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Potential economic value of carbon credits in forest restoration plots in northern Thailand

BACHELOR’S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Potential economic value of carbon credits in forest restoration plots of northern Thailand", independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 17.04.2025

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Pyae Shan Tun

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Abstract

This study evaluates the potential economic value of carbon credits generated through forest restoration using the Framework Species Method (FSM) in northern Thailand. Tree carbon accumulation was measured across four different sites: non-restored control plots, 12- and 24-year-old restoration plots, and reference forests. Using allometric equations and logistic growth modelling, results showed that restored plots accumulated 87.46 tC/ha (49% of reference levels) after 12 years and 149.84 tC/ha (84%) after 24 years. The economic valuation of carbon credits using a cost–benefit analysis indicated that carbon credits could return significant revenue (up to $37,064/ha over 24 years). One ton of CO_2 on the European Emission Allowance (EUA) market was 60.94 EUR/tCO_2, which is equal to 248.04 USD/tC. The cost of carbon sequestration by the FSM for 100% tree-planting restoration is 10.34 USD/tCO_2. Subtracting this establishment cost leaves a profit of 5,687 USD/ha over 24 years, which can outweigh restoration costs significantly. A SWOT analysis underscored Thailand's emerging carbon market strengths, such as institutional partnerships and scientific foundations for forest-based carbon credits, but also identified weaknesses such as governance gaps and inequitable profit sharing.

Key words: species-specific wood density, control sites, forest management, cost-benefit analysis, SWOT analysis

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List of the abbreviations used in the thesis

FORRU-CMU – Forest Restoration Research Unit – Chiang Mai University

UNFCCC – United Nations Framework Convention on Climate Change

WB – The World Bank

FSM – The Framework Species Method

GHGs – Greenhouse Gases

REDD + - Reducing emissions from deforestation and forest degradation

EU ETS – European Union Emissions Trading System

VCS - The Verified Carbon Standard

TGO – Thailand Greenhouse Gas Management Organization

T-VER – Thailand Voluntary Emission Reduction Program

SDGs – Sustainable Development Goals

CSR – Corporate Social Responsibility

1. Introduction

Greenhouse gas emissions, primarily from human activities, drive global warming, with the planet's average surface temperature rising to 1.1°C above pre-industrial levels from 2011 to 2020 (Calvin et al. 2023). Restoring degraded forests has become a cost-effective way to remove excess carbon dioxide from the atmosphere and achieve the aims of the Paris Climate Agreement by holding global temperatures below 2°C (Griscom et al. 2017). As an approach to mitigate CO_2 emissions, forests play a pivotal role, with potentially positive impacts of forest restoration on mitigating climate change, additionally delivering economic benefits through carbon credits (Pietracci et al. 2023).

The surface of the Earth is covered by approximately 22 million km^2 of tropical forests, with significant differences in the distribution of forest types based on rainfall and temperature (Queenborough 2018). Nearly 30% of annual global anthropogenic CO_2 emissions have been sequestered by the world's forests in the past few decades; however, deforestation and forest degradation contribute to about 12% of the world's greenhouse gas emissions (Jia et al. 2022; ArtaxoID et al. 2022). Ten million hectares of tropical forest was lost between 2015 and 2020. Furthermore, 48% of tropical moist forests are prone to loss by 2100 in the event of a "business-as-usual" scenario (FAO 2020; Vieilledent et al. 2023). More than 96% of deforestation occurs mainly in the tropical primary forests, totalling 3.7 million hectares with the production of 2.4 gigatonnes (Gt) of carbon dioxide emission in 2023 (Figure 1). Therefore, tropical forests have an essential role in conserving biodiversity, regulating the water cycle and storing carbon, as well as playing a crucial role in supporting human well-being (ArtaxoID et al. 2022). Nevertheless, degradation and deforestation have increased substantially due to agricultural expansion, illegal logging, and infrastructure development.

Forest-carbon sequestration has captured global attention due to the substantial impact of climate change, because it has the potential to reduce concentrations of atmospheric CO_2 by photosynthesis (Coleman 2018). Tropical forest ecosystems capture carbon faster than other types of forest, such as temperate or boreal forests. For example, during the early stages of restoration, tropical secondary forests can sequester carbon at rates up to 20 times faster than old-growth forests, highlighting their significant capacity for storing carbon following deforestation or degradation (Heinrich et al. 2021; da Silva et al. 2023).

However, deforestation and forest degradation add to atmospheric CO_2, whilst also reducing the carbon absorption capacity of forests, amounting to an annual loss of approximately 0.26 petagrams of above-ground biomass carbon between 1993 and 2012 (Alamgir et al. 2016). Therefore, a comparison of forest-restoration dynamics between short-term (0-12 years) and long-term (>20 years) is needed to quantify above-ground carbon recovery.

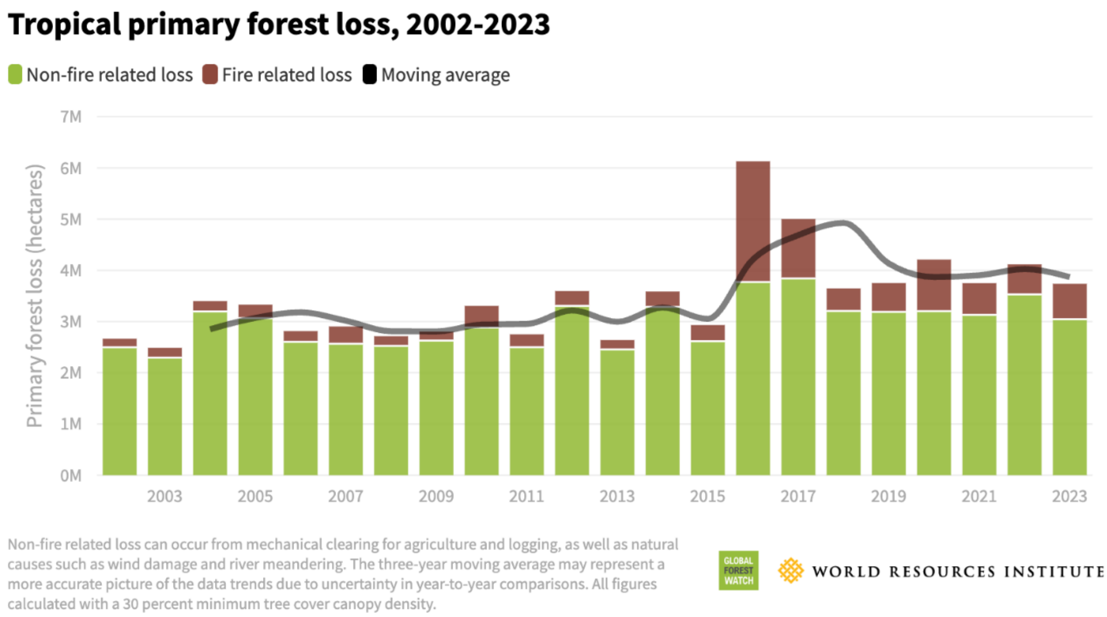

Figure 1. Tropical forest loss, 2002-2023 (Weisse et al. 2023).

A carbon credit is a tradable certificate that represents the removal or reduction of one metric ton of carbon dioxide (CO_2) or its equivalent in other greenhouse gases. Monetization and trading in carbon credits can be used to fund forest restoration and provide a financial reward local people to encourage them to engage in the activity and conserve restored forest afterwards. Thus, forests can become valuable to society, since tree biomass contains about 47% carbon, and forest growth contributes to mitigation of global climate change. If farmers have access to equitable carbon-credit markets, income from carbon credits can amount to 16 times that from maize cultivation (Jantawong et al. 2022), over the first 14 years of implementing the framework species method (FSM) of forest ecosystem restoration. The FSM involves planting tree species, representative of the reference forest, which also exhibit high rates of survival and growth when planted out on exposed deforested sites (Elliott et al. 2022). Carbon credits could pay for the cost of restoration and, at the same time, provide locals with an attractive financial incentive to shift from destructive agriculture to sustainable forest practices. Furthermore, forest restoration can bring many other potentially monetizable environmental benefits, including biodiversity recovery and watershed protection. However, one study argued that inconsistent valuation methodologies and a lack of localized data compromise the carbon market integrity (Carton et al. 2021). Moreover, the determination of payments for carbon credits relies on the amount of sequestered carbon. Therefore, it is crucial to measure carbon storage reliably, during the restoration of forest ecosystems.

Monetizing carbon value through carbon credits is seen as one of the most advanced ways to create diverse income streams for stakeholders involved in forest restoration. Studies indicate that the benefits of restoration, including carbon sequestration, often surpass the private gains from alternative land uses (Birch et al. 2010). However, sustainable monetization and effective marketing of forest values are crucial for achieving socio-economically sustainable forest restoration.

In some cases, carbon credits alone can cover the investment needed to implement ecological restoration, even in high-cost areas. For example, Matzek et al. (2015) reported that carbon credits could repay California's riparian forest restoration costs over 100% after two decades, provided sufficient effort is expended in the initial years. Similarly, Birch et al. reported that on dryland areas in Latin America passive restoration (relying on natural regeneration without planting trees) can be cost-effective, based on the ecosystem services analysed. However, the high cost of active restoration (tree planting) outweighed the benefits (Birch et al. 2010).

High costs of market entry and often the low price of carbon credits present considerable challenges to the use of carbon trading as a financial mechanism to support restoration, especially for small landowners (Charnley et al. 2010). Furthermore, socioeconomic issues such as lack of community engagement, sustainable land-use planning, and supportive policies, particularly those related to land ownership, all present barriers to the implementation of successful restoration projects (Dieng et al. 2023; Tedesco et al. 2023).

Therefore, the objectives of the study, described here, were 1) to calculate carbon accumulation during restoration of upland evergreen forest, by the FSM, in northern Thailand and 2) to explore its potential economic value, as carbon credits, in developing the carbon market in Thailand, encouraging sustainable forest management and supporting the key stakeholders.

2. Literature Review

2.1. Carbon credits and forest restoration

Carbon credits, as a market-driven tool, are tradable permits that encourage climate action by reducing or eliminating greenhouse gas emissions. In practice, one carbon credit equivalent to one metric ton of carbon dioxide equivalent (CO_2e). These credits enable organizations or individuals to alleviate their greenhouse gas emissions by investing in initiatives that either reduce or eliminate carbon from the atmosphere. These credits operate compliance markets such as the EU Emissions Trading System (EU ETS), where governments set emissions caps for industries, and voluntary markets, where enterprises or individuals purchase offsets to meet net-zero commitments, often as part of corporate sustainability efforts (World Bank 2023). The idea of carbon credits originated from international efforts to tackle climate change, especially following the Kyoto Protocol of 1997, which established binding legal duties for Global North states to reduce their greenhouse gas emissions (GHGs) (Böhringer 2003). Carbon credits under the Paris Agreement assisted global carbon markets by allowing countries, particularly developing ones, to access carbon funding. This increases demand for credits, influences policy decisions, and improves the effectiveness of emission trading schemes in meeting climate targets (Caciagli 2018).

Forest-ecosystem restoration is defined as: "directing and accelerating ecological succession towards an indigenous reference forest ecosystem of the maximum biomass, structural complexity, biodiversity and ecological functionality that are self-sustainable within climatic and soil limitations" (Elliott & Blakesley 2013). Forest restoration projects are emerging as one of the most promising approaches to mitigate atmospheric carbon dioxide by sequestering carbon and generating economic returns, using carbon credits as a financial tool. For example, research on riparian forests in California showed that carbon credits could return restoration costs within two decades, provided there is sufficient sampling effort in the early years of restoration (Matzek et al. 2015). Nevertheless, questions remain about whether carbon credits alone can incentivize land-use changes, especially in agricultural regions with high opportunity costs. Further study is needed to determine the effectiveness of carbon credit projects such as equitable distribution of benefits to local communities. Whilst studies about forest-based carbon credits projects have underscored the economic potential of carbon credits and the biodiversity co-benefits of REDD+ strategies, they often focused on specific ecosystems or regions (e.g., riparian or temperate forests), without exploring tropical ecosystems. Few studies examine how restoration methods (e.g., the framework species method or FSM) optimize carbon storage (Jantawong et al. 2017a; Jantawong 2017). Furthermore, lack of monitoring data for carbon sequestration beyond 20 years remains a gap in knowledge. (Samek et al. 2011) also highlights that the developing carbon market in Thailand does not have sufficient analyses regarding financial viability for smallholders and communities. The current study, therefore, examined these gaps by focusing on evergreen forests restored using the FSM in Northern Thailand. It evaluated the cost-benefit ratio of carbon credit projects, specifically forest restoration projects, and explored how the prospective carbon market structure in Thailand could balance corporate demand with community equity.

2.2. Forest management in Thailand and the Framework Species Method (FSM)

In tropical regions, forest ecosystems sequester an impressive 107 million metric tons of above-ground carbon annually (ESA 2023). Forest management practices in Thailand have evolved to balance ecological restoration with community needs. In 2019, the Thai government officially recognized Community-Based Forest Management (CBFM), which gave local communities more authority to manage their forests to achieve conservation outcomes (Agarwal et al. 2022). The Forest Restoration Research Unit (FORRU) at Chiang Mai University has developed the framework species method (Figure 2), which increase the rate of natural ecosystem regeneration by planting native tree species that attract wildlife and improve soil conditions (Elliott et al. 2022). Trials in Chiang Mai, Northern Thailand, demonstrated that FSM plots sequester 105.8 tC/ha within 14 years, nearing natural forest levels (181.5 tC/ha) (Jantawong et al. 2017b). Collaborative projects, such as Ban Mae Sa Mai's community-led restoration, emphasize synergies between biodiversity recovery and water security (Cowan 2022). However, challenges including land- tenure conflicts and legal risks for indigenous communities (Cowan 2022; Boonchai 2023). Studies on the framework species method in Northern

Thailand have shown positive results. For example, a chronosequence analysis of trial plots established by FORRU-CMU proved significant recovery in biomass, biodiversity, and ecological functioning over two decades. Benefits such as improved water security and empowered relationships with authorities of Doi Suthep-Pui National Park have gained by local communities (Elliott et al. 2019).

Although several studies have demonstrated the effectiveness of the FSM in achieving restoration goals, how it might contribute to Thailand's emerging carbon markets remains to be determined. Financial models often exclude non-carbon benefits (e.g., ecosystem services), underestimating restoration's comprehensive impact (Carrasco et al. 2014). Regardless of its success, there are challenges that threaten the sustainability of these restoration activities, such as "project fatigue" and insufficient funding (Elliott et al. 2019). Furthermore, there is limited research on quantifying the economic value of carbon sequestration achieved through this method. This thesis will contribute by linking forest age with carbon storage and its valuation through carbon credits.

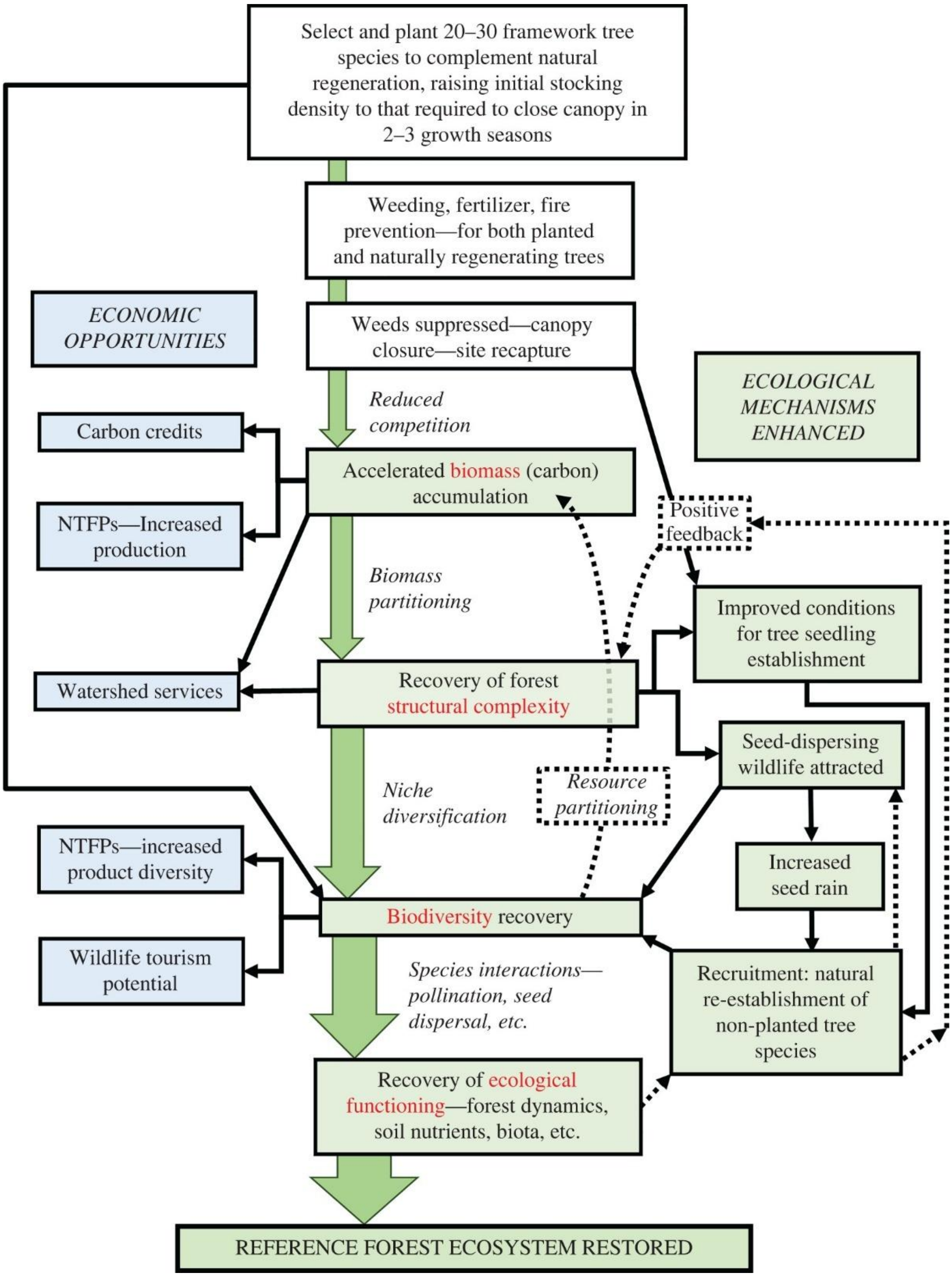

Figure 2. How the framework species method generates forest-ecosystem restoration. Carbon credits as one of the economic opportunities and dotted lines indicate positive feedback (Elliott et al. 2022)**.**

2.3. Economic valuation of forest restoration projects in Thailand

Economic valuation of forest restoration links ecological and financial metrics by quantifying ecosystem services such as carbon sequestration. These valuations assist stakeholders in comparing carbon credit revenue against alternative land uses, attract investments, and inform policy decisions, enabling stakeholders to compare carbon credit revenue against alternative land uses.

For instance, study reported that FSM plots sequestered an average of 105–143 t C/ha over a 14-year period, substantially higher than passive regeneration or monoculture plantations. The economic viability of FSM projects was further supported by a cost-benefit analysis, which showed a net present value (NPV) of $22K–$25K/ha over the same timeframe from carbon credits. However, transaction costs and lack of clear policies can deter participation (Jantawong et al. 2017a, 2022). The 20-year Strategic Plan of Thai government aims to grow carbon forests by 5.1 million hectares; however, profit-sharing mechanisms remain unclear (Dechwan 2022; Boonchai 2023). Additionally, Thailand aims for carbon neutrality by 2050 and net-zero emissions by 2065, supported by policies to position itself as a trading center in Southeast Asia (Polkuamdee 2025).

In Southeast Asia, the willingness of the public to pay for ecosystem conservation has been estimated using contingent valuation techniques. According to a study conducted in the Philippines, residents' socioeconomic reliance on mangroves led them to be willing to pay dedicated taxes for their restoration (Hernando et al. 2024). In a similar way, recent research on rubber plantations in Southern Thailand evaluated carbon offset revenues using voluntary market contracts (Chiarawipa et al. 2024). Current models frequently overlook by secondary costs (e.g., community displacement) and fail to consider changing into carbon pricing for fluctuating carbon. Additionally, few studies have investigated how corporate investment in restoration could be influenced by Corporate Social Responsibility commitments (Dechwan 2022; Boonchai 2023).

These studies contributed insights into economic valuation methods by focusing on specific ecosystems like mangroves or plantations rather than restored evergreen forests. Moreover, most research has not integrated cost-benefit analyses with stakeholder perspectives. This thesis addressed these gaps, by evaluating the economic performance of carbon credits from restored forests using a cost-benefit analysis to quantify carbon credit revenue across restoration stages and evaluated CSR-driven funding as a sustainable financing mechanism.

2.4. Carbon market in Thailand

The primary strategies for generating carbon credits include reforestation, afforestation and improved forest-management practices, which also support climate change mitigation by boosting sequestration of forest carbon (Verma & Ghosh 2022). REDD+ (Reducing Emissions from Deforestation and Forest Degradation) operates under the UNFCCC, with the major objective of incentivizing forest conservation in developing nations through results-based payments for verified emission reductions. The Verified Carbon Standard (VCS), managed by Verra, provides strict prerequisites for voluntary carbon markets (Rights and Resources Initiative & McGill University 2021). Furthermore, the Gold Standard prioritizes projects that are aligned with the SDGs (Kapoor & Motilal 2024). Therefore, international frameworks like REDD+, Verified Carbon Standard (VCS), and Gold Standard govern forest-based carbon projects by incentivizing emissions reductions through payments for forest conservation and restoration.

Thailand is now interested in developing domestic carbon market meets with collective actions to accomplish low-carbon development under the Paris Agreement. The Thai authorities are exploring mechanisms, such as emissions-trading systems and voluntary offset programs, to decrease greenhouse gas emissions (GHGs). It is now taking major steps towards carbon neutrality by 2050, as defined in its Nationally Determined Contribution (NDC), with forests being a crucial carbon sink (Boonchai 2023). The partnership between the Thailand Greenhouse Gas Management Organization (TGO) and Verra plays a critical role in positioning the Thailand Voluntary Emission Reduction Program (T-VER) with the Verified Carbon Standard (VCS), in this way to boost the market's credibility(Verra 2022; Dechwan 2022). Nevertheless, underlying struggles, such as land-use conflicts, weak governance, and insufficient community participation, present significant challenges in order to achieve fair and equitable outcomes (Cowan 2022; Boonchai 2023). For example, it reports that 90% of carbon credit profits are currently allocated to corporations, leaving local stakeholders marginalized and voiceless in this critical process (Boonchai 2023). Research on Thailand's developing carbon market revealed governance challenges and opportunities. A study analysing carbon-market mechanisms in Thailand and Vietnam identified key factors, such as domestic demand for credits, government coordination, and regional linkages with other markets (Smits 2017). Another study underlined the role of voluntary emission reduction (T-VER) in achieving carbon neutrality (Petchchedchoo et al. 2024).

SWOT-based analyses of Thailand's carbon market are needed to incentivize stakeholders and address regulatory risks. While such studies deliver a comprehensive overview of Thailand's carbon market landscape, specific analyses are needed on how forest restoration projects could contribute towards these mechanisms.

This thesis examined how restored forests might integrate with Thailand's carbon market, whilst addressing barriers such as data availability and stakeholder coordination, using a SWOT analysis, to identify market opportunities (e.g., Corporate Social Responsibility partnerships) and barriers (e.g., land tenure disputes). The study puts forward actionable insights for policymakers, to ensure that Thailand's emerging carbon market not only thrives but also benefits all stakeholders.

3. Aims of the Thesis

This study aimed to calculate the economic value of above- and below-ground carbon in trees in upland evergreen forest-restoration plots of two ages (compared with a non-restored control site and reference forest), the forest having been restored by the framework species method (FSM) in Northern Thailand. The study provides insights that can guide more effective and financially viable forest restoration efforts, contributing to both environmental conservation and economic sustainability. For instance, carbon credits issued through mechanisms like the Verified Carbon Standard (VCS) could serve as an incentive for forest restoration, assisting stakeholders in achieving emission reduction and cooperate social responsibility (CSR) goals.

Specific objectives of the study include:

1. To measure the tree carbon accumulation at four adjacent sites: i) control plots (non-planted), ii) 12-year-old restoration iii) 24-year-old restoration and iv) the reference forest – intact upland evergreen forest.
2. To conduct an economic appraisal of the cost and benefits of forest restoration by the FSM.
3. To perform a SWOT analysis (strengths, weaknesses, opportunities, and threats) for a prospective carbon market in Thailand that includes forest-based credits.

4. Methods

4.1. Description of the study area

The highlands of Northern Thailand are distinguished by steep mountains, with slopes often more than 35%. The upland of Mae Rim, particularly Ban Mae Sa Mai, known as a demonstration site for forest-restoration research, such as testing the framework species method FSM. The framework species method (FSM) is an effective forest-ecosystem restoration technique in the tropics, on moderately degraded sites, which combines tree planting with assisted natural regeneration (Elliott et al. 2022). It was first conceived in Queensland, Australia (Goosem & Tucker 2013) and was subsequently adapted to restore various forest-ecosystem types in Thailand (Forest Restoration Research Unit n.d.). The method complements assisted natural regeneration (ANR) with tree-planting, to raise initial stocking density sufficiently to achieve rapid canopy closure (shading out herbaceous weeds), biomass accumulation and structural development. It is effective where fragments of mature reference forest remain in the surrounding landscape as seed sources and habitat, to support viable populations of seed-dispersing animals (Elliott et al. 2022). Framework tree species are those, which are representative of the reference forest, and which also i) attain high rates of survival and growth when planted out in exposed deforested sites. ii) suppress herbaceous weeds (by shade or allelopathy), iii) attract seed-dispersing animals (e.g., by producing foods or habitat resources from a young age) and iv) are easily propagated in nurseries (Elliott et al. 2022; WANGPAKAPATTANAWONG & ELLIOTT 2011).

The study was conducted in FORRU-CMU’s trial plot system, situated in the upper Mae Sa Valley, which lies mainly within Doi Suthep-Pui National Park, in Chiang Mai Province, Northern Thailand, which is part of the Golden Triangle region. The Hmong hill tribe communities of Ban Mae Sa Mai and Ban Mae Sa Noi, with a combined population of 2,197, are situated at 18°52′07.24″ N, 98°51′08.47″ E, 1,018 m above sea level. The FSM trial plot system is located at 18°51′46.62″ N, 98°50′58.81″ E, 1,200-1,325 m above sea level, covering 33 ha of the watershed above the village. The study site was surrounded mostly by agricultural land but connects to a remnant of forest to the east. Before restoration the land it was original degraded land that had been cleared for agricultural purposes (Elliott et al. 2019).

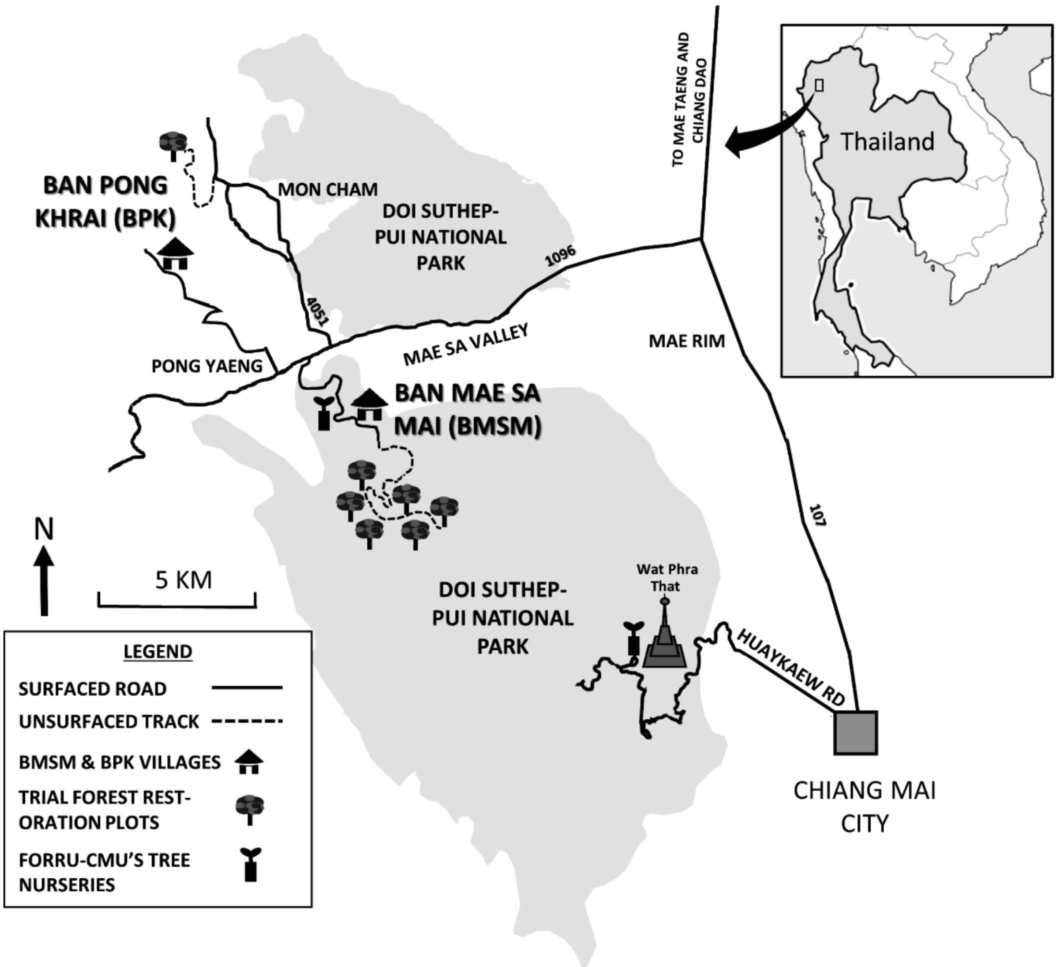

Figure 3. Location of the study area in relation to Chiang Mai, Doi Suthep-Pui National Park.

The study area has two main seasons, which are the wet season (May-October) and the dry season (November-April), with the mean monthly rainfall below 100 mm. The extreme temperatures ranged from a minimum of 4.5 °C in December (cool dry season) to a maximum of 35.5 °C in March (hot dry season) (Figure 2).

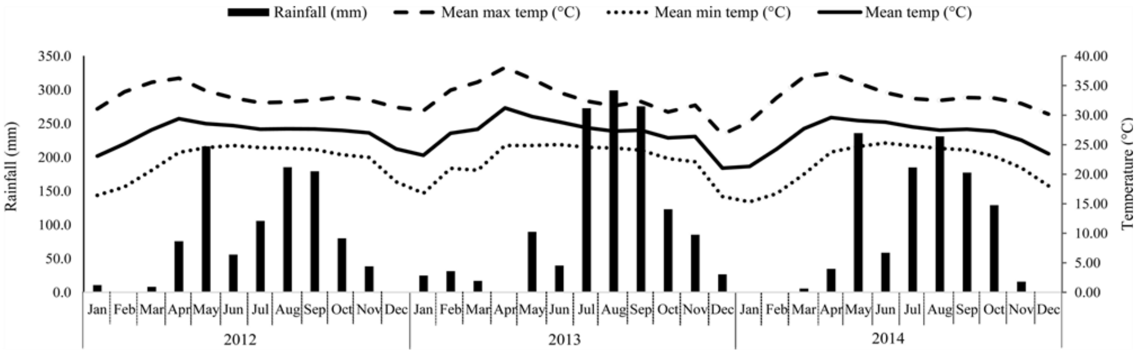

Figure 4. Rainfall, minimum temperature, maximum temperature, mean temperature from the nearest meteorological station of Ban Mae Sa Mai Royal project (Jantawong 2017).

Figure 5. Condition of the site before restoration in 2000 (Left) and 24 years after implementation the FSM (2024) during data collection.

4.1.1. Communities

The Hmong communities practiced shifting cultivation traditionally, mostly producing upland rice, opium, and maize in the past, but the communities have now adopted more commercial agriculture, and cabbages were still cultivated in most of the slopes. Lower down the Mae Sa Valley, large litchi orchards (*Litchi chinensis Sonn., Sapindaceae*) were once existing by growing on most of the slopes underneath the plots. Until recently, the primary source of the communities' income came from litchis. Nevertheless, these orchards were destroyed to create space for horticulture, which uses plastic covers to grow salad veggies, cut flowers, etc. Nowadays, the main sources of villagers' income come from agriculture, selling handicrafts, and employment at the nearby Queen Sirikit Botanical Gardens (Elliott et al. 2019; Chazdon 2021).

For more than 25 years, the Hmong people of Ban Mae Sa Mai village have collaborated with researchers from Chiang Mai University's Forest Restoration Research Unit (CMU-FORRU), who were then experimenting with assisted regeneration techniques, and national park officials to restore agricultural areas to their original state as forests. Between 1997 and 2013, they restored 33 hectares (82 acres) of the region's upland evergreen tropical forest. The restoration effort has been successful with the return of biodiversity and ecosystem services to the restored land (Elliott et al. 2019).

4.2. Data collection

The study was conducted by a mixed-method approach and the data collections involve both quantitative and qualitative data which were collected through primary and secondary sources.

4.2.1. Forest carbon survey

The tree carbon survey (primary data) was conducted in cooperation with the Forest Restoration Research Unit of Chiang Mai University and was collected by a stratified random sampling method. Firstly, the four study sites were stratified as 1) Control site (non-planted), 2) 12-year-old restoration site, 3) 24-year-old restoration site, and 4) reference forest (a mature remnant of the original forest. As the sampling design, eight circular sample plots (5 m radius) were established in each of 4 sites. The measurements made in May and June of 2024 (Figure 6).

Equipment: metal labels (made from drinks cans), permanent marker, metal stylus, wire, nails, tape measures (1.5 m), data sheets, pencils, clipboards, tree height measuring poles (Figure 9), and digital clinometer.

A 5 m long rope was used to mark the plot's circle (Figure 7), and every tree of GBH>5 cm (the girth at breast height) was counted, labelled, and identified (to species level) within each cycle (Figure 8). To measure GBH (in cm), numbered labels were nailed to each tree trunk at a height of 1.3 meters above ground level, and 5 cm long galvanized nails with flat tips were used.

The following data were recorded on the datasheet:

1) Label number,
2) Species name (local name and scientific),
3) GBH (measured with 1.5-m tape),
4) Height (measured with pole or digital clinometer), and
5) Crown length and width.

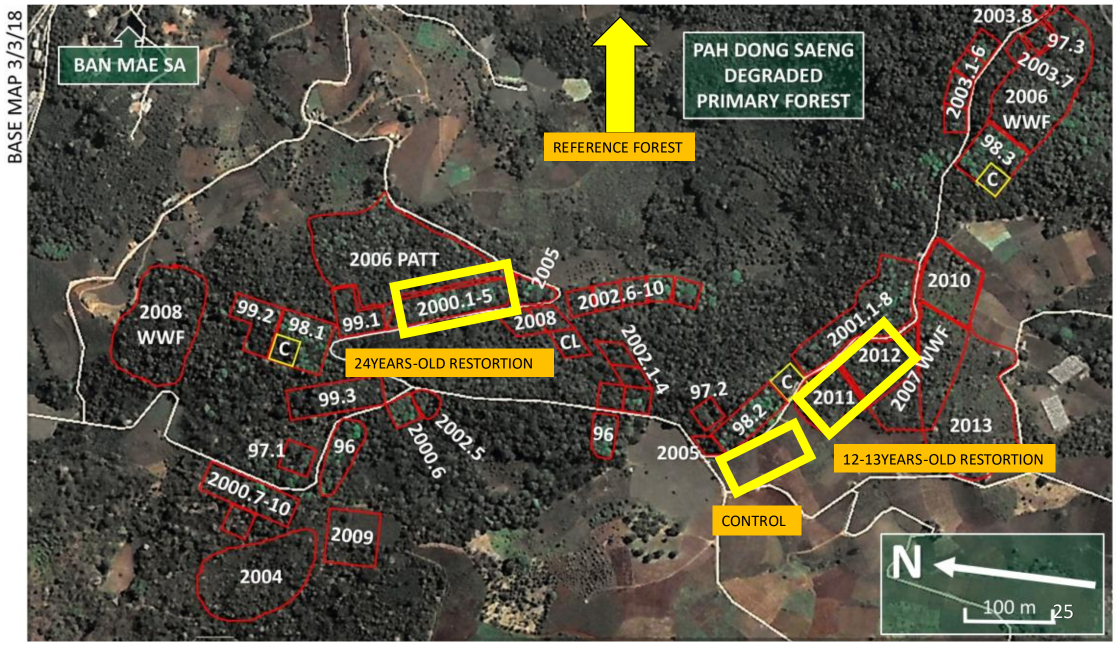

Figure 6. Location of the study habitats where sample plots were placed for the study reported here are highlighted.

Figure 7. Marking the plot's cycle using a 5 m long rope.

Figure 8. Measuring GBH (the girth at breast height).

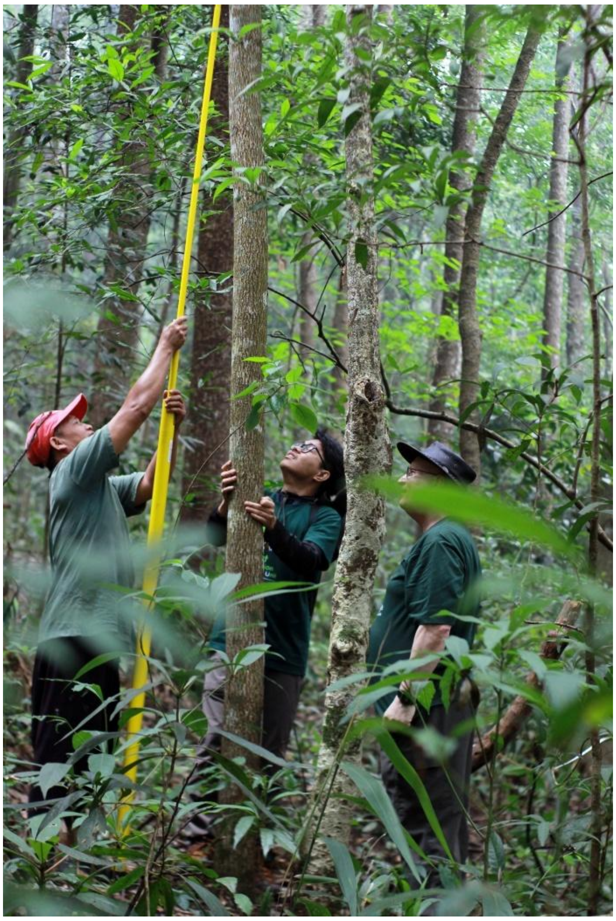

Figure 9. Measuring tree height using height measuring pole.

4.2.2. Socioeconomic data and cost-benefit analysis

A cost-benefit analysis (CBA) of the potential carbon value from restoration efforts was performed based on the previous academic research and the reports from the Forest Restoration Research Unit (FORRU-CMU). To analysis the development opportunities and barriers of the prospective carbon market in Thailand, a variety of secondary sources such as FORRU reports, various academic journals from web of science, existing academic literature, published thesis, books, news articles and relevant reports from the World Bank (WB), the Food and Agriculture Organization (FAO), and the Thailand Greenhouse Gas Management Organization (TGO) to Thailand's carbon market were documented to support SWOT (Strengths, Weaknesses, Opportunities, and Threats) framework.

4.3. Data analysis

4.3.1. Carbon accumulation in trees

Above-ground biomass of each individual tree and tree carbon (kg) was calculated from allometric equations developed for northern Thailand trees by (Pothong et al. 2022). Allometric equations predict a difficult-to-measure parameter (i.e., tree dry biomass) from an easily measured one (i.e., diameter at breast height (DBH)). They are originally constructed by felling trees of different sizes and then drying and weighing the whole tree. The equation, derived from the shape of the curve, is subsequently used to predict above-ground tree dry mass from field measurements, without the need for further destructive sampling. Pothong's equation is a power law relationship with this form:

$$AGB = a \times (D^2 \times H \times WD)^b \quad (1)$$

… where AGB means above-ground dry biomass (kg); D = diameter at breast height (cm); H = tree height (m); and WD = wood density (g/cm^3). The parameters "a" and "b" are constants derived from curve fitting Pothong's field data on felled trees in regenerating forest in northern Thailand. Best fit values are 0.134 and 0.847, respectively, for trees of D 1 to 20 cm and 0.0673 and 0.976 for trees of D > 20 cm. Species-specific wood density data were derived from the data appended and from the global wood-density database (http://db.worldagroforestry.org/wd).

The root dry biomass of each tree was added, using the mean root/shoot ratio determined by (Cairns et al. 1997) for tropical trees (0.24 tons of roots per ton AGB). Pothong reported that the average carbon content of the trees in her study was 44.84% of dry biomass. Therefore, the results were multiplied by 0.4484 to convert from above-ground biomass to carbon mass. The sum values for all trees in each circular plot (kg/circle) were converted to metric tonnes per ha. Thus, eight estimations of tree carbon quantity (metric tonnes per hectare) were derived for each of the four study sites. To determine significant differences among the four sites, F-test and t-tests were used.

The following equation for tree growth model were used to measure the predictions of tree carbon value for each year.

$$Tree\ Carbon\ (\frac{tC}{ha}) = \frac{K}{1+e^{-R(Year-T)}} \quad (2)$$

…where K = carrying capacity (maximum carbon stock for 50 years), R = growth rate, T = time to reach half of the carrying capacity, e = Euler's number (2.718).

4.3.2. Socioeconomic analysis

Total net present value (NPV) of the carbon value of restoration was determined by the following equation, as the sum of the NPVs of profits for each year over 30 years restoration after the establishment of the restoration.

$$NPV = \sum_{t=0}^{n} \frac{FV}{(1+r)^t} \quad (3)$$

….. Where NPV = net present value (USD), FV = future value (USD) or cash flow for each year, r = discount rate, t = year (value of 0 to n) and n = project period.

The following discount rate equation was used to calculate the net present value (NPV).

$$Discount\ rate = (1 + real\ interest\ rate) \times (1 + inflation\ rate) - 1 \quad (4)$$

The results were presented through tables and charts for better visualization. Additionally, the qualitative document research method was used to determine the development opportunities and barriers of the prospective carbon market in Thailand.

4.3.3. Data processing

The collected Quantitative data from the primary data were added, cleaned and analyses using Microsoft Excel Office 365 for analysis. For qualitative secondary data, thematic analysis approach was used.

5. Results

5.1. Tree carbon

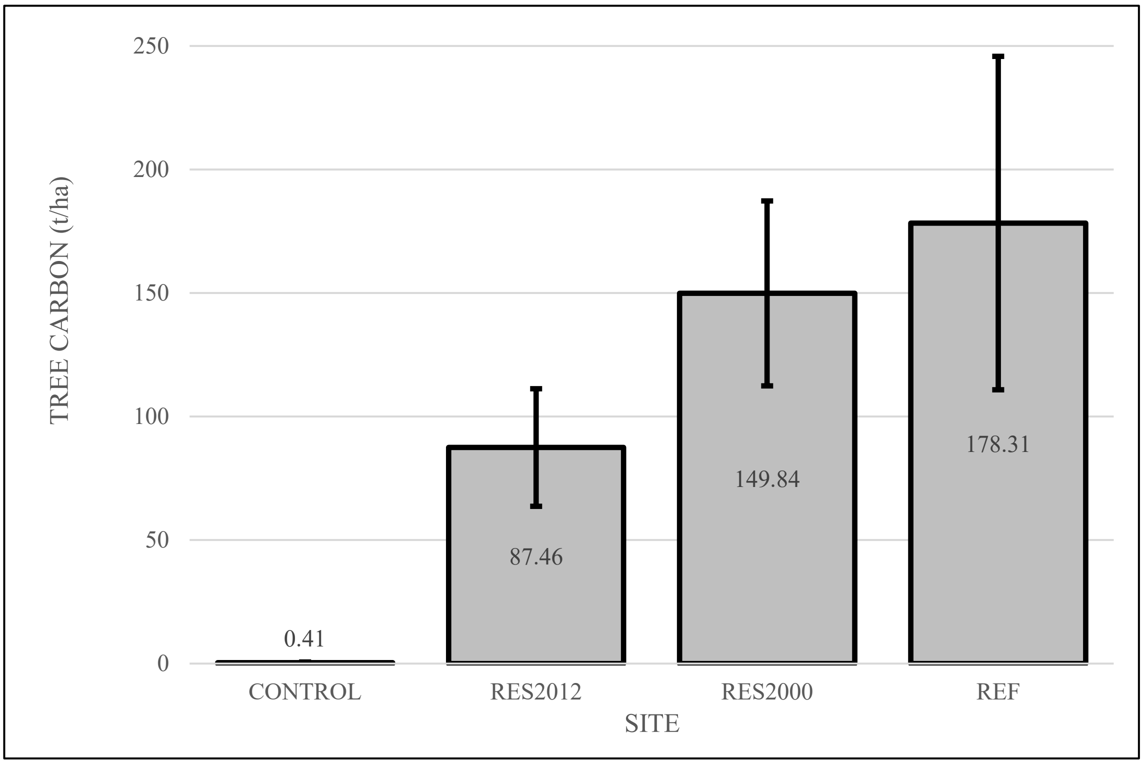

Figure 8. Estimated average tree carbon (tons carbon per hectare) in all four sites. (Measurements made May-June 2024).

The bar graph shows the total tree carbon levels including roots (tons per hectare (t/ha)) for four study sites (CONTROL, 12-year-old restoration (RES2012), 24-year-old restoration (RES2000), Reference Forest (REF)) which can determine the progression over time. The control site shows a minimal amount of total tree carbon (t/ha), which is 0.41 t/ha. RES2012 displays a higher tree carbon level at 87.46 t/ha, while RES2000 presents 149.84 t/ha. The highest tree carbon among four sites is reference forest (REF) with 178.31 t/ha. After establishing forest-ecosystem restoration by the Framework Species Method, the amount of tree-carbon accumulation of the 12-years-old restoration site and 24-years-old restoration site reached 49% and 84% of reference forest values respectively.

Table 1. F-Test Two-Sample for Variances between CONTROL and RES2012.

	CONTROL	*RES2012*
Mean	0.41342	87.461106
Variance	0.2016	2265.0601
Observations	8	8
df	7	7
F	8.9E-05	
P(F<=f) one-tail	1.2E-13	**UNEQUAL**
F Critical one-tail	0.26406	

Table 2. t-Test: Two-Sample Assuming Unequal Variances between CONTROL and RES2012.

	Variable 1	*Variable 2*
Mean	0.413424274	87.46110572
Variance	0.201604838	2265.060108
Observations	8	8
Hypothesized Mean Difference	0	
df	7	
t Stat	-5.173006321	
P(T<=t) one-tail	0.0006454	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.001290799	**SIGNIFICANTLY MORE CARBON IN RES2012**
t Critical two-tail	2.364624252	

F-test for variances between CONTROL and RES2012 showed unequal (P(F<=f) one-tail = 1.2E-13) while RES2012 has significantly more carbon than the CONTROL (P(T<=t) two-tail = 0.00129).

Table 3. F-Test Two-Sample for Variances between 2012 and 2000.

	RES2012	*RES2000*
Mean	87.4611	149.84178
Variance	2265.06	5603.871
Observations	8	8
df	7	7
F	0.4042	
P(F<=f) one-tail	0.12751	**EQUAL**
F Critical one-tail	0.26406	

Table 4. t-Test: Two-Sample Assuming Equal Variances between 2012 and 2000.

	Variable 1	*Variable 2*
Mean	87.46110572	149.8417823
Variance	2265.060108	5603.871009
Observations	8	8
Pooled Variance	3934.465559	
Hypothesized Mean Difference	0	
df	14	
t Stat	-1.989011081	
P(T<=t) one-tail	0.033303928	
t Critical one-tail	1.761310136	
P(T<=t) two-tail	0.066607855	**MARGINALLY SIGNIFICANT**
t Critical two-tail	2.144786688	

Comparing the variances between RES2012 and RES2000 are showed equal (P(F<=f) one-tail = 0.12751) and there is a marginally significant difference in means between RES2012 and RES2000 (P(T<=t) two-tail = 0.0666).

Table 5. F-Test Two-Sample for Variances between RES2000 and REF.

	RES2000	*REF*
Mean	149.842	178.31164
Variance	5603.87	18215.608
Observations	8	8
df	7	7
F	0.30764	
P(F<=f) one-tail	0.07133	**EQUAL**
F Critical one-tail	0.26406	

Table 6. t-Test: Two:Sample Assuming Equal Variances between RES2000 and REF.

	Variable 1	*Variable 2*
Mean	149.8417823	178.3116425
Variance	5603.871009	18215.60756
Observations	8	8
Pooled Variance	11909.73929	
Hypothesized Mean Difference	0	
df	14	
t Stat	-0.521752096	
P(T<=t) one-tail	0.304999436	
t Critical one-tail	1.761310136	
P(T<=t) two-tail	0.609998872	**INSIGNIFICANT DIFFERENCE**
t Critical two-tail	2.144786688	

The variances between RES2000 and REF are considered equal (P(F<=f) one-tail = 0.07133) but there is no significant difference in means between RES2000 and REF (P(T<=t) two-tail = 0.6099).

5.2. Tree community and diversity

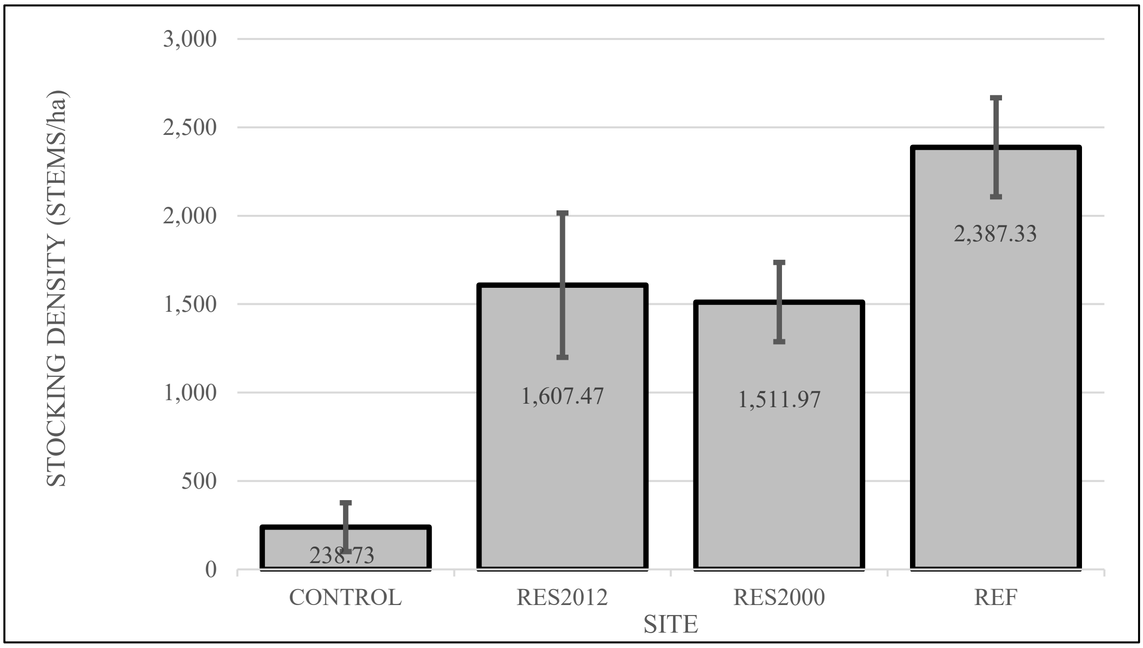

Figure 9. Estimated stocking density (STEMS/ha) in all four sites.

The graph presents the stocking density (stems/ha) for each site. CONTROL shows a low stocking density of 238.73 stems/ha. RES2012 exhibits a significantly higher stocking density of 1,607.47 stems/ha compared to CONTROL while RES2000 has a stocking density of 1,511.97 stems/ha, which is similar to that of RES2012. Displays the highest stocking density among all sites at 2,387.33 stems/ha. The error bars provide a measure of variability.

In basal area (m^2/ha) graph (Figure 12), the CONTROL shows the lowest amount of basal area which is 0.417 m^2/ha while RES 2012 displays a higher basal area of 24.67 m^2/ha. RES2000 reveal that a larger basal area of 41.58 m^2/ha than both CONTROL and RES2012. However, REF has the highest basal area over four sites at 45.19 m^2/ha. The error bars indicate variability within each site. Notably, the error bars for RES2000 and REF overlap, suggesting that the differences between these two may not be statistically significant.

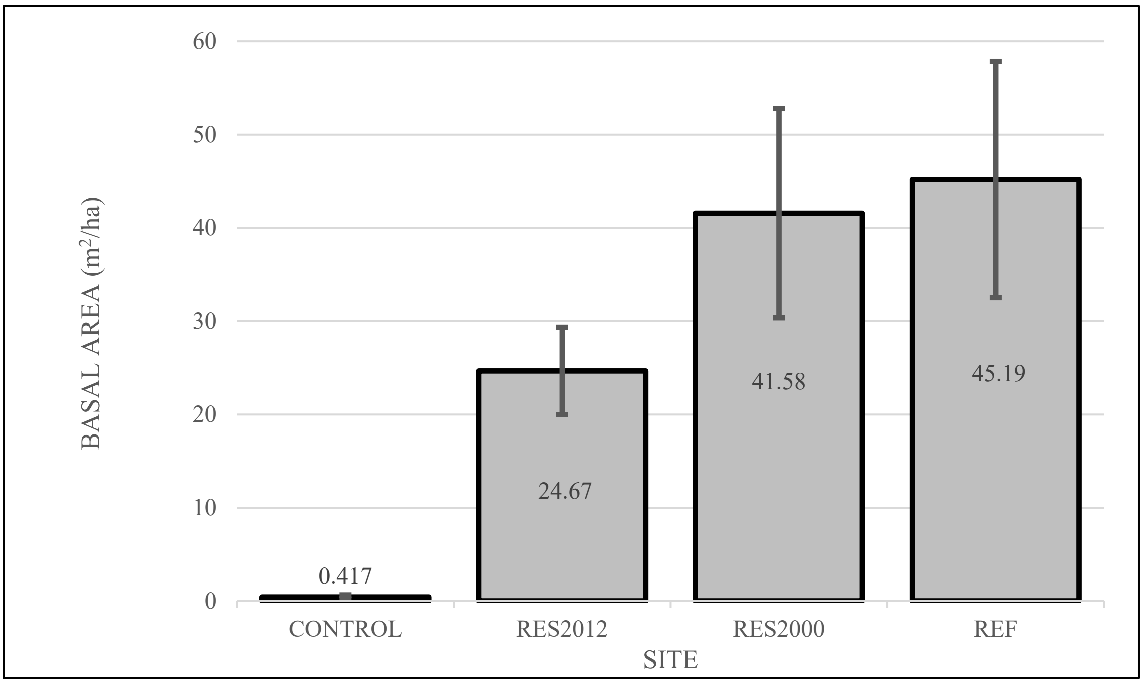

Figure 10. Estimated basal area (m²/ha) in all four sites.

In total, 362 trees representing 102 species were found over all 32 circles. The stocking density in the 12-year-old restoration site and the 24-year-old restoration site (Figure 11) was 1,607.47 and 1,511.97, (STEMS/ha) respectively, representing 67% and 63% of the reference forest levels. After 12 and 24 years, planting density decreased from 3,100/ha to 1,607 and 1,512 trees/ha (DBH>5 cm), likely due to competition and self-thinning. Nevertheless, the restoration plots' basal area (m^2/ha) approached that of the reference forest after 24 years. The basal area values of the 12-year-old restoration site and the 24-year-old restoration site were 56% and 92% of the reference forest value, respectively.

5.3. Cost-benefit Analysis (CBA) of carbon credits from forest restoration efforts via FSM

Table 7. Estimated revenue after subtracting establishment cost (USD/ha) for each site (*cost for 100 % tree planting method).

Forest Age (Since Start of Restoration) (Year)	No. of collected trees	Tree carbon (tC/ha)	tCO_2/ha	Carbon revenue (USD/ha)	Costs per tC sequestered (USD/tC) *	Revenue after subtracting establishment cost (USD/ha)
0	15	0.41	1.50	101.69	4.24	97.46
12	101	87.46	320.72	21693.22	904.34	20788.88
24	95	149.43	547.96	37064.00	1545.11	35518.90
50	151	178.3	653.83	44224.80	1843.62	42381.18

Table 7 show carbon credits revenue (USD/ha) of each site after subtracting the establishment cost (figure?). In the first 24 years, tree carbon increased by 149.43 tC/ha by following initiation of restoration interventions (100% Tree-Planting, Tree-Planting: Assisted Natural Regeneration (ANR) 50:50, 100% Assisted Natural Regeneration (ANR)) above control level. Moreover, the amount of CO_2 sequestration significantly increases with forest age. The table illustrates the rapid gains in the first 12-24 years of restoration interventions which show substantial economic returns.

Table 8. Potential value of incremental cash value (USD).

Forest Age (Since Start of Restoration) (Year)	Tree Carbon (tC/ha)	Increment (tC/ha)	tCO_2/ha	Carbon price USD/tCO_2	Increment Potential Cash Value (USD)
0	0.41	-		-	-
12	87.46	87.05	319.21	67.64	21591.52
24	149.84	62.38	228.75	67.64	15472.48
Total (0-24 Y)		149.43			37064.00

Table 8 indicates increment potential cash value (USD) of RES12 and RES24. At the time of writing (April 2025), the trading price for one ton of CO_2 on the European Emission

Allowance (EUA) market was 60.94 EUR per ton CO_2, which converted to 67.64 USD per ton CO_2, multiplied with the exchange rate (1 EUR = 1.11 USD, as of April 2025). Therefore, the exact number of USD/tC is 248.04 USD/tC (CO_2 is 3.667 times heavier than carbon alone (44/12)).

The tree carbon accumulation followed a logistic curve represented by the equation:

$$Tree\ Carbon\ (\frac{tC}{ha}) = \frac{171.5}{1 + e^{-0.2(Year-12.35)}}$$

Based on this model, predicted tree carbon from forest restoration efforts for approximately 34 years after establishing restoration measures can be seen. Therefore, the model was used to predict the carbon accumulation rate of each year to calculate the net present value (NPV) of future carbon credits value.

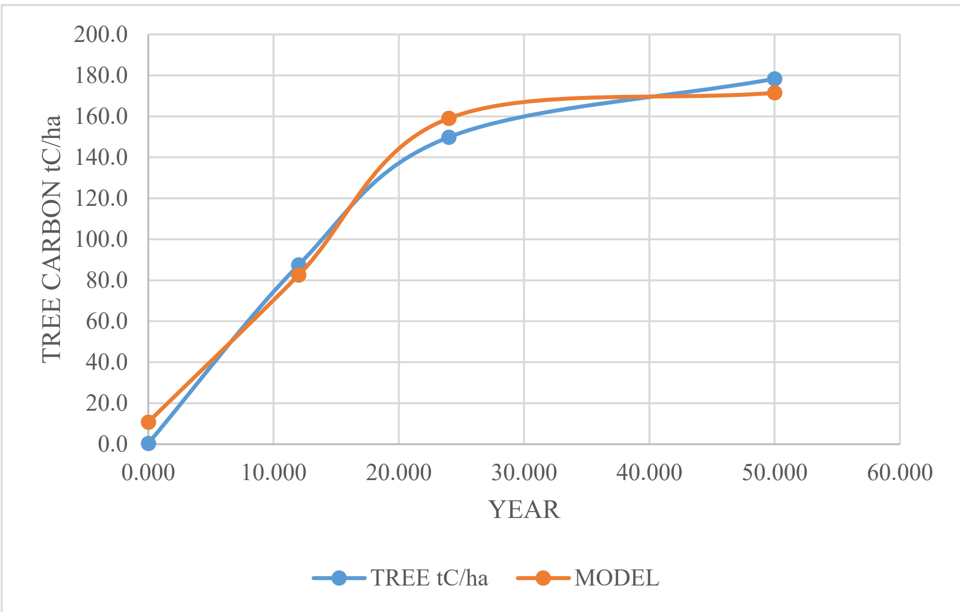

Figure 11. Logistic growth model of tree carbon accumulation (tC/ha). Carbon stocks reach 84% of reference forest levels (178.3 tC/ha) by 24 years.

Table 9. Cost of the framework species method (USD/ha) by standard procedures, including costs per tC sequestered (Elliott & Blakesley 2013)**.**

FIELD ESTABLISHMENT COSTS (USD)	**100% Tree-Planting**	**Tree-Planting: Assisted Natural Regeneration (ANR) 50:50**	**100% Assisted Natural Regeneration (ANR)**
Pre-planting site survey	13.07	13.07	13.07
Site preparation	297.4	244.1	190.8
Tree planting (+initial ANR tasks)	2,346.20	1,218.59	90.98
Maintenance (weeding, fertilizer) 2 years	1,398.36	1,398.36	1,398.36
Monitoring - 2 years	54.19	46.8	39.41
TOTAL FIELD COSTS BY TASK	4,109.21	2,920.91	1,732.61
10% CONTIGENCY FOR UNANTICIPATED TRANSACTION COSTS	410.92	292.09	173.26
SUBTOTAL	4,520.14	3,213	1,905.87
INTEREST	1,160.59	672.39	284.4
GRAND TOTAL	**5,680.72**	**3,885.39**	**2,190.27**
Costs per tC sequestered (USD/tC)	***10.34***	***7.07***	***3.99***
Costs per tree established (USD/tree)	***1.83***	***1.25***	***0.71***

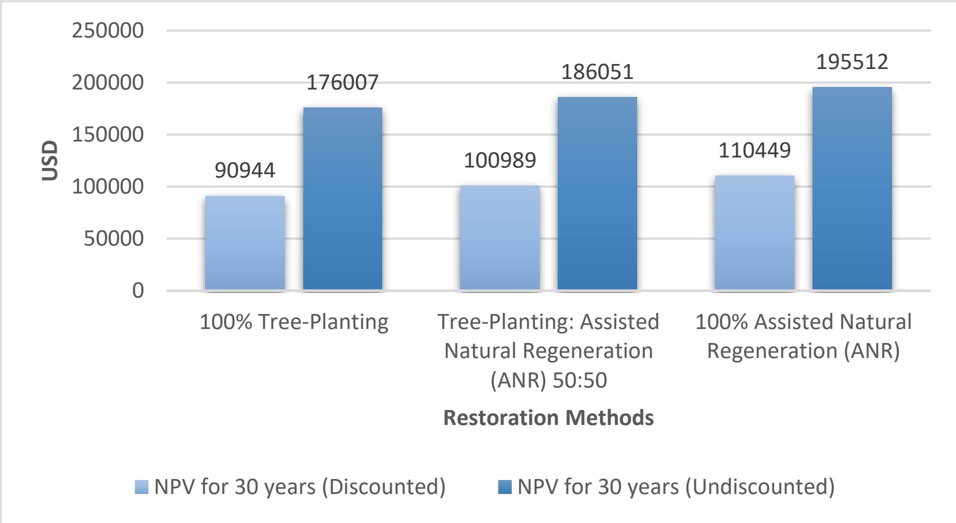

Figure 12. Net Present Value (NPV) of carbon credit revenue for over 30 years of three restoration methods (discount rate = 2.67 %).

The graph demonstrates the predicted net present value (NPV) of 30-year horizon to determine the financial viability of three restoration scenarios by applying discounted rate and undiscounted rate. In this study, the discount rate (r) was 2.67 %, combining the Thai bank annual deposit rate of 1.41 % and the Thailand annual inflation rate of 1.34 % (averaged from 2017 to 2024) which was calculated by the equation 4, a combination of the interest rate that money earn if saved in a bank and inflationary depreciation.

5.4. SWOT Analysis of emerging carbon market in Thailand

INTERNAL FACTORS

STRENGTHS +	WEAKNESSES –
• Strong institutional partnerships (TGO-Verra) • Scientific foundation for forest-based credits (Forest restoration via FSM) • Increasing domestic interest • The potential of community engagement	• Absence of formal carbon market (Governance challenges) • Limited private and public sectors engagement • Inequitable profit sharing and insufficient community participation • High initial costs for project implementation

EXTERNAL FACTORS

OPPORTUNITIES +	THREATS –
• Potential economic value of forest-based carbon credits • The growing interest in corporate social responsibility (CSR) • Micro-level carbon trading • Integration with international carbon market	• Conflicts over land use and ownership (Land tenure conflicts) • Economic pressures for alternative land uses (agriculture, development etc.) • Global carbon market instability • Changes in policy frameworks or verification standards

ANALYSIS SUMMARY
Thailand's emerging carbon market shows strong potential due to institutional partnerships, scientific foundation for forest-based credits, and increasing domestic and corporate interest, especially in forest restoration projects. Nevertheless, challenges like governance gaps, limited stakeholder engagement, and high initial costs are still needed to be considered. Opportunities include the potential economic value of carbon credits, expanding micro-level trading, and integrating with international markets. Land tenure conflicts, market instability, and changes in policy framework are threats for the emerging Thailand's carbon market. In general, Thailand has potential for progressing climate action through market-based mechanisms by addressing the mentioned strengths, weaknesses, opportunities, and threats.

6. Discussion

Carbon accumulation measured in the current study was lower than previous studied by Jantawong et al. (2022) in the same area. Specifically, an increase of 131 tC/ha (x1.24 to include roots) over 14 years using partial harvesting method presented in the previous study. Predicted carbon accumulation in the present study using logistic growth model was around 101 tC/ha over 14 years timeframe (equation 2). In a nearby restoration plot at Mon Cham, 10.5-11.5 years of tree-carbon accumulation at similar evaluation using FSM was estimated at 71.7-80.8 tC/ha which was collected using the same data-collection methods. Once again, the current investigation resulted in lower carbon accumulation, predicted as 64.3-73.3 tC/ha for 10-11 years from the logistic growth model (equation 2). Nevertheless, the carbon accumulation rates of the current study surpassed several benchmarks by comparison. The success natural forest restoration of the pan-tropical average was 69.2 tC/ha for over 20 years (Silver et al. 2000), while the current study's 20-years estimate is 144.4 tC/ha. This estimation is also higher than the estimation of the previous study which is an average gain of 83 tC/ha (x1.24 to include roots) over the first 20 years of natural forest regeneration in Khao Yai National Park, Central Thailand of Réjou-Méchain et al. (2020). Moreover, the teak plantations in western Thailand accumulated just 20 tC/ha (x1.24 to include roots) over 17 years (Chayaporn et al. 2021), while the predicted carbon accumulation of the present study is approximately 126 tC/ha at 17 years.

The specific equation used for logistic growth curve analysed the temporal patterns in carbon accumulation which were average rate of 5.9 tC/ha/year for the first 12 years, average rate of 6.38 tC/ha/year for the second 12 years and average rate of 0.4 tC/ha/year for beyond 24 years is minimal annual accumulation. This aligns with global patterns, where younger forests accumulate faster uptake of carbon due to high photosynthesis activity in rapidly growing pioneer species and reducing respiratory losses in younger tree structures (West 2019). Carbon accumulation rates drop after 50-60 years in recovering tropical secondary forests and (Chayaporn et al. 2021) also published a logistic growth model for teak trees plantations in Thailand, which shows a trend after 80-90 years. Therefore, more data on the carbon balance with logistic growth is necessary to compare carbon revenue to other land uses over longer time periods. Moreover, basal values for tropical woods vary from 20-40 m^2/ha, which is a typical value (Van der Meer et al. 2002), and so, the recorded basal values of the current study appear to be higher (Figure 12).

The study was calculated the value carbon gains for the trees carbon only. Accumulation of 150 tC/ha tree carbon over 24 years (Figure 10, Table 7) is equivalent to 550 tCO_2/ha. If this amount could be traded on global carbon markets, it would yield (at the current price of 67.64 USD/tCO_2) 37064 USD/tCO_2. Costs of carbon sequestration by the FSM range for three restoration methods (100% Tree-Planting, Tree-Planting: Assisted Natural Regeneration (ANR) 50:50, 100% Assisted Natural Regeneration (ANR)) are 3.99, 7.07, and 10.34 USD/tCO_2, respectively (Jantawong et al. 2022). Subtracting these establishment costs leaves 2195, 3889, 5687 USD/ha profit over 24 years.

Jantawong et al. (2022) showed that converting maize fields to forest, using the FSM, would yield around 16 times more income than continuing with maize cultivation—maize being the main driver of deforestation in northern Thailand. However, there no cap-and-trade system for offsetting industrial carbon emissions in Thailand. Companies are not legally required to compete for carbon credits in an open market, which would drive prices up to global levels. Additionally, Thailand does not have an open carbon market, meaning that the balance between supply and demand determine does not determine the price. Currently, only limited number of companies occasionally purchase low-priced "voluntary" carbon. Therefore, for farmers to benefit from converting their fields into forests for carbon trading, implementation of a cap-and-trade system and market for trading compliance credits will be required.

The current study on restored evergreen forests in Northern Thailand significantly demonstrated that economic value for carbon sequestration by cost-benefit analysis. Moreover, the research conducted in Bangkok revealed that micro-level carbon credit trading has the potential for empowering local residents and small businesses in carbon market participation, which can lead to foster broader public awareness and participation in climate change mitigation efforts (Ekwaraleartwong et al. 2025). Thailand's carbon market is developing toward structured trading systems with formal regulations. However, a research article on carbon market mechanisms in Thailand has determined governance challenges, including limited coordination between government agencies and insufficient regulatory clarity (Prapan 2023). These institutional weaknesses also create uncertainty for market participants and potential investors.

7. Conclusion

Forest restoration in northern Thailand using the framework species method (FSM) reveals that potential economic value of carbon credits has significant profits from carbon sequestration, with the comparing of four restored sites accumulating considerable above-ground carbon comparable to natural primary forests. The monetization of these requested carbon as carbon credits can provide a financially incentive for local communities, especially farmers to encourage in participating of sustainable forest management instead of destructive agricultural practices.

The economic valuation indicates that income from carbon credits can far exceed traditional agricultural income, potentially covering restoration costs and offering attractive financial returns. Nevertheless, high market entry costs, low carbon credits prices, socio-political barriers such as land tenure conflicts, lack of supportive policies and governance system are threating to the development of carbon market in Thailand. The limitation of these factors is still needed to consider regarding the accessibility and sustainability of carbon markets for smallholders and local stakeholders.

Even though carbon credits represent a potential financial mechanism for supporting forest restoration and climate mitigation efforts in northern Thailand, the requirements for successful implementation such as enhancing community empowerment, improving market structures, and incorporating non-ecosystem benefits into valuation frameworks are vital by considering in maximizing tackling the socio-economic and environmental impacts of forest restoration projects in the region.

Finally, the integration of forest restoration and carbon credit monetization offers a valuable pathway toward climate change mitigation and sustainable development in northern Thailand by facilitating equitable benefit-sharing mechanisms.

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9. Lists of questions for thesis defence by Dr. Dia Shannon (Research Advisor FORRU-CMU)

1. How do you think the Framework Species Method (FSM) compares to other forest restoration methods in terms of **long-term carbon sequestration?** What are the **advantages** and **limitations** of FSM in the context of northern Thailand?

FSM offers a balanced approach to ecological and economic sustainability.

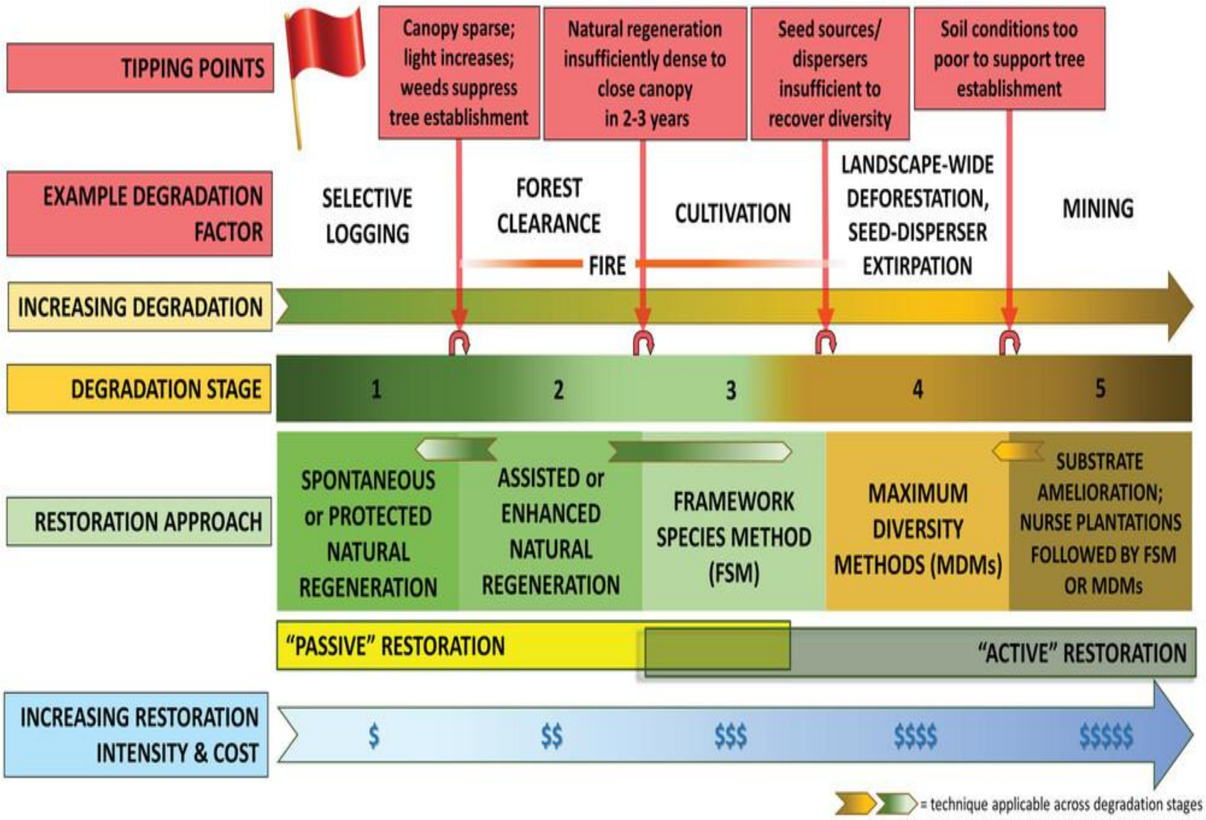

Figure. The FSM lies in the middle of a scale of restoration interventions, which become more intensive and more expensive, as initial degradation level increases (Elliott et al. 2022).

Methods	Degradation stage	Carbon sequestration (long-term)	Compare to FSM
Passive/Assisted	1, 2, 3	Moderate to high	Relies on **nearby forests**, less active planting, and recovery is **slower** than FSM.
FSM	3	High	**Fast** and **sustained** carbon accumulation, ideal for **moderately degraded land** like abandoned farms.
MDMs	4	Very high	May surpass FSM by planting many **native species.**
Substrate Amelioration + Nurse Plantations	5	Potentially high (but delayed)	Long time to recover, and uncertain **carbon returns.**

Table. FSM compares to other forest restoration methods (Source: Author).

Advantages of FSM in the context of northern Thailand

- **Scientifically proven method** adapted for the region.
- **Ecological succession** towards a self-sustaining forest ecosystem, **biodiversity recovery** and **other ecosystem services.**
- Significant **carbon accumulation**, substantial economic returns – outweigh restoration costs – potentially **higher income** than traditional land uses like maize cultivation.

Disadvantages of FSM in the context of northern Thailand

- **High initial costs** compared to passive methods.
- **Economic viability** relies on **the developing carbon market** in Thailand.
- Governance gaps, limited stakeholder engagement, and inequitable profit sharing
- Land tenure conflicts (**major socio-political barrier**)
- Threats like "**project fatigue**" and **insufficient funding**.
- Long lead-in research period needed to set up a FSM for any particular forest type.

2. What **factors might influence** the carbon sequestration rates observed in this study? Could you identify any **potential uncertainties or external variables** that may have affected **your results**?

Factors influencing the carbon sequestration rates

- **Forest age and restoration duration** – older restoration plots (more carbon) than younger ones – rates of carbon accumulation changes over time (faster to slower).
- **Specific site characteristics** (soil, topography, climate – wet/dry seasons) – affect tree growth and carbon uptake.
- **Proximity to intact forests** – influence natural regeneration.
- **Tree species composition and diversity** – influence biomass and carbon calculations.

Potential uncertainties or external variables

- **Single measurement point** – might not capture the full annual accumulation or long-term variability.
- **Allometric equations** for northern Thailand trees based on sample trees – uncertainty when applying to wide range of tree sizes and species.
- **External climate variability** and potential for extreme events.
- **General data availability** for monitoring

3. You’ve demonstrated the economic value of carbon credits from forest restoration. How do you think **carbon credit trading systems** can be **integrated into national policies**, particularly in developing countries like Thailand? What are **the challenges** in doing so?

Actively developing a domestic carbon market for low-carbon development under the Paris Agreement (Carbon Neutrality by 2025, Net-Zero by 2065) with **forests as a crucial sink** but Thailand **does not have** a formal, comprehensive carbon market with **clear governance structures**.

Integrating carbon credit trading systems into national policies	Challenges (in the context of Thailand)
Establish clear **legal and regulatory frameworks** (International standards such as REDD+, VCS, Gold Standard)	Lack of **formal market** and regulatory clarity
Implement **emissions trading systems** (ETS) or **compliance system** to create demand and drive prices, strengthen **voluntary offset programs** (e.g., Thailand Voluntary Emission Reduction Program – T-VER)	**Low carbon credit prices** and **high entry costs** delay active participation, especially for the smallholders
Provide support and ensure **equitable profit-sharing** for communities and project developers, incorporate **Corporate Social Responsibility (CSR)** commitments to attract private sector investment in forest restoration	**Land tenure conflicts** and **inequitable profit** distribution marginalize communities

Table. Integrating carbon credit trading systems into national policies and its challenges

4. In your SWOT analysis, you identified **governance challenges** as a barrier for Thailand's emerging carbon market. How would you propose **addressing these governance gaps** to make the carbon market more effective and equitable for **all stakeholders**, particularly **local communities**?

Governance challenges	Proposed strategies
Absence of formal carbon market	Legislate a **clear carbon market framework**, define **carbon ownership rights** (e.g., landowners vs. developers), adopt **international protocols** (REDD+, VCS, Gold Standard)
Limited private and public sectors engagement	Designate **a lead agency** (e.g., Thai Carbon Governance Office), provide **training programs** (e.g., FORRU-CMU, World Bank), and set **local carbon hubs** for monitoring small carbon projects
Inequitable profit sharing and insufficient community participation	Mandate **fair profit-sharing**, **support community-led projects**, and enable **direct market access** for smallholders
High initial cost for project implementation	Offer **financial support** for initial costs and explore **compliance markets** to boost demand

Table. Governance challenges and proposed strategies

5. Your thesis highlights the potential for carbon credits to generate significant revenue. However, you also noted challenges such as low carbon prices and limited market participation. How do you think the **carbon credit market** could evolve **in the future** to make it more **accessible** and **profitable** for **smallholders** and **rural communities**?

<u>Simplify market entry</u>

- From small farms/communities into larger bundles (e.g., **"carbon cooperatives"**) – to reduce transaction costs and meet buyer demand and create **user-friendly apps** to list credits directly, **bypassing intermediaries**.

<u>Boosting carbon prices</u>

- **Premium pricing** for community credits with social co-benefits (e.g., biodiversity) to attract ESG-focused buyers and set minimum prices for domestic credits.

<u>Reduce costs and risks</u>

- Use satellite monitoring (e.g., Global Forest Watch) to reduce **verification costs** and offer funding (via **Green Climate Fund** or NGOs) to cover setup costs for smallholders.

<u>Strengthen Governance</u>

- Clarify **carbon rights** and offer localized support and participatory governance.

6. How does your study contribute to the broader field of forest restoration and climate change mitigation, both in terms of **scientific knowledge** and **practical application**?

Scientific knowledge

- Provides **real-world data on carbon sequestration rates** from restored forests using FSM in northern Thailand.
- Demonstrates effectiveness of FSM in rapidly restoring carbon stocks (fill a research gap on **long-term monitoring of restored forests**).
- Links **ecology** and **economics** by converting carbon into revenue via **carbon credit valuation**.

Practical application

- Shows carbon credits can make restoration **financially attractive** for local communities.
- Supports **community-based restoration** by showing that local people can benefit from restoration if linked to carbon markets.
- Supports **policy integration of restoration** and **carbon markets** (identifying gaps in governance and suggesting strategies for more inclusive access).
- Informs **best practices** for scaling up restoration in tropical regions.

7. What are the **next steps** for your research? Are there **any additional studies** or **data collection** that could further strengthen the findings of this thesis or expand its scope?

The above-ground tree carbon accumulation (**current study**) is a part of FORRU's ongoing research project **"Effects of ecosystem restoration on forest carbon and biodiversity recovery"**, under the **BKIND project**, funded by The Next Forest. There are **four** BSc research projects.

Additional studies and data collection: below-ground soil carbon accumulation, biodiversity recovery (bird + mammals)

Limitations: focused on a single forest type in one location in northern Thailand

Future research: expanding such studies to more diverse forest types and geographical areas

The study established **standard protocols** for carbon measurement and economic analysis which could easily by applied to expanding such work to other forest types.

Potential further studies: long-term monitoring (beyond 24 years), cost-benefit analyses comparing FSM with other land uses (e.g., **agroforestry**) to guide community decision-making

10. Appendices

Appendix 1: DATA

- **Table - Tree species and no. individuals recorded in 8 circular sample units of 5 m radius**

Appendix 2: DATA FORMATS

- **Data Sheet – Tree Size**

Appendix 1: DATA

Table – Tree species and no. individuals recorded in 8 circular sample units of 5 m radius

SPECIES	CONTROL	12-Y-OLD RESTORATION	24-Y-OLD RESTORATION	REFERENCE FOREST	TOTAL	Note
Actinodaphne henryi				3	3	
Alangium kurzii		1		1	2	
Albizia chinensis			1		1	
Albizia odoratissima		2	3	1	6	
Antidesma bunius				4	4	
Antidesma ghaesembilla		1			1	
Aporosa villosa		1		9	10	
Arthocarpus lanceolata		4	1		5	
Artocarpus lacucha				3	3	
Artocarpus lakoocha		3	1	1	5	
Artocarpus rigidus		1			1	
Baccaurea ramiflora			1		1	
Balakata baccata			3		3	Planted
Berrya mollis		1			1	
Bischofia javanica		2			2	
Bridelia glauca				2	2	
Castanopsis acuminatissima		1	1	4	6	Planted
Castanopsis calathiformis		3			3	
Castanopsis diversifolia		1		3	4	
Castanopsis tribuloides			2		2	Planted
Choerospondias axillaris		6	20		26	Planted
Cinnamomum iners		1			1	
Cinnamomum longipetiolatum				1	1	
Colona floribunda				1	1	
Croton roxburghii				6	6	
Cryptocarya amygdalina				5	5	
Dalbergia cultrala				2	2	
Dalbergia ovata		6	1	6	13	
Dalbergia spinosa				6	6	
Dillenia parvifolia			2		2	
Elaeocarpus glandiflorus		1			1	
Elaeocarpus lanceifolius		2			2	
Engelhardia spicata		1			1	
Engelhardtia spicata		1		1	2	
Erythrina stricta		2			2	Planted
Eugenia albiflora				4	4	
Eugenia claviflora		2	2		4	

SPECIES	CONTROL	12-Y-OLD RESTORATION	24-Y-OLD RESTORATION	REFERENCE FOREST	TOTAL	Note
Eurya acuminata		4		1	5	
Fernandoa adenophylla		2		2	4	
Ficus benjamina			2		2	Planted
Ficus fistulosa		1	1	1	3	
Ficus glaberrima			5		5	Planted
Ficus hispida		2			2	
Ficus subulata				1	1	Planted
Ficus superba			2		2	
Garcinia merguensis				1	1	
Garuga pinnata			1		1	
Gluta usitata				1	1	
Gmelina arborea			1	1	2	Planted
Grewia eriocarpa				1	1	
Helicia nilagirica			1		1	Planted
Heliciopsis terminalis				1	1	
Heynea trijuga			1		1	Planted
Horsfieldia amygdalina		2		1	3	
Hovenia dulcis		1	1		2	Planted
Ilex umbelulata		2			2	
Kydia calycina			1		1	
Lannea coromandelica			1		1	
Lithocarpus elegans			1	6	7	Planted
Lithocarpus garrttianus		4	1		5	
Litsea glutinosa		1	1		2	
Litsea salicifolia		2	2	12	16	
Macaranga denticulata				1	1	
Machilus bombycina		1	3	4	8	Planted
Magnolia champaca		1			1	
Magnolia liliifera			2		2	
Markhamia stipulata		4	2	1	7	
Matadina trichotoma				1	1	
Measa ramenta		1	1		2	
Meliosma simplicifolia				1	1	
Michelia baillonii		2		1	3	
Micromelum minutum				1	1	
Miliusa velutina			1		1	
Morus macroura				1	1	Planted
Nothaphoebe umbelliflora		4		5	9	
Nyssa javanica			1		1	Planted

SPECIES	CONTROL	12-Y-OLD RESTORATION	24-Y-OLD RESTORATION	REFERENCE FOREST	TOTAL	Note
Ostodes paniculata				3	3	
Persea americana	15				15	
Phoebe cathia				1	1	
Phoebe lanceolata		1	5	7	13	
Prunus arborea			1		1	
Prunus cerasoides		5	9		14	Planted
Pterocarpus ovata		1			1	
Quercus semiserrata				2	2	Planted
Reevesia pubescens				3	3	
Sapindus rarak			1	2	3	Planted
Sarcosperma arboreum		1	1	2	4	
Schima wallichii		1		3	4	
Semecarpus cochinchinensis		2			2	
Sterculia villosa		1		1	2	
Stereospermum colais				1	1	
Styrax benzoides		1			1	
Styrax benzoin				2	2	
Symplocos racemosa		1		4	5	
Tarenna hoaensis				1	1	
Toona ciliata		1			1	
Trevesia palmata			1		1	
Turpinia pomifera		2	3	8	13	
Vernonia volkameriifolia		2			2	
Vitex quinata				1	1	
Wendlandia paniculata			4	2	6	
Wendlandia tinctoria		5			5	
No. of trees	**15**	**101**	**95**	**151**	**362**	
No. of tree species	**1**	**50**	**41**	**56**	**102**	

Appendix 2: DATA FORMATS

Data Sheet – Tree Size

LOCATION						**DATE:**
SAMPLE UNIT ID #:		**RECORDER:**		**CONT / RESTN / REF FOR**		
Within 5-m radius circle - count tree of GBH >5 cm only						
Label	**Tree Species**	**GBH (cm)**	**Height (m)**	**Crown Length (m)**	**Crown Width (m)**	**Notes**
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					
	Local Sci.					