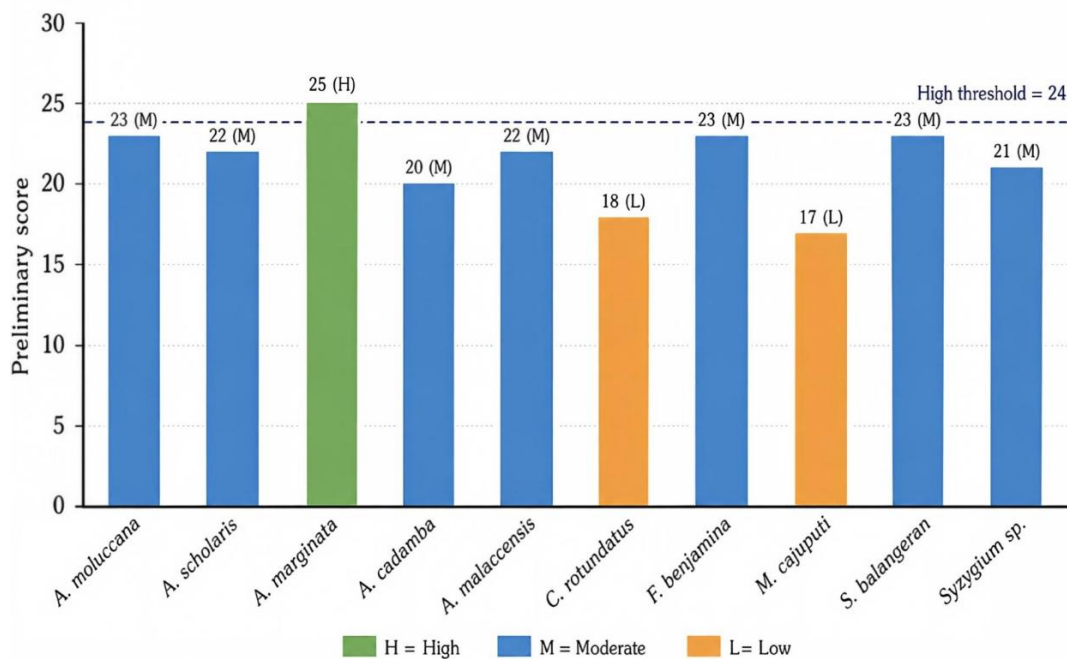


Figure 3. Preliminary screening scores based on social, economic, and ecological criteria.

Note: Classification based on screening criteria. H = High, M = Moderate, L = Low.

Using the revised four-class classification, only *Anisoptera marginata* reached the High preliminary screening class with a score of 25. Seven species were classified as Moderate: *Aleurites moluccana*, *Shorea balangeran*, *Ficus benjamina*, *Aquilaria malaccensis*, *Alstonia scholaris*, *Anthocephalus cadamba*, and *Syzygium* sp. Two species,

Combretocarpus rotundatus and *Melaleuca cajuputi*, were classified as Low. Field trials were conducted on all enrichment planting species under the canopy of primary revegetation trees. The results for plant survival rates (% growth) and initial screening score of enrichment planting species are as follows (Table 6).

Table 6. Survival rate, preliminary screening score, and adaptive potential of native tree species in enrichment planting trials.

No.	Plant Species	Survival	Surv. Score	Prelim. Score	Total	Class/Status
1	<i>Aleurites moluccana</i>	60.95%	3 (M)	23 (M)	26	M/Conditional
2	<i>Alstonia scholaris</i>	62.64%	3 (M)	22 (M)	25	M/Conditional
3	<i>Anisoptera marginata</i>	60.95%	3 (M)	25 (H)	28	H/Primary
4	<i>Anthocephalus cadamba</i>	55.56%	3 (M)	20 (M)	23	M/Conditional
5	<i>Aquilaria malaccensis</i>	65.79%	3 (M)	22 (M)	25	M/Conditional
6	<i>Combretocarpus rotundatus</i>	0.00%	1 (VL)	18 (L)	19	L/Unsuitable
7	<i>Ficus benjamina</i>	63.42%	3 (M)	23 (M)	26	M/Conditional
8	<i>Melaleuca cajuputi</i>	0.00%	1 (VL)	17 (L)	18	L/Unsuitable
9	<i>Shorea balangeran</i>	48.00%	2 (L)	23 (M)	25	M/Conditional
10	<i>Syzygium</i> sp.	48.00%	2 (L)	21 (M)	23	M/Conditional

Note: Plant survival rate was calculated as the percentage of surviving individuals at the end of the field trial. Survival scores were classified into four categories: Very Low = 1 (<25%), Low = 2 (25%–<50%), Moderate = 3 (≥50%–<75%), and High = 4 (≥75%). The total score was obtained by adding the survival score to the preliminary screening score. Adaptive potential was classified into four classes based on the combined total score: Very Low (10–15), Low (16–21), Moderate (22–26), and High (27–31). Abbreviations in the table: VL = Very Low, L = Low, M = Moderate, and H = High.

Aquilaria malaccensis, *Ficus benjamina*, *Alstonia scholaris*, *Anisoptera marginata*, *Aleurites moluccana*, and *Anthocephalus cadamba* showed more than 50% survival (Figure 4). However, under the revised four-class preliminary scoring system, only *Anisoptera marginata* reached the High

preliminary screening class. Therefore, *A. marginata* was classified as the primary recommended species. *A. moluccana*, *A. malaccensis*, *F. benjamina*, *A. scholaris*, and *A. cadamba* were classified as conditional candidates because their field survival was adequate but their preliminary scores were Moderate.

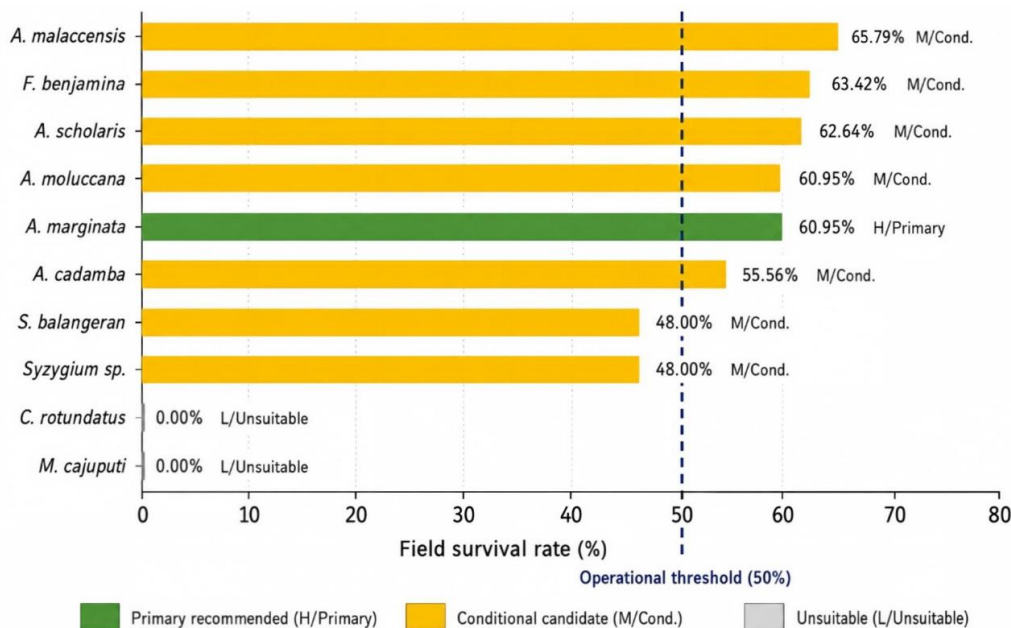


Figure 4. Survival rates of candidate enrichment planting species.

Note: The dashed line indicates the 50% operational early-establishment threshold.

Shorea balangeran and *Syzygium* sp. had Moderate preliminary screening scores and survival rates of 48%. They were therefore classified as conditional candidates requiring improved silvicultural intervention rather than as primary recommended species under the tested operational condition. This classification does not imply that *S. balangeran* is ecologically unsuitable in all post-mining sites. Previous studies have reported higher survival of *S. balangeran* in other mining areas^[24]. The lower survival in this study suggests that local planting method, seedling quality, microsite condition, or maintenance intensity may have limited establishment. Consequently, these species should be tested with improved site preparation, larger seedlings,

better planting-season timing, or additional maintenance before broad operational use.

The sensitivity interpretation shows that species with adequate survival remain within the Moderate to High adaptive-potential range when the survival threshold is increased from >50% to >60% (Table 7). However, the recommendation becomes very restrictive at >65%, and no species reaches the High survival category of $\geq 75\%$. This indicates that most species should be interpreted as moderately adapted during early establishment, not as fully established or long-term successful species. Longer monitoring is needed to confirm whether survival remains stable after the early establishment phase.

Table 7. Decision categories for final species recommendation based on preliminary screening and field survival.

Survival Threshold Used	Species Satisfying Survival Criterion	Primary Recommendation under Revised High Preliminary Class (24–27)
>50%	<i>A. malaccensis</i> , <i>F. benjamina</i> , <i>A. scholaris</i> , <i>A. marginata</i> , <i>A. moluccana</i> , <i>A. cadamba</i>	<i>A. marginata</i>
>60%	<i>A. malaccensis</i> , <i>F. benjamina</i> , <i>A. scholaris</i> , <i>A. marginata</i> , <i>A. moluccana</i>	<i>A. marginata</i>
>65%	<i>A. malaccensis</i>	No species
$\geq 75\%$	No species	No species

4. Discussion

The new statistics show the study is not a simple two-step exclusion process. The first screening and the field testing have different purposes but complementary. The first screening determines feasibility and hazard before planting. “Is the species socially acceptable, economically available and biologically possible for the site? The field trial then tests the species’ ability to survive under the real operational conditions of a revegetated after coal mining stand. This distinction is important since a species may be socially and economically feasible yet not perform under field stress as in *Shorea balangeran* and *Syzygium* sp. In contrast, a species may be able to survive sufficiently but still have operational limits, as in the instance of *Anthocephalus cadamba*.

The clustering of the preliminary scores should be interpreted in the context of the pool of candidate species. The study did not take into account random species from different ecological groups but species that were already considered native, locally known or relevant to forestry activities in South Kalimantan. In such cases a restricted range of scores is projected. Thus, the discrimination precision of the scoring scale is restricted and the final decision should not be

based on the preliminary score alone. In the new paradigm this restriction is eliminated, strengthening a feasibility requirement and a survival condition. This is consistent with restoration planning approaches that consider both species-site matching and the practical capacity to implement^[10,11].

The survival threshold is likewise a subject for careful interpretation. A 50% survival rate isn’t an ecological benchmark for successful restoration across the board. In a major tropical restoration effort in Sumatra, Kardiman et al.^[18] applied a minimum 50% survival criterion to evaluate successful species–microhabitat combinations, demonstrating its practical relevance as a screening benchmark rather than a universal goal. Therefore, >50% in the present study reflects operational early installation under the studied reclamation situation. The sensitivity analysis also demonstrates that the ranking is moderately robust at >60%, with *A. marginata* being the only primary recommendation, but becomes substantially more restrictive at >65%, with only *A. malaccensis* satisfying the survival criterion and no species satisfying both the revised High preliminary class and the survival requirement. At $\geq 75\%$ no species meets the survival requirement. This trend suggests that the research promotes moderate early establishment, rather than long-term restora-

tion success, and that the main advice is subject to how strictly survival is defined. The trial was conducted beneath 70%–80% canopy cover with under-canopy light intensity of 3,900–4,500 lux; therefore, all species recommendations are conditional on this partially shaded environment. Species performing well here should not automatically be assumed to perform similarly in open sites or beneath denser canopy, because light availability can alter both survival and growth in tropical restoration plantings^[18]. Soil pH of 5.95–6.24 was not extremely acidic, but the red-yellow podzolic clay-loam substrate may still impose constraints related to drainage, compaction, and root penetration.

The best choice was *Anisoptera marginata* since it had the greatest preliminary score and a survival rate of over 60%. Its selection is also relevant to conservation. Dipterocarp species are of ecological importance in the lowland forests of Kalimantan. *A. marginata* has conservation value due to its vulnerable status^[25]. The presence of *A. marginata* in enrichment planting may be helping to reintroduce late-successional structural components into a pioneer-dominated reclamation stand. Dipterocarps, however, often need good microsite conditions and long-term development and crown formation and competition should be assessed at different canopy densities in future trials.

Aleurites moluccana was assessed as a conditional candidate with Moderate adaptation potential. Good social and economic feasibility and adequate field survival supported this categorization, although its preliminary score did not achieve the updated High class. The species is known as a multipurpose tree and is widely distributed in different places in Indonesia^[26,27]. The practical value of this approach can facilitate community support for reclamation activities especially if post-mining landscapes are anticipated to produce both ecological recovery and plant resources of local significance. Its ability to adapt to a range of site conditions lends further support to its usage in degraded sites. Long-term monitoring is needed to verify that it adds to structural diversity, and does not operate merely as a utilitarian planting species. Species-profile evidence also supports this interpretation: *A. moluccana* is native to the Indo-Malaysian region, tolerates drought and wind, can grow on poor soils and steep slopes, and is used for soil stabilization, indicating broad ecological plasticity relevant to degraded-land rehabilitation^[28].

Aquilaria malaccensis had the highest survival rate

in the trial and was rated as a conditional candidate with Moderate adaptation potential according to the updated four-class framework. This species has also been documented for post-mining land regeneration in earlier studies^[29]. Its performance suggests that it is able to develop under the partial canopy circumstances of the revegetation stand examined. The species also has high conservation relevance as wild populations are under pressure from agarwood extraction and the species has recognized commercial worth in agarwood production^[30–33]. If correctly managed, planting of *A. malaccensis* in reclamation contexts could contribute to ex situ conservation and lessen reliance on wild sources. However, its economic worth could also lead to harvesting pressure, thus reclamation planning would have to include protective measures and long-term management goals. The species of *Ficus* are found in a range of habitats such as karst, riparian, heath forest and other forest habitats^[34–38]. Members of the genus *Ficus* are frequently important food resources in tropical climates. *F. benjamina* may promote vertical structure growth and wildlife use in post-mining landscapes, which is essential since reclaimed mining areas can eventually provide habitat for mammals and other species^[39]. However, this species needs to be closely monitored in its development because it can dominate due to its quick growth and adaptability unless it is balanced by other local species. *Alstonia scholaris* was likewise categorized as a conditional candidate with a Moderate adaptive potential. Due to its relatively good survival, seedling availability and fast-growing character, it is still beneficial for enrichment planting when rapid establishment is necessary. As a native tree, tolerant of a range of climatic circumstances, it may provide an opportunity to diversify stands dominated by early reclamation species. The non-timber value of *Alstonia scholaris* has also been recognized, and much research has validated its phytochemical and antioxidant characteristics^[40]. Besides survival, their ecological roles should be assessed with regard to height growth, contribution to the canopy and interactions with the current revegetation species. Also, *Anthocephalus cadamba* requires a more precise interpretation as the species is known as a fast-growing tree with a vast silvicultural potential^[41]. Its survival rate was more than 50%, showing potential for early establishment. However, its preliminary screening score was Moderate in the study environment because seedling availability, supply

continuity, and pricing were not very good. Therefore, it was maintained as a conditional competitor rather than a prime recommended species. The story of *Shorea balangeran* also underscores the need to balance between preliminary feasibility and survival in the field. Based on earlier reclamation research^[24,42], *S. balangeran* scored Moderate in the preliminary test and has demonstrated to grow well in the favorable conditions. But only 48% survived in the field tests. The difference could be the effect of local microsite conditions, seedling quality, season of planting or early management on survival. *S. balangeran* should not be seen as unsuitable in general but as a species that needs improved silvicultural intervention in the research site. Suggested improvements are bigger seedlings, better handling of the root ball, planting at the start of the rainy season, site specific organic nutrients and focused weeding to reduce competition. The conservation and economic rationale is further supported by evidence that *A. malaccensis* is heavily valued for agarwood, while depletion and unsustainable harvesting of wild *Aquilaria* resources have created a strong need for cultivation and sustainable production systems^[43].

Combretocarpus rotundatus and *Melaleuca cajuputi* had zero survival under the tested condition, indicating a strong species–microsite mismatch rather than evidence of universal ecological unsuitability. *C. rotundatus* is characteristic of peat-swamp forest and has shown superior seedling growth on peat media with high water-holding capacity^[44]. *M. cajuputi* is likewise associated with peat-swamp environments in South Kalimantan and can occur under strongly acidic, wet substrates^[45]. In contrast, the present enrichment plots were established on red-yellow podzolic mineral soil beneath a relatively closed 70%–80% canopy. Their zero survival may therefore reflect interacting differences in substrate type, soil moisture regime, drainage, and under-canopy light. Follow-up testing should involve duplicated microsite treatments contrasting wetter versus better drained sites, peat-rich versus mineral soils, and lower versus higher canopy openness. At the same time monitor soil moisture, depth to water table or drainage quality, light availability and seedling physiological status. This directed testing would elucidate whether death was predominantly due to moisture/substrate mismatch, shade limitation, planting-stock quality, or combinations among these factors before either species is removed from reclamation usage. More broadly, mine-rehabilitation

studies demonstrate that vegetation establishment can shift sharply across substrate pH and other geochemical thresholds, supporting the interpretation that poor survival at a single site may reflect microsite mismatch rather than universal species unsuitability^[13]. Evidence from South Kalimantan restoration research also emphasizes that species selection should integrate ecological suitability with community knowledge, participation, and socio-economic feasibility^[46].

The broader conservation implication is that enrichment planting should be designed as an adaptive management process that simultaneously rebuilds vegetation structure and creates managed populations of conservation-relevant native taxa. Three candidate species are particularly important in this regard: *Anisoptera marginata* is listed as Vulnerable^[25], *Aquilaria malaccensis* is a threatened agarwood-producing species subject to pressure from wild harvesting^[32,33], and *Shorea balangeran* is also currently assessed as Vulnerable^[47]. Establishing such taxa in reclaimed landscapes can diversify pioneer-dominated stands, increase representation of native forest lineages, and provide ex situ or complementary conservation value when planted populations are protected and monitored. However, conservation benefit should not be inferred from planting alone. It requires long-term survival, growth to reproductive maturity, maintenance of adequate genetic diversity, protection from harvesting, and integration with landscape-level habitat recovery. Increasing vegetation structure and species diversity may also support bird and mammal communities because faunal composition responds to habitat complexity and vegetation structure^[39,48–50]. Accordingly, monitoring should extend beyond early survival to height and diameter growth, canopy development, reproductive status, recruitment, and wildlife use. These conservation interpretations, like the species recommendations themselves, remain conditional on the partially shaded 70%–80% canopy environment tested in this study and require validation across contrasting canopy conditions. This broader biodiversity interpretation is consistent with evidence from reclaimed surface mines showing that vegetation structure, canopy development, surface heterogeneity, and connectivity to source habitats influence faunal recolonization and should be considered in biodiversity-oriented reclamation^[51]. Integrated post-mining monitoring should therefore combine survival and growth of planted native species with vegetation diversity, soil conditions, microcli-

mate, and other ecosystem indicators rather than relying on a single measure of restoration progress^[12].

This study has several limitations. The field trial was conducted in an operational reclamation context without duplicated experimental plots across distinct site blocks, restricting the disentanglement of species impacts from local spatial variation. Second, plot-level gradients in soil chemistry, compaction, moisture, drainage, and nutrient availability were not measured as explanatory variables. Third, canopy cover and under-canopy light were characterized for the study site but not altered experimentally, although partial shade constituted an important condition of the trial. Fourth, the preliminary grading scale 1-3 has limited discriminatory resolution and early survival alone could not reflect the long-term restorative performance. Therefore, a replicated randomized-block or factorial design testing candidate species across differing canopy openness classes and measured soil-gradient conditions ought to be used in a subsequent controlled trial. At minimum, independent blocks should represent low, intermediate, and high shade conditions, while soil measurements should include pH, organic carbon, available nutrients, bulk density or penetration resistance, texture, and soil moisture or drainage status. Species $\times$ canopy and species $\times$ soil-condition interactions should be evaluated, with standardized seedling size, planting season, amendment, and maintenance. Repeated survival and growth measurements over multiple years would allow mixed-effects or survival-analysis models to distinguish true species responses from block- and microsite-level variation.

However, the better decision structure enhances transparency and reproducibility. It distinguishes between an initial feasibility evaluation and field performance, sets forth precise principles for primary and conditional recommendations, and clarifies why species with apparently comparable total scores may be placed in various final categories. Such a framework can help mining firms, restoration practitioners and forest managers in more judicious selection of native species for conservation-oriented enrichment planting in post-coal mining environments.

5. Conclusion

This study developed a revised four-class decision framework for selecting native tree species for enrichment

planting in revegetated post-coal mining sites. The preliminary screening based on social, economic, and ecological indicators was clarified as a weighting and risk-diagnosis stage rather than an elimination filter. The total preliminary screening score was classified into Very Low (9–13), Low (14–18), Moderate (19–23), and High (24–27). Field survival was then used as the empirical confirmation of early establishment, with survival scores classified as Very Low, Low, Moderate, and High. Primary recommended species were those that achieved both a High preliminary screening class and survival greater than 50%.

Based on this revised assessment, *Anisoptera marginata* was the only primary recommended species because it achieved the High preliminary class and adequate field survival. *Aleurites moluccana*, *Aquilaria malaccensis*, *Ficus benjamina*, *Alstonia scholaris*, and *Anthocephalus cadamba* were classified as conditional candidates with Moderate adaptive potential because they showed adequate survival but only Moderate preliminary feasibility. *Shorea balangeran* and *Syzygium* sp. were also conditional candidates requiring improved field intervention because their survival rates were below the operational threshold. *Combretocarpus rotundatus* and *Melaleuca cajuputi* were classified as unsuitable under the tested enrichment planting condition because both showed zero survival.

The findings show that enrichment planting recommendations in post-mining landscapes should not rely on a single criterion. Species selection should integrate feasibility, ecological appropriateness, field performance, and adaptive monitoring. The revised four-class scoring system provides a more conservative and transparent basis for identifying species that are ready for operational use, species that require conditional management, and species that should be restricted to more suitable microsites. The present recommendations should therefore be interpreted as condition-specific evidence for enrichment beneath approximately 70%–80% canopy cover; operational deployment in more open or more heavily shaded reclamation stands should be preceded by replicated canopy- and soil-gradient trials.

Author Contributions

Conceptualization, K. and R.M.N.P.; methodology, K. and W.N.H.; validation, K., R.M.N.P. and W.N.H.; formal

analysis, K. and W.N.H.; investigation, K., R.M.N.P. and W.N.H.; resources, K.; data curation, W.N.H.; writing—original draft preparation, K. and W.N.H.; writing—review and editing, K., P.Y.S., R.M.N.P. and W.N.H.; visualization, W.N.H.; supervision, K.; project administration, R.M.N.P. and W.N.H.; funding acquisition, K. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Institute for Research and Community Service (LPPM), Universitas Lambung Mangkurat.

Institutional Review Board Statement

Ethical approval was not sought for this study because the research involved non-medical interviews with adult participants, did not involve any clinical or experimental intervention, and did not collect sensitive personal or identifiable information. Participation was voluntary, and the study posed no more than minimal risk to the participants.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly archived because they include field observation records, interview-based information, and supporting documentation related to the revegetated post-coal mining site and local respondents.

Acknowledgments

The authors express their gratitude to the Institute for Research and Community Service (LPPM), Universitas Lambung Mangkurat, for funding and institutional support. The authors also extend their appreciation to the site management and field personnel for facilitating access to the revegetated post-coal mining sites. Appreciation is further extended to

the local communities, seedling suppliers, and all parties who assisted in interviews, field observations, planting trials, and documentation in Pengaron Subdistrict, Banjar Regency, South Kalimantan, Indonesia.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

AI Use Statement

During the preparation of this revised manuscript, artificial intelligence was used solely for language refinement, editorial restructuring, and formatting support. No AI tools were used for data analysis, data interpretation, or generation of scientific findings. All outputs were critically reviewed and edited by the authors. The authors take full responsibility for the integrity and accuracy of the work.

References

- [1] Lestari, K.G., Budi, S.W., Suryaningtyas, D.T., 2022. The impact of revegetation activities in various post-mining lands in Indonesia (study of literature). IOP Conference Series: Earth and Environmental Science. 959(1), 012038. DOI: <https://doi.org/10.1088/1755-1315/959/1/012038>
- [2] Pratiwi, Narendra, B.H., Siregar, C.A., et al., 2021. Managing and reforesting degraded post-mining landscape in Indonesia: A review. *Land*. 10(6), 658. DOI: <https://doi.org/10.3390/land10060658>
- [3] Pambudi, P.A., Utomo, S.W., Soelarno, S.W., et al., 2023. Coal mining reclamation as an environmental recovery effort: A review. *Journal of Degraded and Mining Lands Management*. 10(4), 4811–4821.
- [4] Hartati, W., Sudarmadji, T., 2022. The dynamics of soil carbon in revegetated post-coal mining sites: A case study in Berau, East Kalimantan, Indonesia. *Biodiversitas Journal of Biological Diversity*. 23(10), 4984–4991. DOI: <https://doi.org/10.13057/biodiv/d231004>
- [5] Indonesian Government, 2010. Government Regulation of the Republic of Indonesia Number 78 of 2010 Concerning Reclamation and Post-Mining. Available from: <https://jdih.esdm.go.id/dokumen/view?id=162> (cited 6 June 2026). (in Indonesian)
- [6] Ministry of Forestry, 2011. Forest Reclamation Guidelines (The Regulation of the Minister of Forestry of

- Republic of Indonesia Number P. 4/Menhut-II/2011, 14 January 2011). Available from: <https://lpr.adb.org/sites/default/files/resource/%5bnid%5d/ins107031.pdf> (cited 6 June 2026).
- [7] Rusdiana, O., Setiadi, A., 2019. The evaluation of the success of plant revegetation in post-coal mining Block M1W PT Jorong Barutama Greston, South Kalimantan. *Jurnal Silvikultur Tropika*. 10(3), 125–132. DOI: <https://doi.org/10.29244/j-siltrop.10.3.125-132> (in Indonesian)
- [8] Yunanto, T., Amanah, F., Siregar, I.Z., 2021. The influence of fast-growing species composition on natural regeneration of coal mine reclamation. *IOP Conference Series: Earth and Environmental Science*. 918, 012048. DOI: <https://doi.org/10.1088/1755-1315/918/1/012048>
- [9] Staporn, D., Marod, D., Wongprom, J., et al., 2022. Drivers of native species regeneration in the process of restoring a dry evergreen forest from exotic tree plantations in northeastern Thailand. *Forests*. 13(8), 1321. DOI: <https://doi.org/10.3390/f13081321>
- [10] Brancalion, P.H.S., Holl, K.D., 2020. Guidance for successful tree planting initiatives. *Journal of Applied Ecology*. 57(12), 2349–2361. DOI: <https://doi.org/10.1111/1365-2664.13725>
- [11] Xu, C., Zhang, H., Yang, H., et al., 2024. A quick and effective trait-based protocol for selecting appropriate native plant species for the reforestation of degraded tropical mines. *Frontiers in Plant Science*. 15, 1456740. DOI: <https://doi.org/10.3389/fpls.2024.1456740>
- [12] Trimanto, T., Hapsari, L., Budiharta, S., 2021. Integrating indicators of natural regeneration, enrichment planting, above-ground carbon stock, micro-climate and soil to assess vegetation succession in postmining reclamation in tropical forest. *Turkish Journal of Botany*. 45(5), 457–467. DOI: <https://doi.org/10.3906/bot-2103-35>
- [13] Craw, D., Rufaut, C., 2021. Geoecological zonation of revegetation enhances biodiversity at historic mine sites, Southern New Zealand. *Minerals*. 11(2), 181. DOI: <https://doi.org/10.3390/min11020181>
- [14] Harsono, R., Suba, R.B., Kustiawan, W., et al., 2024. Vegetation diversity at various ages of revegetation in post-coal mining reclamation land PT Indominco Mandiri, Kalimantan Timur. *Jurnal Ilmu Lingkungan*. 22(3), 589–599. DOI: <https://doi.org/10.14710/jil.22.3.589-599> (in Indonesian)
- [15] Slik, J.W.F., 2006. *Trees of Sungai Wain*. National Herbarium Nederland, Leiden University Branch: Leiden, The Netherlands.
- [16] Wiryono, Lukman, A.H., Nurliana, S., 2022. The species diversity and composition of seedlings for degraded land rehabilitation in different phytogeographical regions in Indonesia. *Biodiversitas Journal of Biological Diversity*. 23(11), 5771–5781. DOI: <https://doi.org/10.13057/biodiv/d231130>
- [17] Supranto, J., 2000. *Statistics: Theory and Applications*, Volume 1, 6th ed. Penerbit Erlangga: Jakarta, Indonesia. (in Indonesian)
- [18] Kardiman, R., Afriandi, R., Schmidt, L.H., et al., 2019. Restoration of tropical rain forest success improved by selecting species for specific microhabitats. *Forest Ecology and Management*. 434, 235–243. DOI: <https://doi.org/10.1016/j.foreco.2018.12.028>
- [19] Ashton, P.S., 1982. *Dipterocarpaceae*. In: van Steenis, C.G.G.J. (Ed.). *Flora Malesiana Series I*, Volume 9. National Herbarium of the Netherlands: Leiden, The Netherlands. pp. 237–552.
- [20] Rana, R., Langenfeld-Heyser, R., Finkeldey, R., et al., 2009. Functional anatomy of five endangered tropical timber wood species of the family Dipterocarpaceae. *Trees*. 23, 521–529. DOI: <https://doi.org/10.1007/s00468-008-0298-4>
- [21] Veneklaas, E.J., Santos Silva, M.P.R.M., den Ouden, F., 2002. Determinants of growth rate in *Ficus benjamina* L. compared to related faster-growing woody and herbaceous species. *Scientia Horticulturae*. 93(1), 75–84. DOI: [https://doi.org/10.1016/S0304-4238\(01\)00315-6](https://doi.org/10.1016/S0304-4238(01)00315-6)
- [22] Hendrayana, Y., Ismail, A.Y., Handayani, et al., 2025. Soil fertility mapping on *Ficus* trees for rehabilitation of degraded land in Kuningan Regency, Indonesia. *Brazilian Journal of Biology*. 85, e290726. DOI: <https://doi.org/10.1590/1519-6984.290726>
- [23] Starr, F., Starr, K., Loope, L., 2003. *Ficus benjamina*: Weeping Fig. U.S. Geological Survey, Biological Resources Division, Haleakalā Field Station: Makawao, HI, USA.
- [24] Adman, B., Nugroho, A.W., Yassir, I., 2020. The growth of local tree species on post-coal mining areas in East Kalimantan. *Indonesian Journal of Forestry Research*. 7(2), 83–97. DOI: <https://doi.org/10.59465/ijfr.2020.7.2.83-97>
- [25] Kalima, T., Kusumadewi, Y., Purwaningsih, et al., 2020. *Anisoptera marginata*. The IUCN Red List of Threatened Species 2020: e.T33066A68069678. International Union for Conservation of Nature and Natural Resources (IUCN): Gland, Switzerland. DOI: <https://doi.org/10.2305/IUCN.UK.2020-2.RLTS.T33066A68069678.en>
- [26] Krisnawati, H., Kallio, M., Kanninen, M., 2011. *Aleurites moluccana* (L.) Willd.: Ecology, Silviculture and Productivity. Center for International Forestry Research (CIFOR): Bogor, Indonesia.
- [27] Rahmawaty, Frastika, S., Rauf, A., et al., 2024. Evaluating land suitability for kemiri (*Aleurites moluccana*) as a multi-purpose tree species in community agroforestry land within Langkat District, North Sumatra. *Global Forest Journal*. 2(2), 90–99. DOI: <https://doi.org/10.32734/gfj.v2i02.15626>
- [28] Elevitch, C.R., Manner, H.I., 2006. *Aleurites moluc-*

- cana* (kukui). In: Elevitch, C.R. (Ed.). Species Profiles for Pacific Island Agroforestry, Ver. 2.1. Permanent Agriculture Resources: Holualoa, HI, USA.
- [29] Yuwono, S.B., Alawiyah, A., Riniarti, M., et al., 2021. The roles of ameliorants on tree seedling growth for land rehabilitation. *Biodiversitas Journal of Biological Diversity*. 22(5), 2706–2714. Available from: <https://smujo.id/biodiv/article/view/8133>
- [30] Kamarubahrin, A.F., 2025. Agarwood (*Aquilaria malaccensis*): A review on ecosystem, functions, threats, and potential market in Malaysia. *International Wood Products Journal*. 16(2), 157–162. DOI: <https://doi.org/10.1177/20426445251332393>
- [31] Siran, S.A., 2011. The developing of database regarding the potency of gaharu-yielding trees in Indonesia. In: Turjaman, M. (Ed.). *Proceeding of Gaharu Workshop: Bioinduction Technology for Sustainable Development and Conservation of Gaharu*. R&D Centre for Forest Conservation and Rehabilitation: Bogor, Indonesia. pp. 1–8.
- [32] Harvey-Brown, Y., 2018. *Aquilaria malaccensis*. The IUCN Red List of Threatened Species 2018: e.T32056A2810130. International Union for Conservation of Nature and Natural Resources (IUCN): Gland, Switzerland. DOI: <https://doi.org/10.2305/IUCN.UK.2018-1.RLTS.T32056A2810130.en>
- [33] Asian Regional Workshop, 1998. *Aquilaria malaccensis*. The IUCN Red List of Threatened Species 1998: e.T32056A9677920. International Union for Conservation of Nature and Natural Resources (IUCN): Gland, Switzerland. DOI: <https://doi.org/10.2305/IUCN.UK.1998.RLTS.T32056A9677920.en>
- [34] Yelastri, Y., Sulistijorini, S., Djuita, N.R., 2023. Diversity and distribution of *Ficus* (Moraceae) in the karst ecosystem of Bantimurung Bulusaraung National Park. *Journal of Tropical Biodiversity and Biotechnology*. 8(2), jtbb78811. DOI: <https://doi.org/10.22146/jtbb.78811>
- [35] Sumarni, S., Oktavianus, 2022. Study of riparian tree species along the Belitang River in Ijuk Village, Sekadau Regency. *PIPER*. 18(1), 56–62. Available from: <https://jurnal.unka.ac.id/index.php/piper/article/view/625> (in Indonesian)
- [36] Soendjoto, M.A., Riefani, M.K., Diana, S., 2023. Floristic diversity and composition of Kuala Tambangan heath forest in Tanah Laut District, South Kalimantan, Indonesia. *Biodiversitas Journal of Biological Diversity*. 24(10), 5418–5427. DOI: <https://doi.org/10.13057/biodiv/d241024>
- [37] Shanahan, M., So, S., Compton, S.G., et al., 2001. Fig-eating by vertebrate frugivores: A global review. *Biological Reviews*. 76(4), 529–572. DOI: <https://doi.org/10.1017/S1464793101005760>
- [38] Kurniawan, F.H., Rahayuningsih, M., Kartijono, N.E., et al., 2022. Evaluation on the population of strangler figs (*Ficus* subgen. *Urostigma*) in Mount Ungaran, Central Java. *Media Konservasi*. 27(3), 83–90. DOI: <https://doi.org/10.29244/medkon.27.3.83-90>
- [39] Cristescu, R.H., Frère, C.H., Banks, P.B., 2012. A review of fauna in mine rehabilitation in Australia: Current state and future directions. *Biological Conservation*. 149(1), 60–72. DOI: <https://doi.org/10.1016/j.biocon.2012.02.003>
- [40] Antony, M., Menon, D., James, J., et al., 2011. Phytochemical analysis and antioxidant activity of *Alstonia scholaris*. *Pharmacognosy Journal*. 3(26), 13–18. DOI: <https://doi.org/10.5530/pj.2011.26.3>
- [41] Krisnawati, H., Kallio, M., Kanninen, M., 2011. *Anthocephalus cadamba* Miq.: Ecology, Silviculture and Productivity. Center for International Forestry Research (CIFOR): Bogor, Indonesia.
- [42] Setyowati, R.D.N., Amala, N.A., Aini, N.N.U., 2018. Study on the selection of revegetation plants for the success of mined land reclamation. *Al-Ard: Jurnal Teknik Lingkungan*. 3(1), 14–20. DOI: <https://doi.org/10.29080/alard.v3i1.256> (in Indonesian)
- [43] Justin, S., Lihan, S., Elvis-Sulang, M.R., et al., 2020. Formulated microbial consortium as inoculant for agarwood induction. *Journal of Tropical Forest Science*. 32(2), 161–169. DOI: <https://doi.org/10.26525/jtfs32.2.161>
- [44] Irma, Burhannudin, Wulandari, R.S., 2022. Growth of tumih (*Combretocarpus rotundatus* (Miq.) Danser) in different growing media in the nursery. *Jurnal Lingkungan Hutan Tropis*. 1(2), 497–503. Available from: <http://jurnal.untan.ac.id/index.php/jlht/article/view/61136> (in Indonesian)
- [45] Arifin, Y.F., Hamidah, S., Arifin, Y.F., 2016. Ecological analysis of gelam (*Melaleuca cajuputi*) on peatland in South Kalimantan. *Jurnal Silviculture Tropika*. 7(3), S77–S79. DOI: <https://doi.org/10.29244/j-siltrop.7.3.S77-S79>
- [46] Pitri, R.M.N., Hatta, G.M., Kurnain, A., et al., 2023. Revamping the process of selecting the appropriate plant species for restoring peat ecosystems in South Kalimantan, Indonesia, through the implementation of a new approach. *Pakistan Journal of Life and Social Sciences*. 21(1), 107–119. DOI: <https://doi.org/10.57239/PJLSS-2023-21.1.009>
- [47] Robiansyah, I., 2020. *Shorea balangeran*. The IUCN Red List of Threatened Species 2020: e.T33103A68072336. International Union for Conservation of Nature and Natural Resources (IUCN): Gland, Switzerland. DOI: <https://doi.org/10.2305/IUCN.UK.2020-1.RLTS.T33103A68072336.en>
- [48] Castaño-Villa, G.J., Ramos-Valencia, S.A., Fontúrbel, F.E., 2014. Fine-scale habitat structure complexity determines insectivorous bird diversity in a tropical forest. *Acta Oecologica*. 61, 19–23. DOI: <https://doi.org/10.1016/j.actao.2014.10.002>

- [49] MacArthur, R.H., MacArthur, J.W., 1961. On bird species diversity. *Ecology*. 42(3), 594–598. DOI: <https://doi.org/10.2307/1932254>
- [50] Balestrieri, R., Basile, M., Posillico, M., et al., 2015. A guild-based approach to assessing the influence of beech forest structure on bird communities. *Forest Ecology and Management*. 356, 216–223. DOI: <https://doi.org/10.1016/j.foreco.2015.07.011>
- [51] Larkin, J.L., Maehr, D.S., Krupa, J.J., et al., 2008. Small mammal response to vegetation and spoil conditions on a reclaimed surface mine in Eastern Kentucky. *Southeastern Naturalist*. 7(3), 401–412.