Diversity and Succession of Perennial Trees in the Rehabilitation Areas of a Limestone Mine, Saraburi Province, Thailand

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***Abstract*—This study aimed to investigate the structure and composition of plant community to i) identify tree species that can colonize, grow, and form communities and ii) identify species under natural succession whose seedlings can be used in forest rehabilitation. Experimental plots of size 40 m × 40 m were established in 13-, 10-, and 5-year-old rehabilitation areas (13YRA, 10YRA, and 5YRA), where characterized as flatted, sloped, and benched areas, respectively. The survey found 24 genera, 12 families, and 25 species of plants. Plant species that were found in all plots were *Zollingeria dongnaiensis* Pierre., *Pterocarpus macrocarpus* Kurz., *Albizia lebbek* (L.) Benth., and *Azadirachta indica* A. Juss.) which can potentially grow well in several conditions of post-mining areas. The 13YRA plot had the most significant number of naturally regenerating species (11 species) as the area was next to a natural forest or buffer zone and had been under restoration for the most prolonged period. The community succession of the rehabilitation plots relative to the natural forest was relatively slow. Nonetheless, the pioneer species can help to improve the environmental factors to optimum levels for the natural succession of the plant community. This can also be useful while selecting pioneer species for restoring areas previously used for limestone mining and help reduce the time for succession in terms of increasing the species composition.**

***Index Terms*—Plant community characteristic, forest rehabilitation, natural succession, limestone mine**

I. Introduction

The mining industry has been one of the more important industries contributing to the Thai economy. In the past, Thailand encouraged the production of minerals for export and the income generated was then used to develop the country. Subsequently, the role of the mining industry changed according to the country's socio-economic structure. However, the mining industry, especially limestone mining, still plays a vital role in economic development, but mining causes the destruction of forest areas, causing severe changes to the surrounding environment [1–3]. Therefore, it is necessary to implement forest rehabilitation in areas that had been previously undermined.

By allowing time for spontaneous succession, a degraded ecosystem can recover to its natural undisturbed condition on its own. Nevertheless, poor soil conditions, together with several limiting factors caused by mining result in a slow and lengthy recovery. Hence, area management processes must be implemented to transform the mined areas to near pre-limestone mining conditions. This can be done by planting pioneer or fast-growing exotic species found in the original forest in the degraded forest areas. This would help shorten the succession phase of plant community by increasing the species composition and biodiversity [4–9].

The initial rehabilitation of the limestone mine focused on restoring the area to near pre-mining conditions, preparing optimal conditions for tree planting, and introducing pioneer species. Thus, the key objectives of this study were to investigate the structure and composition of plant community in rehabilitation areas; to identify plant species that could successfully colonize and grow in the area, and to identify which sapling species were able to successfully rehabilitate in the plots prior used for limestone mining in Saraburi Province. This information will serve as a database for managing and restoring the rest of Kaeng Khoi limestone mining areas by reducing the succession time needed by plant communities in terms of increasing species composition.

II. Methodology

A. Study Area

The ten selected limestone and shale mining concession areas of the Siam Cement (Kaeng Khoi) Co., Ltd., are listed in the national forest reserve and Class 1, Class 2, Class 3, and Class 4 watersheds with an approximate area of 2,575 rai. This area is part of the Nong Kop limestone mountain range stretching from the southeast to northwest with elevations between 10–252 m from the mean sea level and slope angles between 35–70 degrees. The northern side of the mountain range has a higher slope angle than the southern side. The study area gets average annual precipitation of 1,304 mm and experiences an average temperature between 28–29 ℃. Humidity levels appropriate for planting were determined to be in 2 periods: dry or drought period during December-March and wet or flooding period during June–September [10].

There has been a rapid expansion of the mining area every year, given the continued quarrying of limestone. After using explosives to blast out the limestone for cement manufacturing, the mining area is restored through forest plantation starting from the edge of a mine pit down to the bottom. The rehabilitation period started from Year 1 to Year 25 segmented into 5 periods starting from the initial restoration in 2006. The objectives of the restoration were 1) to restore the area back to pre-mining conditions or to restore the area for other usage; 2) to address and prevent the environmental impacts; 3) to improve the appearance of the

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area to a state similar to that of the surrounding nature; 4) to develop learning centers [10].

B. Data Collection

The study was conducted in 3 areas: 1) a 13-year-old area under rehabilitation (13YRA) which is a flatland whose restoration was initiated in 2006; 2) a 10-year-old area under rehabilitation (10YRA) which is located at the pit wall with a slope of approximately 45 degrees, whose restoration was initiated 2009; and 3) a 5-year-old area under rehabilitation (5YRA) which is situated on the bench pit, whose restoration was initiated in 2014.

Eight plots of size 40 m × 10 m were established along the length of the areas. There were three plots in 13YRA, two in the 10YRA, and three in the 5YRA (Fig. 1). In each of the plots, three subplots were established, and included sub-plots of sizes 10 m × 10 m, 4 m × 4 m, and 1 m × 1 m (Fig. 2).

In the 10 m × 10 m sub-plot, species, height, and diameter at breast height (DBH) of trees with DBH more than 4.5 cm and height more than 1.3 m were recorded. In the 4 m × 4 sub-plots established at a corner of the 10 m × 10 m plots, species and height of the saplings were recorded. In the 1 m × 1 m sub-plots installed at all the corners of the 4 m × 4 m plots, species and number of seedlings with a height less than 1.30 m were recorded.

Fig. 1. Sample plots in the 13-, 10-, and 5-year-old rehabilitation area (13YRA, 10YRA, and 5YRA) at limestone quarry at Kaeng Khoi, Saraburi Province, Thailand.

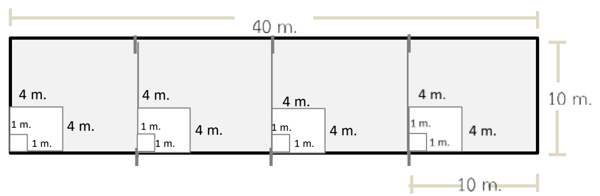

Fig. 2. Design of the temporary plots for the survey of forest structure and species composition.

C. Analysis of Plant Community Composition

Plant community composition was estimated using three indices which were

1) Analysis of Importance Value Index
2) Analysis of Species Diversity Index using Shannon – Wiener Species Diversity Index [11]
3) Analysis of Similarity Index and Dissimilarity Index using Sorensen's equation [12] to compare the plant communities in 13YRA, 10YRA, and 5YRA plots with representative plant communities in the dry evergreen forest (SKK1) and limestone forest (SKK4). The information about the representative plant communities in the SKK1 and SKK4 natural forests was based on plant community characteristics in the sampled plots prior to the establishment of the Kaeng Khoi limestone quarry in surveys conducted by the Forest Research Center [13].

III. RESULTS

A. Characteristics of Plant Community in the Rehabilitation Plots

The results from the plant community survey of the 13YRA, 10YRA, and 5YRA plots indicated that introduced plant species colonized and grew differently. A total of 25 species, 24 genera, and 12 families were recorded in the study areas. The 5YRA plot had the highest number of species, followed by 13YRA and 10YRA plots, respectively, with the number of species varying with tree density. Plants in the 13YRA plot had the highest average DBH and height, followed by plants in the 10YRA and 5YRA plots, respectively (Table I). The 5YRA plot had the highest Species Diversity Index of 2.337 followed by 10YRA and 13YRA plots, with Species Diversity Index of 2.143 and 1.905, respectively (Fig. 3).

B. Plant Community in the 13-Year-Old Rehabilitation Area

Initially, there were ten tree species introduced to the 13YRA plot. During this study, 18 species were found in the 13YRA plot, which included seven species that were introduced: *Z. dongnaiensis*, *Bombax anceps Pierre.*, *P. macrocarpus*, *Millingtonia hortensis* L.f., *Afzelia xylocarpa* (Kurz) Craib., *A. lebbek*, and *A. indica*; and 11 naturally growing species: *Holoptelea integrifolia* (Roxb.) Planch, *Hydnocarpus ilicifolius* King *Arfeuillea arborescens* Pierre ex Radlk., *Fernandoa adenophyla* (Wall. ex G.Don) Steenis, *Antheroporum glaucum* Z. Wei, *Grewia eriocarpa* Juss., *Diospyros mollis* Griff, *Vitex limonifolia* Wall., *Lagerstroemia venusta* Wall. ex C. B. Clarke., *Bauhinia saccocalyx* Pierre., and *Micromelum minutum* Wight & Arn. The species that were introduced and were unable to survive were *Acacia mangium* Willd., *Samanea saman* (Jacq.) Merr., and *Lagerstroemia speciosa* Pers. However, the top five tree species based on the Importance Value Index were *A. lebbek*, *Z. dongnaiensis*, *A. xylocarpa*, *A. indica*, and *P. macrocarpus*, respectively (Table II).

C. Plant community in the 10-Year-Old Rehabilitation Area

There were 17 tree species initially introduced to the 10YRA plot. During the survey, 14 species were found, which included nine species that had been introduced: *Z. dongnaiensis*, *Senna siamea* (Lam.) Irwin & Barneby, *Stereospermum tetragonum* DC., *Peltophorum pterocarpum* (DC.) K. Heyne, *Adenanthera microsperma* Teijsm. & Binn., *A. xylocarpa*, *A. lebbek*, *Millettia* *leucantha* Kurz., and *B. saccocalyx* and 5 naturally occurring species: *A. indica*, *P. macrocarpus*, *Broussonetia papyrifera* (L.) L'Herit, *Spondias pinnata* (L. f.) Kurz, and *G. eriocarpa*. The eight introduced species unable to survive in the 10YRP plot were *Dalbergia cultrata* Grah. Ex Banth, *Cassia fistula* L., *M. hortensis*, *Oroxylum indicum* (L.) Vent., *Spondias bipinnata* Airy Shaw & Forman, *Tectona grandis* L.f., *Sterculia foetida* L, and *Lagerstroemia macrocarpa* Wall. The top five tree species based on the Importance Value Index were *Z. dongnaiensis*, *P. macrocarpus*, *P. pterocarpum*, *S. tetragonum*, and *A. indica*, respectively (Table II).

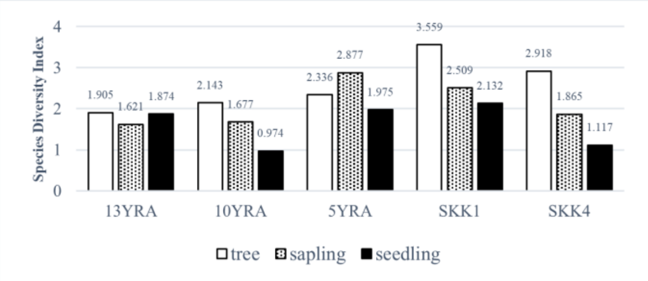

Fig. 3. Species Diversity Index in the 13-, 10-, and 5-year-old rehabilitation area (13YRA, 10YRA, and 5YRA) and in plots established in the two natural forests (SKK1/SKK4).

TABLE I: NUMBER OF SPECIES, AVERAGE DIAMETER, AVERAGE HEIGHT, AND DENSITY OF TREES, SAPLINGS, AND SEEDLINGS IN THE REHABILITATION PLOTS

Parameters	Number of Species	Average Diameter (cm)	Average Height (m)	Density (trees ha^{-1})
13-year-old rehabilitation area				
Tree	12	12.8	9.07	918.75
Sapling	7	2.85	3.61	1,356.25
Seedling	8	-	-	14,168.75
Total	18	-	-	-
10-year-old rehabilitation area				
Tree	10	9.87	6.76	362.50
Sapling	6	2.34	2.50	1,093.75
Seedling	3	-	-	10,000.00
Total	14	-	-	-
5-year-old rehabilitation area				
Tree	15	7.71	3.82	450.00
Sapling	20	2.49	2.27	2,668.75
Seedling	11	-	-	25,831.25
Total	22	-	-	-

TABLE II: IMPORTANCE VALUE INDEX OF TREE SPECIES IN 13-, 10-, AND 5-YEAR-OLD REHABILITATION AREAS (13YRA, 10YRA, AND 5YRA)

Species	13YRA	10YRA	5YRA
Adenanthera microsperma Teijsm. & Binn.	-	27.95	16.67
Afzelia xylocarpa (Kurz) Craib.	41.01	-	-
Albizia lebbek (L.) Benth.	98.97	19.16	38.89
Albizia procera (Roxb.) Benth.	-	-	22.22
Arfeuillea arborescens Pierre ex Radlk.	-	-	5.56
Azadirachta indica A.Juss.	29.81	32.85	11.11
Bauhinia saccocalyx Pierre.	-	-	27.78
Bombax anceps Pierre.	14.64	-	
Broussonetia papyrifera (L.) L'Herit	-	24.32	
Caesalpinia pulcherrima (L.) Sw.	-	-	77.78
Fernandoa adenophyla (Wall. ex G.Don) Steenis	2.93	-	16.67
Grewia eriocarpa Juss.	9.72	17.42	
Lagerstroemia venusta Wall. ex C. B. Clarke.	13.76	-	-
Micromelum minutum Wight & Arn.	3.45	-	-
Millettia leucantha Kurz.	-	12.16	-
Millingtonia hortensis L.f.	3.15	-	5.56
Peltophorum pterocarpum (DC.) K.Heyne	-	39.75	
Phyllanthus emblica L.	-	-	22.2
Pterocarpus macrocarpus Kurz.	23.77	43.38	5.56
Sindora siamensis Teijsm. & Miq.	-	-	5.56
Spondias pinnata (L. f.) Kurz	-	-	11.11
Stereospermum tetragonum DC.	-	32.85	
Syzygium cumini (L.) Skeels	-	-	5.56
Vitex limonifolia Wall.	2.9	-	-
Zollingeria dongnaiensis Pierre.	55.89	50.27	27.78

D. Plant Community in the 5-Year-Old Rehabilitation Area

There were 37 species initially introduced to the 5YRA plot. During the study, 22 species were found, which included 20 species that were introduced: *Z. dongnaiensis*, *A. arborescens*, *F. adenophyla*, *Albizia procera* (Roxb.) Benth., *Butea monosperma* (Lam.) Taub., *P. macrocarpus*, *Alangium salviifolium* (L.f.) Wangerin, *M. hortensis*, *O indicum*., *S. pinnata*, *Phyllanthus emblica* L., *Sindora siamensis* Miq., *A. xylocarpa*, *A. lebbek*, *V. limonifolia*, *A. indica*, *S. foetida*, *B.*

saccocalyx, *Syzygium cumini* (L.) Skeels, and *Caesalpinia pulcherrima* (L.) Sw along with two naturally occurring species: *A. microsperma* and *L. venusta*. It was observed that 17 introduced species were unable to survive and included *Careya arborea* Roxb, *Millettia brandisiana* Kurz *Cassia bakeriana* Craib, *Artocarpus heterophyllus* Lam., *S. siamea*, *C. fistula*, *S. tetragonum*, *S. saman* , *Cassia javanica* L., *Lagerstroemia floribunda* Jack, *Sterculia pexa* Pierre *Tamarindus indica* L. *Pithecellobium dulce* (Roxb.), *Mangifera indica* L., *T. grandis*, *M. leucantha*, and *L. macrocarpa*. Besides, the top 5 tree species based on the Importance Value Index were *C. pulcherrima*, *A. lebbek*, *Z. dongnaiensis*, *B. saccocalyx*, and *A. procera* (Table II).

E. Similarity of Plant Community in the Rehabilitation Areas of Kaeng Khoi Limestone Mine, Saraburi Province

The results of Similarity Index and Dissimilarity Index of the plant community: tree, saplings, and seedlings for the 13YRA, 10YRA, 5YRA plots, dry evergreen forest (SKK1), and limestone forest (SKK4) were shown in Table III. The Similarity Index was calculated to compare the trees, saplings, and seedlings of the plants in the dry evergreen forest and 13YRA, 10YRA, and 5YRA plots. The analysis indicated that trees had the highest Similarity Index of 15.15%, 9.38%, and 8.70% in the 13YRA, 10YRA, and 5YRA plots, respectively; followed by saplings with a Similarity Index of 13.33%, 8.00%, and 6.06%, in the 13YRA, 10YRA and 5YRA plots, respectively. For saplings, the Similarity Index for the 13YRA plot was 11.11%, while there was no similarity of saplings in the 10YRA and 5YRA plots (Table III).

IV. Discussion

The 13YRA plot was located on a flat area at the edge of the mine pit and in close proximity with the natural forest (near the dry evergreen and limestone forest plots). The 13YRA plot was the oldest area under rehabilitation by introducing pioneer species from the experiment plots in zone C of the area previously mined for limestone in the Kaeng Khoi Limestone Mine.

TABLE III: Similarity Index and Dissimilarity Index among 13-, 10-, and 5-Year-Old Rehabilitation Areas (13YRA, 10YRA, and 5YRA) and in the Plots Established in the Natural Forests (SKK1 and SKK4)

		Similarity Index				
		SKK1	SKK4	13YRA	10YRA	5YRA
	SKK1					
	Tree	-	9.88	15.15	9.38	8.70
	Sapling	-	10.81	11.11	-	-
	Seeding	-	14.82	13.33	8.00	6.06
	SKK4					
	Tree	90.12	-	5.13	5.41	9.52
	Sapling	89.19	-	-	12.50	-
	Seeding	85.19	-	-	25.00	-
	13YRA					
Dissimilarity Index	Tree	84.85	94.87	-	45.46	44.44
	Sapling	88.89	100.00	-	26.67	28.57
	Seeding	86.67	100.00	-	36.36	31.58
	10YRA					
	Tree	90.63	94.60	54.55	-	40.00
	Sapling	100.00	87.50	73.33	-	22.22
	Seeding	92.00	75.00	63.64	-	28.57
	5YRA					
	Tree	91.30	90.48	55.56	60.00	-
	Sapling	100.00	100.00	71.43	77.78	-
	Seeding	93.94	100.00	68.42	71.43	-

The results indicated that ten species were initially introduced to the 13YRA plot. During the study, 18 species were recorded, including seven introduced and 11 naturally occurring species. The ten naturally occurring species were similar to species found in the dry evergreen forest plot. These species were *H. integrifolia*, *H. ilicifolius*, *A. arborescens*, *A. glaucum*, *G. eriocarpa*, *D. mollis*, *V. limonifolia*, *L. venusta*, *B. saccocalyx*, and *M. minutum*. In addition, there were four species in the 13YRA plot similar to the limestone forest: *A. glaucum*, *G. eriocarpa*, *D. mollis*, and *B. saccocalyx*. Most of the species in the plots were pioneer species. In addition, there were indicator species specific to dry evergreen forest in the plots and included *H. ilicifolius*, *H. integrifolia*, *A. arborescens*, *L. venusta*, and *M, minutum*.

A comparison among the three rehabilitation plots revealed that the 13YRA plot had the most naturally occurring species as it was older than the other two plots. The 13YRA plot was located on flat land near the natural forest. This finding is consistent with [14], who concluded that the distance of an area under rehabilitation from a natural forest is one of the factors determining successful colonization of plants.

The 10YRA plot was characterized by a 45-degree slope with a distance of about 1 km from the limestone mountain. This plot was covered by mulch mat and Ruzi grass (*Urochloa ruziziensis* Crins.) to prevent soil erosion. The introduced species were partly collected from the species that were able to survive in the 13YRA with the new addition of some pioneer species.

The study showed that 17 tree species were introduced to the 10YRA plot. However, during the study, only 14 species were recorded, consisting of nine introduced and five naturally occurring species. The naturally occurring species were pioneer species that could grow in low nutrient soil and moisture, apart from an effective covering of the surface contributing to their successful colonization and growth [15]. These species were *B. papyrifera* and *G. eriocarpa,* which produce a high number of fruits which can disperse in a large area; and *A. indica*, *S. pinnata*, and *P. macrocarpus* Kurz., which produce relatively large fruits (approximately 1-2 cm, 3-5 cm, and 5-7 cm in size, respectively), which could attach to the mulch net and Ruzi grass and grow. In contrast, eight of the introduced species did not survive due to a difficulty in restoration related to a poor natural regeneration due to limited seed dispersal. Furthermore, the densely distributed Ruzi grass with an approximate height of 60-100 cm and fast growing produces a large number of seeds and can grow in soil with low fertility, which can outcompete these species. Therefore, it is necessary to weed some of the Ruzi grass to allow the seedlings to get sufficient sunlight and ensure their growth in the area.

The 5YRA plot was characterized by benches or steps situated farthest away from the edge of the natural forest. This area had *Leucaena leucocephala* (Lam.) de Wit. distributed widely in the area. Species found in the 5YRA plot were those that survived in the 13YRA and 10 YRA plots, in addition to some introduced pioneer species.

The analysis indicated that the 5YRA plot had the highest number of species. This was due to the highest number of species (37 species) introduced in the plot. During the survey, 22 species were recorded, with 20 introduced species and two naturally occurring species. In contrast, the 5YRA plot also had the highest number of species unable to survive (17 species). The high number of such species could be due to the presence of the invasive species *L. leucocephala*, which prevents colonization of the seedling of endemic species. This finding is consistent with a study of Marod *et al*. [16] on plant community succession after planting *L. leucocephala* for rehabilitation. Marod *et al.* [16] indicated that forest restoration through the planting of *L. leucocephala* limited the growth of seedlings and saplings of the indigenous species. Therefore, it is necessary to thin down the population of *L. leucocephala* in the 5YRA plot to allow other seedlings and saplings to grow uniformly.

Moreover, the low number of naturally occurring species in the 5YRA plot could be explained by the location of the plot being further away from the natural forest leading to a lower seed dispersion from the natural forest. Therefore, only two naturally occurring species were found. For a more significant number of endemic species to occupy the 5YRA plot, it might require the vegetation in the 13YRA and 10YRA plots to grow and reproduce. The trees would then be able to disperse a sufficient number of seeds to the 5YRA plot. Once the seeds colonize and grow into canopy trees in the 5YRA plot, the local plants can germinate, grow under the canopy, and further distribute their seeds to other rehabilitation areas.

The analysis of Importance Value Index demonstrated that that the pioneer spices remained the dominant species (Table II). Common species in all the areas were *Z. dongnaiensis*, *P macrocarpus*, *A lebbek*, and *A. indica*. It can be implied that these species found in multiple sites/plots had the ability to grow efficiently in various conditions [17]. In case of this study, these four species could effectively grow on the flat areas, slopes, and bench areas of the former limestone mine. However, each of these species grew differently in each area. In other words, *Z. dongnaiensis*, *P. macrocarpus*, and *A. indica* grew best on the slopes, followed by flat land and bench area, respectively, while *A. lebbek* grew best on the flat land, followed by bench area and slopes, respectively.

The assessment of the Species Diversity Index indicated that the 13YRA plot had the lowest value despite being situated near a natural forest. In contrast, the 5YRA plot had the highest Species Diversity Index even though it was located farthest from the natural forest. This could be due to the 5YRA plot having the highest number of initially introduced species. This finding was inconsistent with the study by Kongdam *et al.* [18], which reported that the edge of the forest, which connected to a dry evergreen forest, had a high value on Species Diversity Index (3.51), indicating that the endemic species had started to colonize and disperse in the shaded area of the open canopy under high light intensity.

When comparing the similarity between plants in the limestone forest plot and the 13YRA, 10YRA, and 5YRA plots, it was found that trees had the highest Similarity Index of 5.13%, 5.41%, and 9.52% in 13YRA, 10YRA, and 5YRA plots, respectively, followed by seedlings in the 10YRA plot (25.00%) and saplings in the 10YRA plot (12.50%). There was no similarity between saplings in the 13YRA and 5YRA plots and the limestone forest (Table III).

The Similarity Index evaluated in this study was lower than that reported by Marod *et al*. [19] on the characteristics of the forest community structure and succession of seedlings in the rehabilitation plots at Wang Nam Khiao Forestry Student Training and Research Station, Nakhon Ratchasima Province. Kongdam *et al*. [18] reported that the Similarity Index of trees and saplings between dry evergreen forests and plots under rehabilitation for 4, 6, 12, and 14 years were 42.55%, 38.38%, 40.00%, and 55.86%, respectively. Furthermore, Similarity Indices of the seedlings were 12.90%, 5.56%, 7.69%, and 15.79%, respectively. This suggests that the succession of endemic species in the rehabilitation plots of the present study was slow due to various limiting factors in the areas under restoration areas due to prior usage as a limestone quarry. Soil compaction made it hard for roots to penetrate and expand, low soil fertility, and high temperature increased the difficulty for the endemic species to colonize in such environmental conditions successfully. This is consistent with [17], who suggested that limestone mining affected the limestone forest's environmental conditions, resulting in difficulty for plants to reproduce. Furthermore, this recent finding indicated that the limestone quarry contributed to changes in plant community structure and environmental parameters, particularly soil compaction; and made the natural restoration of plants in such forests, prior used for mining, more complex.

The results from this survey can be used as a database during the decision-making processes related to rehabilitation. The following steps can be taken: 1) if the plantation area has a slope, the area should be adjusted by creating benches or steps to prevent soil erosion; 2) dominant species found in the rehabilitation plots should be used as pioneer species. These include *A. lebbek*, *Z. dongnaiensis*, *A. xylocarpa*, *P. pterocarpum*, and *C. pulcherrima*. In particular, *A. lebbek*, *Z. dongnaiensis*, *P. macrocarpus*, and *A. indica* were found to be very successful in restoration; 3) if there is a dense ground cover vegetation (such as Ruzi grass), it should be thinned to reduce the competition for light and nutrients between the ground cover and seedlings; 4) endemic species such as *H. ilicifolius*, *H. integrifolia*, *D. mollis*, *V. limonifolia*, and *A. glaucum*, can be introduced and planted in the understory f the pioneer species; and 5) once there is colonization and succession of plant community in the restoration plots of the quarry, the plant community will attract birds and animals to help with a successful dispersal of seeds. The faster the colonization and succession of the plant community, the quicker the animals will be attracted to utilize the area. This will increase the chances of the animals to carry seeds from nearby forests to the rehabilitated area, furthering the restoration process. In addition to seed dispersal by animals, insect eaters, nectar suckers, and predators will also use the area, which will make the structure of the restored plots more complex, with a larger plant species composition, and quickly return it to the primitive forest conditions.

V. Conclusion

Plant community succession of rehabilitated plots prior used for limestone mining in the Saraburi Province was studied. It was found that each of the restored plots had different dominant species, such as *A. xylocarpa*, *P. pterocarpum*, and *C. pulcherrima*. In addition, common tree species were found in all the three plots including *Z. dongnaiensis*, *P. macrocarpus*, *A. lebbek*, and *A. indica*. Such species found in all the plots would lead to a successful restoration. In addition, they are pioneer species that can help improve the ecosystem conditions to suit the colonization of endemic species. Regarding the duration needed to transform the area to its primitive state, Similarity Index suggested that it will take some more time for the plant community to succession in the rehabilitated areas.

Furthermore, it is suggested that existing environmental conditions in the former mines should be adjusted before introducing pioneer species such as *Z. dongnaiensis*, *P. macrocarpus*. and *A. indica*. Once the area is suitable for colonization and growth of plants, indigenous species such as *H. ilicifolius*, *H. integrifolia*, *D. mollis*, *V. limonifolia*, and *A. glaucum* can be introduced to reduce the time needed for the plant community succession to its primitive state. In summary, the results of this study can be used as a database and implemented in the area management of Kaeng Khoi limestone mine or other such areas with degraded environmental conditions and similar conditions.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

WS, RM, ST, and RP conducted the research; RS collected and analyzed the data; WS and RP wrote the paper; all authors had approved the final version.

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References

[1] C. Sansupa, W. Purahong, T. Wubet, P. Tiansawat, W. Pathom-Aree, N. Teaumroong, P. Chantawannakul, F. Buscot, S. Elliott, and T. Disayathanoowat, "Soil bacterial communities and their associated functions for forest restoration on a limestone mine in northern Thailand," *PLoS ONE*, vol. 16, no. 4, pp. 1–19, 2021.

[2] M. Pla-ard, W. Hoonheng, B. Kaewdee, T. Panganta, K. Charaspet, N. Khoiesri, P. Paansri, P. Kanka, Y. Chanachai, J. Thongbanthum, P. Bangthong, and R. Sukmasuang, "Abundance, diversity and daily activity of terrestrial mammal and bird species in disturbed and undisturbed limestone habitats using camera trapping, Central Thailand," *Biodiversitas*, vol. 22, no. 8, pp. 3620–3631, 2021.

[3] S. Pumjan, T. T. Long, H. H. Lo, and E. Park, "Deep well injection for the waste brine disposal solution of potash mining in Northeastern Thailand," *J. Environ. Manag.*, vol. 311, pp. 1–11, 2022.

[4] M. Lohbeck, L. Poorter, H. Paz, L. Pla, V. Breugel, M. Mart ńez-Ramos, and F. Bongers, "Functional diversity changes during tropical forest succession," *Perspectives in Plant Ecology, Evolution and Systematics*, vol. 14, no. 2, pp. 89–96. 2012.

[5] W. Suanpaga and W. Suanpaga, "Relationships of vegetation indices and biomass of mangrove forest plantation in Thailand," *Int. J. Environ. Sci. Development*, vol. 10, no. 3, pp. 86–90, 2019.

[6] J. Wongprom, "Growth performance of Dipterocarp species planted on abandoned mining area in Southern, Thailand," *Biodiversitas*, vol. 27, no. 2, pp. 115–124, 2020.

[7] J. Wongprom, R. Poolsiri, S. Diloksumpun, and C. Ngernsaengsaruay, "Soil properties and tree composition in a 27-year-old *Acacia mangium* Willd. Plantatin on abandoned mining area at Phanggna Forestry Research Station," *Biodiversitas*, vol. 27, no. 2, pp. 125–133, 2020.

[8] Y. Oo, W. Suanpaga, and P. Meunpong, "Assessment of forest degradation condition in Natmataung National Park Watershed, Myanmar," *Biodiversitas*, vol. 22, no. 3, pp. 1354–1362, 2021.

[9] P. Pattanasak, W. Suanpaga, N. Tangtham and W. Suanpaga, "Estimating above ground biomass of *Fraxinus griffithii* C. B. Clarke using remotely sensed data in royal project area, Chiang Mai, Thailand," *International Journal of Geoinformatics*, vol. 13, no. 4, pp. 57–64, 2017.

[10] The Siam Cement (Kaeng Khoi) Co., Ltd., *Quarry Rehabilitation*, Amarin Printing and Publishing Public Co., Ltd., Bangkok, 2017.

[11] C. E. Shannon, "Mathematical theory of communication," *Bell Syst. Tech. J.*, vol. 27, pp. 379–423, 1948

[12] T. Sorrensen, "A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons," *Biologiske Skrifter*, vol. 5, pp. 1–34, 1948.

[13] Forestry Research Center, The study on plant community 5 reference samples at Limestone Quarry, The Siam Cement (Kaeng Khoi) Co., Ltd., Faculty of Forestry, Kasetsart University, Bangkok, 2015.

[14] L. Asanok, R. Taweesuk, and N. Papakjan, "Woody species colonization along edge-interior gradients of deciduous forest remnants

in the Mae Khum Mee Watershed, Northern Thailand," *Int. J. For. Research*, vol 2020, pp. 1-13, 2020.

[15] L. Asanok and D. Marod, "Environmental factors influencing tree species regeneration in different forest stands growing on a limestone hill in Phrae Province, Northern Thailand," *J. For. Environ. Sci*., vol. 32, no. 3, pp. 237–252, 2016.

[16] D. Marod, P. Duengkae, U. Kutintara, S. Sungkaew, C. Wachrinrat, L. Asanok, and N. Klomwattanakul, "The influences of an invasive plant species (*Leucaena leucocephala*) on tree regeneration in Khao Phuluang Forest, Northeastern Thailand," *Kasetsart J. (Nat. Sci.),* vol. 46, pp. 39–50, 2012.

[17] L. Asanok, D. Marod, P. Duengkae, U. Pranmongkol, H. Kurokawa, M. Aiba, M. Katabuchi, and T. Nakashizuka, "Relationships between functional traits and the ability of forest tree species to reestablish in secondary forest and enrichment plantations in the uplands of northern Thailand," *For. Ecol. Manag*., vol. 296, pp. 9–23, 2013.

[18] P. Kongdam, S. Pimprasit, C. Vacharinrat, and D. Marod, "Forest structure and species composition in restoration by teak plantation at Jedkhod-Pongkhonsao natural study and ecotourism center, Kheang Khoi district, Saraburi provinc," *Thai Journal of Forestry*, vol. 35, no. 1, pp. 11–23, 2016.

[19] D. Marod, W. Phumphuanga, and C. Wachrinrat, "Effect of environmental gradients on tree distribution in lowland dry evergreen forest, northeastern Thailand," *Agr. Nat. Resour*., vol. 55, pp. 795–805, 2021.