

Research Article

Plant Community Structure and Carbon Sequestration of the Forest Restoration Areas at Kamnoetvidya Science Academy

Worawut Ngampiboonwet ^a, Karun Chaivanich ^b, Praphaiphon Kewkasem ^c, Amnuayvit Thitibordin ^c
 and Yutthana Thoenglom ^{a*}

^a Program in Agroforestry, Maejo University Phare Campus, Phare 54140, Thailand.

^b Department of Ordnance Engineering, Academic Division, Chulachomklao Royal Military Academy, Nakhonnayok 26001, Thailand.

^c Kamnoetvidya Science Academy, Rayong 21210, Thailand.

ABSTRACT

Article history:

Received: 2026-02-12

Revised: 2026-08-03

Accepted: 2026-08-06

Keywords:

Plant community structure;
 Forest restoration;
 Carbon sequestration;
 Biodiversity

This study evaluated the plant community structure, species diversity, and carbon sequestration potential of two distinct forest restoration models at Kamnoetvidya Science Academy, Rayong Province, Thailand. Two silvicultural approaches were observed: (1) Rubber–Palm Intercropping Plots (RPP) and (2) Mixed-Orchard Plots (OP). Vegetation data were collected from 20 x 50 m sample plots in each restoration approach, with each plot subdivided into ten 10 x 10 m subplots, to determine species composition, canopy architecture, and the Importance Value Index (IVI). Biodiversity was quantified using the Shannon–Wiener Index, while biomass and carbon stocks were estimated via established allometric equations. The results revealed higher taxonomic richness in OP (36 species) compared to RPP (25 species), with OP exhibiting higher diversity and evenness indices. Phytosociological analysis identified *Hevea brasiliensis* as the sole dominant species in RPP, whereas OP displayed a co-dominance of various fruit and indigenous forest species. Despite differences in composition, total carbon stocks were comparable between the two systems, with RPP yielding 45.59 tC/ha and OP yielding 46.23 tC/ha. Carbon distribution was highly concentrated in rubber trees within RPP, while OP exhibited a more heterogeneous distribution across multiple taxa. These findings demonstrate that both integrated agricultural models effectively enhance biodiversity and structural complexity while providing substantial carbon sinks. Consequently, RPP and OP represent viable strategies for rehabilitating degraded agricultural landscapes, contributing to both sustainable land management and global climate change mitigation efforts.

© 2026 Ngampiboonwet, W., Chaivanich, K., Kewkasem, P., Thitibordin, A. and Thoenglom, Y. Recent Science and Technology published by Rajamangala University of Technology Srivijaya

1. Introduction

Climate change represents a profound global challenge, posing enduring threats to ecological systems, economic stability, and human well-being. This phenomenon is largely driven by increased concentrations of greenhouse gases, most notably CO₂, resulting from human activities such as fossil fuel combustion, transportation, and industrial processes. Moreover, the loss of forest cover due to land-use change and deforestation reduces natural carbon sequestration, further exacerbating global warming and climatic instability.

Woody plant and forests ecosystems play a pivotal role as natural carbon sinks, sequestering atmospheric carbon through photosynthesis and storing it within both aboveground and belowground biomass. Carbon stocks held within vegetation and soil are critical components of the ecosystem's carbon balance, governed by biological processes such as plant growth, autotrophic and heterotrophic respiration, and organic matter decomposition (Intergovernmental Panel on Climate Change, 2006). Furthermore, the carbon sequestration potential of forested and restored areas is contingent upon species composition, stand age, density, spacing, environmental

* Corresponding author.

E-mail address: yutthana.thoe@gmail.com

conditions, and specific silvicultural management practices (Thailand Greenhouse Gas Management Organization, 2016).

A critical factor driving the decline in forest cover and the disruption of carbon balance is land-use change, specifically the conversion of forests into agricultural land and infrastructure development. This process not only results in net forest loss but also leads to forest degradation, characterized by diminished plant community structures and impaired ecosystem functions. Degraded forest areas (resulting from intensive agriculture, land-use intensification, and inappropriate management practices) have thus become a primary target for contemporary reforestation and restoration efforts. These initiatives aim to restore ecosystem performance, enhance carbon sequestration capacity, and promote sustainable land utilization. Recently, forest restoration integrated with diversified land-use strategies, particularly agroforestry systems, which combine forest trees with commercial crops or trees, has been increasingly promoted. This approach simultaneously restores ecological functions and supports livelihoods (Intergovernmental Panel on Climate Change, 2022).

Restoration plantings on degraded lands have been widely recognized as an effective strategy for recovering forest ecosystem functions by improving vegetation structure, enhancing biodiversity, and restoring ecosystem services (da Rosa and Marques, 2022). Among various restoration approaches, agroforestry has received increasing attention because it integrates ecological restoration with sustainable livelihoods. This approach enables the recovery of forest ecosystem functions while simultaneously generating long-term economic benefits for local communities (Murniati *et al.*, 2022). The incorporation of multiple tree species within restoration systems also contributes to greater habitat heterogeneity and biodiversity, which are important for improving ecosystem resilience and supporting long-term ecosystem functioning (Murniati *et al.*, 2022; da Rosa and Marques, 2022). Successful forest restoration enhances biomass accumulation and carbon sequestration, contributing to climate-change mitigation and the recovery of degraded tropical landscapes (Koutika, 2022; Koch and Kaplan, 2022). These ecological and socio-economic benefits have been consistently demonstrated in recent empirical studies. For example, ecological restoration in the western Himalaya exhibited 66.4% greater woody plant species richness (125 species) and approximately 38% greater aboveground carbon stock (49.5 tC/ha) than the reference forest, demonstrating the effectiveness of restoration in promoting biodiversity conservation and biomass accumulation (Dangwal *et al.*, 2022). Similarly, agroforestry restoration of degraded land in the semi-arid tropics enhanced atmospheric CO₂ sequestration (7.9 – 30.2 tC/ha) and improved oxygen production, highlighting its contribution to climate-change mitigation (Siddesh *et al.*, 2025). Beyond ecological benefits, agroforestry-based restoration also provides tangible socio-

economic advantages. A case study in Gowa, Indonesia, showed that agroforestry systems contributed 26% of total household income, while coffee–clove agroforests generated the highest average annual income of IDR 43,017,192 (approximately 3,025 US dollars), demonstrating that agroforestry can simultaneously restore degraded landscapes, improve rural livelihoods, and support sustainable land management (Hasannudin *et al.*, 2022).

The ecological performance of forest restoration is not universal. Restoration outcomes are influenced by species composition, vegetation structure, environmental conditions, and management practices, indicating that different restoration models may vary considerably in their capacity to recover biodiversity and store carbon. Evaluating the ecological characteristics, biodiversity, and carbon sequestration potential of different restoration approaches under specific environmental conditions is therefore essential for identifying restoration strategies that are best suited to particular sites and management objectives. These context-appropriate restoration strategies can maximize ecosystem recovery and promote sustainable land management (da Rosa and Marques, 2022; Koch and Kaplan, 2022). The integration of rubber tree (*Hevea brasiliensis*) and oil palm (*Elaeis guineensis*) represents a prevalent land-use model across various regions of Eastern Thailand. As both are vital cash crops significantly contributing to the local economy, this system reflects continuous agricultural management oriented toward economic sustainability. In contrast, fruit tree-based systems are characterized by the co-cultivation of diverse fruit species alongside indigenous forest trees, resulting in high species richness and complex community structures. These systems represent agroforestry practices with multi-layered canopy structures and are recognized for their dual capacity to support economic livelihoods and facilitate ecological restoration (Siarudin *et al.*, 2021). Both rubber-oil palm integrated systems and diversified fruit tree systems serve as promising models for restoring degraded forest lands previously impacted by agricultural activities.

Kamnoetvidya Academy (KVIS), located in Pa Yup Nai Subdistrict, Wang Chan District, Rayong Province, is a senior high school established by the PTT Group as part of its core mission to operate non-profit corporate social responsibility (CSR) initiatives for sustainable development. Within this framework, KVIS has implemented forest restoration plantings since 2015, utilizing two distinct land-use models: a rubber-oil palm integrated system and a diversified fruit tree system. These sites offer a compelling opportunity to serve as case studies for assessing the potential of such land-use strategies in rehabilitating degraded forest lands, particularly within the context of educational institutions—an area of research that remains relatively limited in Thailand. Studying these areas will not only elucidate the effectiveness of these restoration approaches but also support the development of the site as

a learning center and a model for sustainable resource management that harmonizes forestry with agricultural utilization.

Empirical data on the restorative capacity of integrated land-use systems remain scarce. This research investigates the ecological structure and carbon sequestration potential of two distinct land-use models at Kamnoetvidya Academy: a rubber-oil palm integrated system and a diversified fruit tree system. The research objectives are to: (1) characterize plant community composition and structure; (2) analyze tree species diversity and its ecological importance; and (3) quantify biomass and carbon storage potential within these restoration areas. This study provides a data-driven foundation for rehabilitating degraded landscapes while maintaining economic viability, offering a scalable prototype for sustainable land management and carbon mitigation in both academic and agricultural sectors.

2. Materials and Methods

The study was conducted at the forest restoration and enrichment planting sites of Kamnoetvidya Academy (KVIS), located at 999 Moo 1, Pa Yup Nai Subdistrict, Wang Chan District, Rayong Province. The restoration project was initiated in 2015, comprising two distinct planting systems: 1) rubber–oil palm intercropping plots (RPP) and 2) orchard plots (OP).

Sampling plots were established within both land-use systems using a selective sampling approach to identify areas representative of the overall plant community (Kutintara, 1999). Both sites shared similar land-use history and management practices, allowing for an in-depth analysis of plant community structure and carbon sequestration potential within the specific local context. In each system, a 20 × 50 m (0.1 ha) sampling plot was established. The RPP plot was located at coordinates 13.00083° N, 101.44735° E, while the OP plot was situated at 12.9983° N, 101.44986° E. Each 0.1-ha plot was further subdivided into ten 10 × 10 m subplots for detailed surveying and data recording.

Data collection within the sample plots encompassed the following parameters: 1) Taxonomic identification and verification of arborescent species through photographic documentation and reference to 'Thai Plant Names' (Smitinand, 2014), 2) Diameter at Breast Height (DBH) measurements for all woody individuals, 3) Total tree height, 4) Vertical structure profiles to illustrate spatial distribution, and 5) Canopy cover assessment to evaluate the degree of foliage density and spatial occupancy.

The collected data were analyzed following the criteria established by Kutintara (1999), including density (D), dominance or basal area (Do), and frequency (F). These parameters were further used to calculate relative density (RD), relative dominance (RDo), relative frequency (RF), and the Importance Value Index (IVI). To assess biodiversity, the Shannon–Wiener Diversity Index (H') was calculated according to Magurran (1988), while species evenness (J') was derived following Pielou (1975). Aboveground biomass for woody species (AGB) was estimated using the

allometric equations of Ogawa *et al.* (1965). Specific biomass equations were applied for specialized taxa: Pearson *et al.* (2005) for palms and Hytönen *et al.* (2018) for rubber trees. The total carbon stock (CS) and total CO₂ sequestration (CO₂-seq) within tree biomass were calculated following the equations provided by the Intergovernmental Panel on Climate Change (2006). Finally, oxygen production (O₂-prod) was calculated from the estimated CS using the molecular weight ratio of oxygen to carbon (32/12), following Uttaruk *et al.* (2024).

3. Results and Discussion

This study was designed as a case-based ecological assessment, focusing on an in-depth analysis of plant community structure, species diversity, and carbon sequestration potential within specific forest restoration sites. Purposive sampling was employed to select plots that represent the distinct characteristics of each land-use system, rather than for the purpose of population-level statistical comparison. The findings are presented through descriptive and ecological analyses to reflect the unique potential and specific attributes of the study areas. These results are intended to characterize the studied sites and are not aimed at providing a representative generalization for all forest restoration areas at a regional or national scale.

3.1 Plant community composition and vertical structure of restored forest plantations at KVIS

Across the entire study area, a total of 47 tree species belonging to 38 genera and 24 families were identified. The family Fabaceae exhibited the highest taxonomic richness with 10 species, followed by Dipterocarpaceae (5 species) and Lythraceae (4 species) (Table 1).

When categorized by land-use system, the RPP contained 25 tree species from 21 genera and 16 families. Within this plot, Fabaceae was the most diverse family (5 species), followed by Dipterocarpaceae (4 species) and Lythraceae (3 species). In contrast, the OP exhibited higher floristic diversity, with 36 tree species across 30 genera and 21 families. Fabaceae remained the dominant family in OP with 7 species, followed by Lythraceae and Dipterocarpaceae (3 species each) (Table 1). The differences in floristic composition observed between the RPP and OP are likely associated with their contrasting restoration designs and management objectives. Similar patterns of biodiversity recovery have been reported among different forest restoration approaches, where restoration outcomes are influenced by restoration practices, previous land use, and local environmental conditions (Atkinson *et al.*, 2022; da Rosa and Marques, 2022). These findings further support the concept that the ecological characteristics of restored forests should be interpreted within the context of restoration objectives and site-specific conditions rather than expecting identical community structures across different restoration systems (da Rosa and Marques, 2022).

Table 1 Floristic diversity, taxonomic composition, and number of individuals of tree species in the RPP and OP systems at KVIS.

No.	Plant species	Family	No. in RPP	No. in OP
1	Ma-kha Mong (<i>Azelia xylocarpa</i> (Kurz) Craib)	Fabaceae	-	8
2	Sok Ra Ya (<i>Amherstia nobilis</i> Wall.)	Fabaceae	-	2
3	Chong-kho (<i>Bauhinia purpurea</i> L.)	Fabaceae	3	-
4	Thong Kwao (<i>Butea monosperma</i> (Lam.) Taub.	Fabaceae	-	4
5	Fang (<i>Caesalpinia sappan</i> L.)	Fabaceae	-	1
6	Ching-chan (<i>Dalbergia oliveri</i> Gamble ex Prain)	Fabaceae	5	-
7	Pha-yung (<i>Dalbergia cochinchinensis</i> Pierre)	Fabaceae	1	1
8	A-rang (<i>Peltophorum dasyrthachis</i> (Miq.) Kurz)	Fabaceae	6	8
9	Khi-lek Fa-rang (<i>Senna spectabilis</i> (DC.) H.S.Irwin & Barneby)	Fabaceae	5	-
10	Ma-kha Tae (<i>Sindora siamensis</i> Teijsm. ex Miq.)	Fabaceae	-	1
11	Yang Na (<i>Dipterocarpus alatus</i> Roxb. ex G. Don)	Dipterocarpaceae	3	-
12	Ta-khian Thong (<i>Hopea odorata</i> Roxb.)	Dipterocarpaceae	7	1
13	Pha-yom (<i>Shorea roxburghii</i> G.Don)	Dipterocarpaceae	8	1
14	Rang (<i>Shorea siamensis</i> Miq.)	Dipterocarpaceae	3	-
15	Khiam Kha-nong (<i>Shorea henryana</i> Pierre)	Dipterocarpaceae	-	1
16	Ta-baek Na (<i>Lagerstroemia floribunda</i> Jack)	Lythraceae	4	1
17	In-tha-nin (<i>Lagerstroemia macrocarpa</i> Wall. ex Kurz)	Lythraceae	2	-
18	In-tha-nin Nam (<i>Lagerstroemia speciosa</i> (L.) Pers.)	Lythraceae	1	1
19	In-tha-ra-chit (<i>Lagerstroemia loudonii</i> Teijsm. & Binn.)	Lythraceae	-	1
20	Muang Lueat (<i>Knema angustifolia</i> (Roxb.) Warb.)	Myristicaceae	2	4
21	Wan Na (<i>Syzygium cumini</i> (L.) Skeels)	Myrtaceae	-	5
22	Chom-phu Nam-dok-mai (<i>Syzygium jambos</i> (L.) Alston)	Myrtaceae	2	-
23	Pip (<i>Radernachera ignea</i> (Kurz) Steenis)	Bignoniaceae	1	1
24	Khae Na (<i>Dolichandrone serrulata</i> (Wall. ex DC.) Seem.)	Bignoniaceae	-	1
25	Bun-nak (<i>Mesua ferrea</i> L.)	Calophyllaceae	-	2
26	Sa-ra-phi (<i>Mammea siamensis</i> (Miq.) T.Anderson)	Calophyllaceae	-	2
27	Mang-khut (<i>Garcinia mangostana</i> Linn.)	Clusiaceae	-	1
28	Cha-muang (<i>Garcinia cowa</i> Roxb. ex Choisy)	Clusiaceae	-	2
29	Ma-kham Pom (<i>Phyllanthus emblica</i> L.)	Phyllanthaceae	-	3
30	Ma-ka Ton (<i>Bridelia ovata</i> Decne.)	Phyllanthaceae	1	-
31	Ma-kluea (<i>Diospyros mollis</i> Griff.)	Ebenaceae	-	9
32	Ma-rid (<i>Diospyros discolor</i> Willd.)	Ebenaceae	-	3
33	Ma-muang (<i>Mangifera indica</i> L.)	Anacardiaceae	-	4
34	Lam-duan (<i>Mitrephora wangii</i> Hu)	Annonaceae	-	2
35	Tin-pet Nam (<i>Cerbera odollam</i> Gaertn.)	Apocynaceae	4	-
36	Palm (<i>Elaeis guineensis</i> Jacq.)	Arecaceae	1	
37	Kha-nun (<i>Artocarpus heterophyllus</i> Lam.)	Moraceae	1	2
38	Yang Pa-ra (<i>Hevea brasiliensis</i> (Willd. ex A.Juss.) Müll.Arg.)	Euphorbiaceae	28	-
39	Kan-krao (<i>Fagraea fragrans</i> Roxb.)	Gentianaceae	4	1
40	Tio Khon (<i>Cratogeomys formosum</i> (Jack) Benth. & Hook.f. ex Dyer)	Hypericaceae	4	6
41	Sak (<i>Tectona grandis</i> L. f.)	Lamiaceae	1	1
42	Op-choei (<i>Cinnamomum verum</i> J.Presl)	Lauraceae	-	2
43	Cham-pi (<i>Magnolia baillonii</i> Pierre)	Magnoliaceae	-	1
44	Ma-hat (<i>Artocarpus lacucha</i> Roxb. ex Buch.-Ham.)	Moraceae	-	7
45	Ma-fueang (<i>Averrhoa carambola</i> L.)	Oxalidaceae	8	10
46	Ket (<i>Manilkara hexandra</i> (Roxb.) Dubard)	Sapotaceae	-	5
47	Krit-sa-na (<i>Aquilaria crassna</i> Pierre ex Lec.)	Thymelaeaceae	1	1
Total		24	106	106

The plant community in the RPP system exhibited high tree density and diversity, primarily dominated by species in the upper canopy layers. This structure resulted in a canopy cover of 86.40%. The vertical structure of this restored forest plantation can be categorized into four distinct strata--1) emergent layer: comprising the tallest trees within the community, these individuals extend above the main canopy with a relatively sparse distribution. The height in this layer ranges from approximately 14.60 to 18.00 m, key species found in this stratum include Yang Pa-ra, Pha-yom, A-rang, and Ma-Ka Ton. 2) Top canopy: with a height range of 11.60 to 14.75 m, this layer forms a relatively dense canopy cover. Dominant species identified in this stratum, include Kan-krao, Rang, Tio Khon, and Khi-lek Fa-rang. 3) Secondary canopy: This layer, ranging from 8.26 to 11.50 m in height, consists of numerous trees distributed throughout. Species found in this layer include Ching-chan, Chong-kho, Pip, and Kha-nun, and 4) lower canopy: reaching heights of 5.00-8.25 m, this stratum comprises medium-sized trees, some of which are younger individuals of species also found in the upper layers; representative species in this layer include Ma-fueang and Chom-phu Nam-dok-mai (Figure 1).

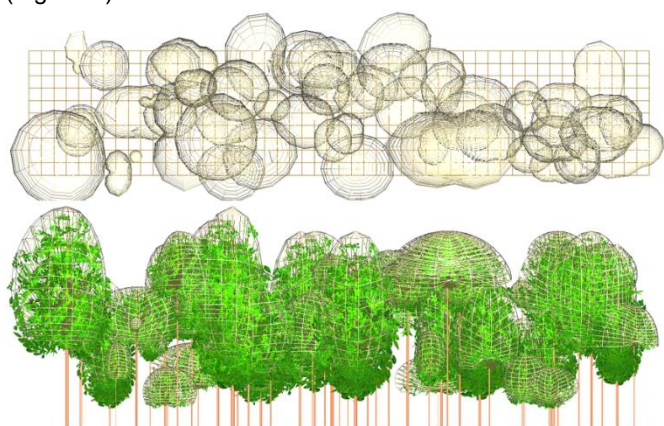


Figure 1 Vertical structure and canopy of the restored forest plantation by RPP. The vertical structure of the forest was visualized using the Sexl-FS software.

The plant community in the OP system was characterized by high tree density and diversity, primarily dominated by species in the upper canopy. This resulted in a canopy cover of 87%. Similar to the RPP, the vertical structure of this restored forest plantation is categorized into four distinct strata -- 1) emergent layer: trees in this highest stratum reach heights ranging from 17.10 to 21.50 m, representative species, include Ma-hat, Cha-muang, and Kha-nun. 2) Top canopy: with a height range of 12.50 to 17.00 m, this layer forms a relatively dense canopy cover, dominant species identified in this stratum include A-rang, Ma-kham Pom, Krit-sa-na, Ma-kha Mong, Kan-krao, Ta-khian Thong, Cham-pi, and Ma-kha Tae. 3) Secondary canopy: this layer, ranging from 8.10-12.50 meters in height, consists of numerous trees distributed throughout, key species include Wan Na, Tio Khon, Ma-kluea, In-tha-ra-chit, and Ma-rid, and 4) lower

canopy: reaching heights of 3.50-8.00 m, this stratum comprises medium-sized trees, some of which are younger individuals of species also found in the upper layers, species found in this layer include Ma-fueang, Op-choei, Khiam Kha-nong, Ket, Mang-khut, Thong Kwao, Khae Na, Fang, Bun-nak, and Lam-duan (Figure 2).

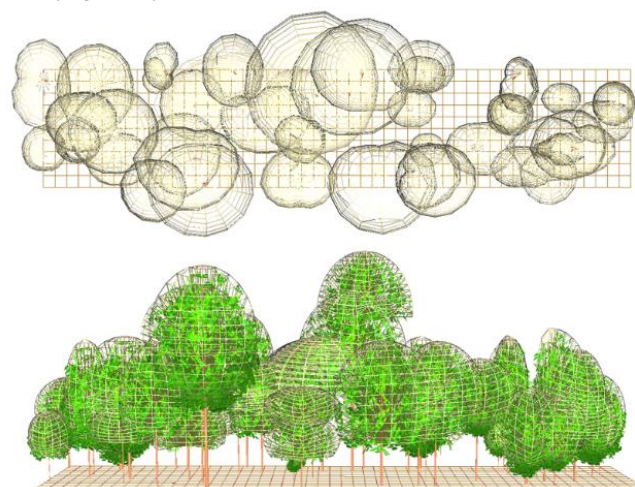


Figure 2 Vertical structure and canopy of the restored forest plantation by OP. The vertical structure of the forest was visualized using the Sexl-FS software.

The findings of this study demonstrate that both forest restoration systems have developed distinct vertical structures consisting of the four strata described above since their establishment in 2015. Vertical stratification reflects efficient utilization of growing space and is recognized as a key characteristic of developing forest ecosystems because it increases habitat heterogeneity and facilitates the gradual recovery of ecosystem functions (Marod and Kutintara, 2009). The vertical stratification observed in both restoration systems at KVIS is consistent with findings from young subtropical plantations, where greater tree species richness was associated with increased vertical heterogeneity and stand structural complexity over time (Perles-Garcia *et al.*, 2021). In addition to increasing habitat heterogeneity, the presence of diverse tree species across multiple canopy layers is associated with greater structural complexity and facilitates the distribution of biomass and carbon storage among tree species. These structural attributes are essential for the long-term stability of restored forest systems and support the recovery of plant community structures and ecological functions within an agricultural context. Overall, these findings suggest that both restoration systems at KVIS are progressing toward increasingly complex forest stands while maintaining their respective planting compositions and restoration objectives.

3.2 Tree species diversity and ecological significance of plant species within the forest restoration areas at KVIS

The survey of tree species within the RPP identified 25 species from 21 genera and 16 families. Recorded ecological parameters included a D of 1,060 stems/ha, a Do of 20.75

m²/ha, an H' of 2.75, and a J' of 0.85. In contrast, the OP contained 36 species from 30 genera and 21 families, with a D of 1,060 stems/ha, a Do of 22.78 m²/ha, an H' of 3.34, and a J' of 0.93. Both restoration systems exhibited relatively high tree species diversity. The higher H' value in the OP reflects greater tree species diversity than in the RPP. This difference is attributable to previous land-use characteristics; the OP was established using a multi-species planting approach from the outset, creating an environment conducive to the establishment and growth of diverse taxa. Conversely, the RPP is characterized by the presence of pre-existing economic trees, particularly Yang Pa-ra, resulting in a community structure influenced by the rubber canopy. The relatively high H' values observed in both restoration systems are comparable to those reported in recent tropical forest restoration studies. Keller *et al.* (2023), for example, reported H' of 3.61 in actively restored tropical rainforest and 3.21 in naturally regenerating forest in Malaysian Borneo. The findings of Keller *et al.* (2023) indicate that both restoration approaches were capable of maintaining relatively high tree species diversity, although active restoration exhibited significantly greater diversity. However, direct numerical comparisons should be interpreted cautiously because diversity indices are influenced by stand age, restoration history, species composition, sampling design, and local environmental conditions. The H' values reported in the present study provide ecological information on the community organization and biodiversity characteristics of each restoration system under the specific restoration context of KVIS. Thus, these indices should be interpreted within the restoration objectives and site conditions of the study area rather than as direct measures for comparison with other restoration sites.

The H' and J' values should be interpreted together with species composition and dominance patterns because no single diversity index can fully represent the ecological condition of a restored forest. Long-term studies of tropical forest regeneration have shown that different biodiversity components, including species richness, diversity, and evenness, may follow distinct recovery trajectories throughout the restoration process (Chazdon *et al.*, 2023; Zhou *et al.*, 2023). Rosenfield *et al.* (2023) further emphasized that ecological integrity in recovering tropical forests should be evaluated using multiple indicators, including species composition, vegetation structure, regeneration, and ecosystem functioning, rather than relying on a single diversity metric. Interpreting the H' and J' values together with the observed community composition and species dominance indicates that the RPP and OP systems at KVIS represent distinct ecological pathways of forest restoration. Although the two systems differ in community organization, each reflects its respective planting design and restoration objectives while contributing to biodiversity enhancement and forest restoration at KVIS. The present survey represents the ecological condition of the sites at a single point in time.

Repeated inventories would enable future studies to evaluate how species richness, diversity, evenness, and community composition change as restoration progresses.

Analysis of the RPP revealed that the five species with the highest RD were Yang Pa-ra (26.42), Pha-yom (7.55), Ma-fueang (7.55), Ta-khian Thong (6.60), and A-rang (5.66). The top five species for RDo were Yang Pa-ra (42.79), Palm (10.83), Pha-yom (6.92), Ta-khian Thong (6.29), and A-rang (5.44). The five species with the highest IVI values were Yang Pa-ra (80.16), Pha-yom (21.32), Ta-khian Thong (21.12), A-rang (19.32), and Ma-fueang (15.79) (Table 2). These results indicate that the plant community structure in the RPP is distinctly dominated by Yang Pa-ra, as reflected by its substantially higher RD, RDo, and IVI compared to other tree species. This dominance is consistent with the land-use history and management objective of maintaining a pre-existing economic tree as the principal component of the system, and its high IVI reflects the continuing structural influence of the original rubber plantation within the restored community. The IVI analysis complements the diversity indices by identifying the species that contribute most strongly to the structural organization of the restored community. Unlike the H' and J' indices, which describe overall community diversity, IVI identifies the individual species that exert the greatest influence on community structure. The consistently high RD, RF, and RDo of Yang Pa-ra resulted in the highest IVI, indicating that it is the principal species shaping the community structure of the RPP. A comparable pattern was reported by Sukprung *et al.* (2021), who evaluated the phytosociological structure of mixed deciduous forests established through active restoration planting approximately 15 and 30 years earlier in northern Thailand. Their restoration approach promoted the establishment of native tree communities. However, only a limited number of species attained markedly higher IVI values than the remaining species, indicating that community structure was still strongly influenced by a few dominant taxa during stand development. Likewise, Yang Pa-ra exhibited substantially higher RD, RF, RDo, and IVI than the other tree species in the present study. However, unlike the restoration sites investigated by Sukprung *et al.* (2021), where species dominance reflected the natural development of restored native forest communities, the dominance of Yang Pa-ra at KVIS primarily resulted from the restoration strategy of retaining the pre-existing rubber plantation while enriching the stand with native forest species. This dominance should not be interpreted as evidence of limited restoration performance. Rosenfield *et al.* (2023) emphasized that ecological integrity should be evaluated using multiple ecological indicators, including species composition, vegetation structure, regeneration, and ecosystem functioning, rather than relying on a single structural characteristic. The relatively high IVI values of several restored forest species, particularly Pha-yom, Ta-khian Thong, and A-rang (Table 2), indicate that these species

have established important structural roles within the rubber-dominated community. Their presence suggests that the RPP supports the coexistence of restored forest species while

retaining Yang Pa-ra as its principal economic and structural component.

Table 2 Ecological parameters of tree species within the RPP system at KVIS.

No.	Vernacular name	D	Do	F	RD	RDo	RF	IVI
1	Yang Pa-ra	280	8.88	80	26.42	42.79	10.96	80.16
2	Pha-yom	80	1.44	50	7.55	6.92	6.85	21.32
3	Ta-khian Thong	70	1.31	60	6.60	6.29	8.22	21.12
4	A-rang	60	1.13	60	5.66	5.44	8.22	19.32
5	Ma-fueang	80	0.57	40	7.55	2.76	5.48	15.79
6	Ching-chan	50	0.71	40	4.72	3.43	5.48	13.62
7	Khi-lek Fa-rang	50	0.59	40	4.72	2.84	5.48	13.04
8	Tin-pet Nam	40	0.20	40	3.77	0.97	5.48	10.22
9	Tio Khon	40	0.48	30	3.77	2.32	4.11	10.20
10	Kan-krao	40	0.36	30	3.77	1.76	4.11	9.64
11	Ta-baek Na	40	0.36	30	3.77	1.74	4.11	9.62
12	Yang Na	30	0.55	30	2.83	2.63	4.11	9.57
13	Chong-kho	30	0.21	30	2.83	1.01	4.11	7.95
14	Rang	30	0.15	30	2.83	0.73	4.11	7.67
15	In-tha-nin	20	0.15	20	1.89	0.73	2.74	5.36
16	Chom-phu Nam-dok-mai	20	0.14	20	1.89	0.66	2.74	5.29
17	Muang Lueat	20	0.13	20	1.89	0.60	2.74	5.23
18	Palm	10	2.25	10	0.94	10.83	1.37	13.14
19	Ma-ka Ton	10	0.41	10	0.94	1.99	1.37	4.30
20	Krit-sa-na	10	0.39	10	0.94	1.87	1.37	4.18
21	Pha-yung	10	0.11	10	0.94	0.53	1.37	2.84
22	Sak	10	0.08	10	0.94	0.38	1.37	2.69
23	In-tha-nin Nam	10	0.06	10	0.94	0.31	1.37	2.62
24	Pip	10	0.06	10	0.94	0.28	1.37	2.60
25	Kha-nun	10	0.04	10	0.94	0.17	1.37	2.49
Total		1,060	20.75	730	100.00	100.00	100.00	300.00

In the OP, the survey revealed that the five tree species with the highest RD were Ma-fueang (9.43), Ma-kluea (8.49), A-rang (7.55), Ma-kha Mong (7.55), and Ma-hat (6.60). Regarding RDo, the top five species were Ma-muang (21.77), Ma-hat (9.08), Kha-nun (8.26), Wan Na (6.86), and Ma-fueang (6.28). The five species with the highest IVI values were Ma-muang (30.42), Ma-fueang (24.25), Ma-hat (21.78), Ma-kha Mong (19.54), and Ma-kluea (18.89) (Table 3). These analytical results indicate that the plant community in the OP is not dominated by a single species. This reflects a diverse and complex community structure within the forest restoration area of the OP system at KVIS. Unlike the RPP, no single tree species overwhelmingly dominated the IVI ranking in the OP. Instead, the relatively similar IVI values among Ma-muang, Ma-fueang, Ma-hat, Ma-kha Mong, and Ma-kluea indicate that structural importance is distributed among several tree species rather than concentrated in a single dominant species. Some active mixed-species forest restoration studies have reported that one or a few fast-growing or

environmentally well-adapted species attain disproportionately high IVI values during stand development because they establish rapidly and become the principal structural components of the developing forest (Nero, 2021; Silva Junior *et al.*, 2026). These dominant species can strongly influence the subsequent development of the regenerating community. In contrast, the OP at KVIS exhibited relatively similar IVI values among its dominant tree species, indicating that no single planted species overwhelmingly controlled community structure. This pattern may reflect the multispecies planting design adopted during restoration, which enabled several tree species with different growth characteristics and ecological roles to establish simultaneously and contribute to stand development. This interpretation is also consistent with the higher H' and J' values observed in the OP, suggesting that the multispecies planting approach successfully promoted the development of a structurally complex and diverse forest community.

Table 3 Ecological parameters of tree species within the OP system at KVIS.

No.	Vernacular name	D	Do	F	RD	RDo	RF	IVI
1	Ma-fueang	100	1.43	70	9.43	6.28	8.54	24.25
2	Ma-kluea	90	0.98	50	8.49	4.30	6.10	18.89
3	Ma-hat	70	2.07	50	6.60	9.08	6.10	21.78
4	A-rang	80	1.31	40	7.55	5.74	4.88	18.17
5	Ma-kha Mong	80	1.07	60	7.55	4.68	7.32	19.54
6	Wan Na	50	1.56	40	4.72	6.86	4.88	16.46
7	Tio Khon	60	1.32	30	5.66	5.80	3.66	15.12
8	Ket	50	0.39	50	4.72	1.69	6.10	12.51
9	Ma-muang	40	4.96	40	3.77	21.77	4.88	30.42
10	Thong Kwao	40	0.51	30	3.77	2.23	3.66	9.67
11	Muang Lueat	40	0.40	40	3.77	1.74	4.88	10.39
12	Ma-kham Pom	30	0.78	30	2.83	3.43	3.66	9.92
13	Ma-rid	30	0.20	30	2.83	0.89	3.66	7.38
14	Kha-nun	20	1.88	20	1.89	8.26	2.44	12.58
15	Cha-muang	20	0.29	20	1.89	1.29	2.44	5.61
16	Sa-ra-phi	20	0.14	10	1.89	0.62	1.22	3.72
17	Sok Ra Ya	20	0.09	20	1.89	0.39	2.44	4.72
18	Bun-nak	20	0.09	10	1.89	0.39	1.22	3.49
19	Lam-duan	20	0.08	10	1.89	0.37	1.22	3.48
20	Op-choei	20	0.07	10	1.89	0.32	1.22	3.42
21	Ma-kha Tae	10	0.56	10	0.94	2.44	1.22	4.60
22	Krit-sa-na	10	0.42	10	0.94	1.86	1.22	4.03
23	Ta-khian Thong	10	0.41	10	0.94	1.81	1.22	3.98
24	Fang	10	0.35	10	0.94	1.54	1.22	3.71
25	Pip	10	0.24	10	0.94	1.06	1.22	3.22
26	Cham-pi	10	0.22	10	0.94	0.98	1.22	3.14
27	Kan-krao	10	0.19	10	0.94	0.84	1.22	3.00
28	Pha-yom	10	0.16	10	0.94	0.71	1.22	2.88
29	In-tha-nin Nam	10	0.15	10	0.94	0.68	1.22	2.84
30	In-tha-ra-chit	10	0.14	10	0.94	0.61	1.22	2.77
31	Ta-baek Na	10	0.09	10	0.94	0.39	1.22	2.56
32	Mang-khut	10	0.07	10	0.94	0.29	1.22	2.46
33	Khae Na	10	0.06	10	0.94	0.27	1.22	2.43
34	Pha-yung	10	0.04	10	0.94	0.19	1.22	2.36
35	Sak	10	0.02	10	0.94	0.10	1.22	2.26
36	Khiam Kha-nong	10	0.02	10	0.94	0.08	1.22	2.24
Total		1,060	22.78	820	100.00	100.00	100.00	300.00

3.3 Aboveground biomass and carbon sequestration within the forest restoration areas at KVIS

The assessment of biomass and carbon sequestration in the RPP revealed a total AGB of 96.99 t/ha. The CS was estimated at 45.59 tC/ha, while the total CO_{2-seq} and O_{2-prod} were 167.15 tCO₂/ha and 121.56 tO₂/ha, respectively. The top five tree species contributing most significantly to these values were identical across all parameters: Yang Pa-ra, Pha-yom, Ta-khian Thong, A-rang, and Kan-krao (Table 4). The presence of diverse forest species across various canopy layers enhances structural complexity and supports the distribution of carbon sequestration at the species level (Magurran, 1988). However, this study found

that Yang Pa-ra served as the principal structural species in the RPP and contributed the greatest proportion of aboveground biomass and carbon storage. This is reflected by its consistently higher structural indicators, particularly Do and IVI (Table 2), together with its substantially greater AGB and CS than those of all other species (Table 4). The combined interpretation of IVI and CS indicates that the retained Yang Pa-ra trees continued to define both the community structure and aboveground carbon accumulation of the RPP. This pattern is attributable to the retention of mature Yang Pa-ra trees from the original plantation, which possessed larger stem diameters and basal areas, thereby contributing disproportionately to aboveground biomass

and carbon storage. These findings suggest that this restoration approach promotes carbon sequestration potential through carbon concentration, whereby a large proportion of ecosystem carbon is accumulated within a few structurally dominant tree species (Magurran, 1988). A comparable ecological pattern was reported by Pasion *et al.* (2021), who found a strong positive relationship between species dominance (IVI) and carbon density in a tropical forest, with most ecosystem carbon

concentrated in a relatively small number of dominant tree species. Their findings emphasized that structurally dominant species contributed disproportionately to ecosystem functioning through aboveground carbon storage, which is consistent with the dominant role of Yang Pa-ra observed in the present study. For O₂ production, it was calculated directly from carbon stock, so its distribution closely mirrored the patterns observed for carbon storage and CO₂ sequestration (Table 4).

Table 4 Aboveground biomass (AGB), carbon stock (CS), CO₂ sequestration (CO_{2-seq}), and O₂ production (O_{2-prod}) within the RPP system at KVIS.

No.	Vernacular name	AGB (t/ha)	CS (tC/ha)	CO _{2-seq} (tCO ₂ /ha)	O _{2-prod} (tO ₂ /ha)
1	Yang Pa-ra	47.12	22.15	81.21	59.06
2	Pha-yom	7.55	3.55	13.02	9.47
3	Ta-khian Thong	7.11	3.34	12.24	8.91
4	A-rang	5.92	2.78	10.21	7.43
5	Kan-krao	3.64	1.71	6.28	4.57
6	Ching-chan	3.39	1.59	5.84	4.25
7	Yang Na	3.03	1.42	5.22	3.79
8	Khi-lek Fa-rang	3.02	1.42	5.21	3.79
9	Tio Khon	2.55	1.20	4.39	3.19
10	Ma-ka Ton	2.40	1.13	4.14	3.01
11	Krit-sa-na	2.22	1.04	3.82	2.78
12	Ma-fueang	1.69	0.79	2.90	2.11
13	Ta-baek Na	1.54	0.72	2.66	1.93
14	Palm	0.91	0.43	1.57	1.14
15	Chong-kho	0.79	0.37	1.36	0.99
16	Rang	0.64	0.30	1.10	0.80
17	Pha-yung	0.61	0.28	1.04	0.76
18	Tin-pet Nam	0.60	0.28	1.03	0.75
19	In-tha-nin	0.50	0.24	0.86	0.63
20	Muang Lueat	0.47	0.22	0.82	0.60
21	Sak	0.35	0.16	0.60	0.44
22	Chom-phu Nam-dok-mai	0.34	0.16	0.59	0.43
23	In-tha-nin Nam	0.25	0.12	0.43	0.31
24	Pip	0.21	0.10	0.36	0.26
25	Kha-nun	0.13	0.06	0.23	0.16
Total		96.99	45.59	167.15	121.56

The study of the OP revealed a total AGB of 98.36 t/ha, with a total CS of 46.23 tC/ha. The overall CO_{2-seq} and O_{2-prod} were estimated at 169.50 tCO₂/ha and 123.28 tO₂/ha, respectively. The top five species contributing most significantly to these parameters were identical: Ma-muang, Ma-hat, Kha-nun, A-rang, and Wan Na (Table 5). However, the values of the dominant species (Ma-muang) differed only slightly from those of the second-ranked species (Ma-hat), followed by a gradual decline among the remaining dominant species (Table 5). This pattern contrasts markedly with that observed in the RPP, where Yang Pa-ra contributed disproportionately more biomass and carbon than all other species. These findings indicate that forest restoration using the OP system promotes carbon sequestration

through carbon distribution, whereby biomass and carbon are allocated across several co-dominant tree species rather than being concentrated in a single dominant species (Magurran, 1988). A similar ecological pattern has been reported in mixed-species forests, where greater species diversity promotes biomass accumulation and enhances ecosystem carbon storage through the collective contribution of multiple tree species rather than reliance on a single dominant species (Zhang *et al.*, 2026). Moreover, Ahmad *et al.* (2025) demonstrated that polyculture forests generally store more biomass carbon than less diverse stands, emphasizing that stand structure and species diversity together contribute to carbon-diversity conservation. These findings are consistent with the relatively balanced carbon

contributions observed among the dominant tree species in the OP, indicating that carbon storage resulted from the combined contribution of several co-dominant species rather than from a single structurally dominant taxon. The distribution of estimated O₂ production also closely followed the carbon storage pattern, with no single species overwhelmingly dominating O₂ production in the OP (Table 5). This pattern is consistent with the higher *H'*, *J'*, and relatively balanced IVI values observed in the OP (Tables 3 and 5), suggesting that species composition, community structure, and carbon storage developed

concurrently within the restored stand. The combined interpretation of diversity indices, IVI, and carbon storage indicates that multiple tree species contributed to both community structure and ecosystem functioning in the OP restoration system, supporting the concept of ecological integrity proposed by Rosenfield *et al.* (2023). In addition, forest communities in which biomass and carbon are distributed among multiple tree species may exhibit greater ecological stability than communities where biomass is concentrated within only a few dominant species (Magurran, 1988).

Table 5 Aboveground biomass (AGB), carbon stock (CS), CO₂ sequestration (CO_{2-seq}), and O₂ production (O_{2-prod}) within the OP system at KVIS.

No.	Vernacular name	AGB (t/ha)	CS (tC/ha)	CO _{2-seq} (tCO ₂ /ha)	O _{2-prod} (tO ₂ /ha)
1	Ma-muang	17.99	8.46	31.01	22.55
2	Ma-hat	12.44	5.85	21.44	15.59
3	Kha-nun	9.95	4.68	17.14	12.47
4	A-rang	6.87	3.23	11.85	8.61
5	Wan Na	6.50	3.05	11.20	8.15
6	Ma-kha Mong	5.11	2.40	8.81	6.41
7	Tio Khon	5.08	2.39	8.76	6.37
8	Ma-kluea	4.37	2.05	7.53	5.48
9	Ma-fueang	4.15	1.95	7.16	5.21
10	Ma-kham Pom	3.57	1.68	6.16	4.48
11	Ma-kha Tae	3.00	1.41	5.17	3.76
12	Krit-sa-na	2.33	1.09	4.01	2.92
13	Ta-khian Thong	2.06	0.97	3.55	2.58
14	Cha-muang	1.87	0.88	3.22	2.34
15	Thong Kwao	1.80	0.85	3.10	2.26
16	Cham-pi	1.40	0.66	2.41	1.75
17	Muang Lueat	1.38	0.65	2.39	1.73
18	Fang	1.11	0.52	1.91	1.39
19	Ket	1.05	0.49	1.81	1.32
20	Kan-krao	1.05	0.49	1.81	1.31
21	Ma-rid	0.72	0.34	1.24	0.90
22	Pip	0.69	0.33	1.19	0.87
23	In-tha-nin Nam	0.59	0.28	1.02	0.74
24	In-tha-ra-chit	0.59	0.28	1.01	0.74
25	Pha-yom	0.55	0.26	0.94	0.68
26	Sa-ra-phi	0.42	0.20	0.73	0.53
27	Ta-baek Na	0.33	0.15	0.56	0.41
28	Bun-nak	0.27	0.13	0.46	0.33
29	Lam-duan	0.26	0.12	0.46	0.33
30	Sok Ra Ya	0.20	0.10	0.35	0.26
31	Pha-yung	0.14	0.07	0.24	0.18
32	Op-choei	0.14	0.06	0.24	0.17
33	Khae Na	0.14	0.06	0.23	0.17
34	Mang-khut	0.13	0.06	0.23	0.17
35	Sak	0.05	0.03	0.09	0.07
36	Khiam Kha-nong	0.03	0.01	0.05	0.04
Total		98.36	46.23	169.50	123.28

A comparative assessment of the two restoration systems showed that the RPP and OP achieved comparable AGB, CS, $\text{CO}_2\text{-seq}$, and $\text{O}_2\text{-prod}$, with the OP exhibiting slightly higher values. Although both restoration systems attained similar levels of aboveground carbon storage, they achieved this outcome through contrasting structural pathways. In the RPP, carbon accumulation was primarily associated with the structural dominance of retained Yang Pa-ra trees. In contrast, carbon storage in the OP resulted from the collective contribution of several co-dominant species. These contrasting patterns demonstrate that comparable ecosystem carbon stocks can be achieved under different restoration strategies and community structures (Ahmad *et al.*, 2025). The present findings provide additional evidence that restoration systems with contrasting community structures can achieve similar levels of aboveground carbon storage through different ecological pathways. Both restoration models function as effective aboveground carbon sinks, supporting previous findings on the carbon sequestration potential of tree-based restoration systems (Ahmad *et al.*, 2025; Zhang *et al.*, 2026). Ultimately, these systems contribute to greenhouse gas mitigation while simultaneously enhancing biodiversity, structural complexity, and the long-term sustainability of integrated land-use systems. Since this study represents a case study, the findings reflect the restoration potential and ecological characteristics of the specific forest restoration areas investigated. Therefore, applying or scaling the RPP or OP systems to other areas should consider site-specific factors, including tree species composition, restoration strategy, land-use management, stand age, and local ecological conditions, to maximize forest restoration success and carbon sequestration efficiency.

This study has data collection limitations because the assessment of biomass and carbon sequestration considered only aboveground trees, excluding belowground biomass, litter, deadwood, the root system, and soil organic carbon. This may result in the estimated total ecosystem carbon stock being lower than the reality. However, these results remain useful in demonstrating the role of educational institutions in restoring degraded forests to regain biodiversity while integrating agricultural use within the same area. The present dataset also provides an important baseline for long-term monitoring of restoration performance, allowing future evaluations of biomass accumulation and carbon sequestration trajectories as these restored forest stands continue to develop. These results improve the understanding of biomass accumulation and carbon sequestration within integrated restoration systems and provide valuable information for forest restoration planning, sustainable land-use management, and future carbon credit initiatives. Furthermore, the dataset may support the development of Measurement, Reporting, and Verification (MRV) frameworks for greenhouse gas mitigation projects in the forestry and agricultural sectors (Intergovernmental Panel on Climate

Change, 2006; Thailand Greenhouse Gas Management Organization, 2016).

4. Conclusion

The study of restored forest areas using the RPP and OP systems at KVIS revealed that: The overall plant community comprised 47 species, 38 genera, and 24 families. The RPP contained 25 species (21 genera, 15 families), while the OP contained 36 species (31 genera, 20 families). Both systems featured four distinct canopy layers (Emergent, Main Canopy, Understory, and Ground Layer), indicating complex ecosystem structures and high tree species diversity. The RPP community had a D of 1,060 stems/ha, Do of $20.75 \text{ m}^2/\text{ha}$, H' of 2.75, and J' of 0.85, with a clear dominance by Yang Pa-ra. The OP also had a D of 1,060 stems/ha but showed slightly higher ecological indices: Do of $22.78 \text{ m}^2/\text{ha}$, H' of 3.34, and J' of 0.93. Unlike the RPP, the OP was not dominated by any single species. Regarding biomass and carbon sequestration, the RPP recorded an AGB of 96.99 t/ha, CS of 45.59 tC/ha, $\text{CO}_2\text{-seq}$ of $167.15 \text{ tCO}_2/\text{ha}$, and $\text{O}_2\text{-prod}$ of $121.56 \text{ tO}_2/\text{ha}$, characterized by carbon concentration in dominant species. The OP values were slightly higher: AGB of 98.36 t/ha, CS of 46.23 tC/ha, $\text{CO}_2\text{-seq}$ of $169.50 \text{ tCO}_2/\text{ha}$, and $\text{O}_2\text{-prod}$ of $123.28 \text{ tO}_2/\text{ha}$, exhibiting a balanced carbon distribution across multiple species. Overall, restoring degraded forests at KVIS through RPP or OP models not only enhances biodiversity and promotes integrated land use but also significantly increases biomass and carbon sequestration potential. These findings serve as a case study for planning and managing degraded forest restoration elsewhere to achieve sustainable and integrated resource utilization in the long term.

5. Acknowledgments

The authors would like to express their sincere gratitude to KVIS for providing the research site and facilities. Special thanks are extended to the KVIS Eco & Low Carbon School Student Committee for their coordination and assistance throughout the research activities. Finally, we would like to thank Mr. Tammarat Kamawanit for his support during the fieldwork within the forest restoration plots at KVIS.

6. References

- Ahmad, A., Khan, M., Ahmad, T., Ahmad, S., Ullah, S. and Farooqi, A. 2025. Carbon dynamics with stand structure and species diversity in the Hindu Kush Himalaya ranges of Pakistan. **Scientific Reports** 15(1): 35440.
- Atkinson, J., Brudvig, L.A., Mallen-Cooper, M., Nakagawa, S., Moles, A.T. and Bonser, S.P. 2022. Terrestrial ecosystem restoration increases biodiversity and reduces its variability, but not to reference levels: A global meta-analysis. **Ecology Letters** 25(7): 1725-1737.

- Chazdon, R.L., Norden, N., Colwell, R.K. and Chao, A. 2023. Monitoring recovery of tree diversity during tropical forest restoration: Lessons from long-term trajectories of natural regeneration. **Philosophical Transactions of the Royal Society B: Biological Sciences** 378(1867): 20210069.
- da Rosa, C.M. and Marques, M.C. 2022. How are biodiversity and carbon stock recovered during tropical forest restoration? Supporting the ecological paradigms and political context involved. **Journal for Nature Conservation** 65: 126115.
- da Silva Junior, R.G., Ângelo, A.C., Cosmo, N.L., Rios, R.C., Bressiani, L.S.T., Mastella, A.D.F., Schneider, C.R., de Souza, K.K.F., Isernhagen, I., Capellesso, E.S. and Oliveira, E.S. 2026. Effect of planting mixed and facilitating species on the regenerating community. **Brazilian Journal of Botany** 49: 21.
- Dangwal, B., Rana, S.K., Negi, V.S. and Bhatt, I.D. 2022. Forest restoration enhances plant diversity and carbon stock in the sub-tropical forests of western Himalaya. **Trees, Forests and People** 7: 100201.
- Hasannudin, D.A.L., Nurrochmat, D.R. and Ekayani, M. 2022. Agroforestry management systems through landscape-life scape integration: A case study in Gowa, Indonesia. **Biodiversitas** 23(4): 1864-1874.
- Hytönen, J., Kaakkurivaara, N., Kaakkurivaara, T. and Nurmi, J. 2018. Biomass equations for rubber tree (*Hevea brasiliensis*) components in southern Thailand. **Journal of Tropical Forest Science** 30(4): 588–596.
- Intergovernmental Panel on Climate Change. 2006. **2006 IPCC guidelines for national greenhouse gas inventories, Volume 4: Agriculture, forestry and other land use**. The Institute for Global Environmental Strategies, Hayama.
- Intergovernmental Panel on Climate Change. 2022. **Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change**. Cambridge University Press, Cambridge.
- Keller, N., Niklaus, P.A., Ghazoul, J., Marfil, T., Godoong, E. and Philipson, C.D. 2023. Biodiversity consequences of long-term active forest restoration in selectively-logged tropical rainforests. **Forest Ecology and Management** 549: 121414.
- Koch, A. and Kaplan, J.O. 2022. Tropical forest restoration under future climate change. **Nature Climate Change** 12(3): 279-283.
- Koutika, L.S. 2022. Boosting C sequestration and land restoration through forest management in tropical ecosystems: A mini-review. **Ecologies** 3(1): 13-29.
- Kutintara, U. 1999. **The Basic Ecological for Forestry**. Faculty of Forestry, Kasetsart University, Bangkok. (in Thai)
- Magurran, A.E. 1988. **Ecology Diversity and Its Measurement**. Croom Helm, London.
- Marod, D. and Kutintara, U. 2009. **Forest Ecology**. Faculty of Forestry, Kasetsart University, Bangkok. (in Thai)
- Murniati, Suharti, S., Minarningsih, Nuroniah, H.S., Rahayu, S. and Dewi, S. 2022. What makes agroforestry a potential restoration measure in a degraded conservation forest?. **Forests** 13(2): 267.
- Nero, B.F. 2021. Structure, composition and diversity of restored forest ecosystems on mine-spoils in South-Western Ghana. **PLoS One** 16(6): e0252371.
- Ogawa, H., Yoda, K., Ogino, K. and Kira, T. 1965. Comparative ecological studies on three main type of forest vegetation in Thailand. II. Plant biomass. **Nature and Life in Southeast Asia** 4: 49-80.
- Pasion, B.O., Barrias, C.D.P., Asuncion, M.P., Angadol, A.H., Pabiling, R.P., Pasion Jr., A., Braulio, A.A., and Baysa Jr., A.M. 2021. Assessing tree diversity and carbon density of a riparian zone within a protected area in southern Philippines. **Journal of Asia-Pacific Biodiversity** 14(1): 78-86.
- Pearson, T., Walker, S. and Brown, S. 2005. **Sourcebook for Land Use, Land-Use Change and Forestry Projects**. World Bank, Washington, D.C.
- Perles-Garcia, M.D., Kunz, M., Fichtner, A., Härdtle, W. and von Oheimb, G. 2021. Tree species richness promotes an early increase of stand structural complexity in young subtropical plantations. **Journal of Applied Ecology** 58(10): 2305-2314.
- Pielou, E.C. 1975. **Ecological Diversity**. John Wiley & Sons, New York.
- Rosenfield, M.F., Jakovac, C.C., Vieira, D.L.M., Poorter, L., Brancalion, P.H.S., Vieira, I.C.G., de Almeida, D.R.A., Massoca, P., Schietti, J., Albernaz, A.L.M., Ferreira, M.J. and Mesquita, R.C.G. 2023. Ecological integrity of tropical secondary forests: Concepts and indicators. **Biological Reviews** 98(2): 662-676.
- Thailand Greenhouse Gas Management Organization. 2016 **Thailand Voluntary Emission Reduction Program Reference Manual: Forestry and Agriculture Sector**. Thailand Greenhouse Gas Management Organization (Public Organization), Bangkok. (in Thai)
- Uttaruk, Y., Khoa, P.V. and Laosuwan, T. 2024. A guideline for greenhouse gas emission reduction and carbon sequestration in forest sector based on Thailand voluntary emission reduction programme. **Sains Malaysiana** 53(3): 477-486.
- Siarudin, M., Rahman, S.A., Artati, Y., Indrajaya, Y., Narulita, S., Ardha, M.J. and Larjavaara, M. 2021. Carbon sequestration potential of agroforestry systems in degraded landscapes in West Java, Indonesia. **Forests** 12(6): 714.

- Siddesh, R., Pathak, H., Chavan, S.B., Halli, H.M., Kakade, V.D., Morade, A.S., Salunkhe, S., Nangare, D.D., Salunkhe, V.N., Singh, A.K., Pradhan, A. and Reddy, K.S. 2025. Fruit tree-based restoration strategy to mitigate greenhouse gas emissions, and enhance the profitability of degraded land in semi-arid tropics. **Science of The Total Environment** 1000: 18049.
- Smitinand, T. 2014. **Thai Plant Names**. The Forest Herbarium, Department of National Parks, Wildlife and Plant Conservation, Bangkok. (in Thai)
- Sukprung, T., Maelim, S. and Teejuntuk, S. 2021. Restoration on mixed deciduous forest at Mae Thang Watershed Conservation and Development Study Unit, Phrae province. **Thai Journal of Science and Technology** 10(2): 208-222.
- Zhang, H., Feng, H., Qu, X., Yang, M., Huang, M., Jacobs, D.F. and Guo, J. 2026. Species mixing promotes plant biomass accumulation and nutrient cycling in forest plantations. **Communications Biology** 9(1): 348.