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A Comprehensive Analysis of Land Use Types and Plant Characteristics in Carbon Sequestration in Ngiwngam

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Abstract

This study examined land use patterns, tree species diversity, biomass distribution, carbon sequestration, and oxygen release in Ngiwngam Subdistrict, Phitsanulok Province, Thailand. The research encompassed a total area of 6,054.72 hectares, categorized into 20 distinct land use types. Rice paddies dominated the landscape, covering over 97% of the area. A systematic sampling method using fifteen 40x40 meter plots revealed 18 tree species from 13 families, with banana trees being the most prevalent. Biomass estimation showed significant variations across land use types, with an average total biomass of 189.39 t/ha. Eucalyptus plantations exhibited the highest biomass (1,797.50 t/ha) and carbon stock (898.75 t/ha). The study quantified carbon sequestration and oxygen release rates, finding a total sequestration of 6,944.14 t/ha across all land use types, with Eucalyptus plantations leading at 3,295.42 t/ha. Oxygen release patterns closely mirrored carbon sequestration, totaling 5,050.28 t/ha. The research highlights the superior performance of tree-based systems, particularly fast-growing species like Eucalyptus and Bamboo, in carbon sequestration and oxygen production compared to annual crops and grasslands. These findings underscore the potential for strategic land use planning to enhance climate change mitigation efforts and ecosystem services in the region, suggesting that increasing tree cover through various means could significantly boost the landscape's capacity for carbon storage and oxygen generation.

Key Words	Land use, Carbon sequestration, Carbon stock, Agriculture
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Introduction

Anthropogenic climate change, primarily driven by the exponential increase in atmospheric greenhouse gas concentrations, particularly carbon dioxide (CO_2), presents an unprecedented challenge to global ecosystems and human civilization (Intergovernmental Panel on Climate Change [IPCC], 2021). The relentless rise in global mean surface temperature has precipitated a cascade of interconnected environmental perturbations, including accelerated sea-level rise, intensification of extreme weather events, and profound disruptions to agricultural systems and biodiversity. In this context of escalating climate crisis, carbon sequestration has emerged as a critical mitigation strategy, offering a potential mechanism to attenuate the rate of atmospheric CO_2 accumulation.

Carbon sequestration defined as the process of capturing and storing atmospheric carbon dioxide in long-term reservoirs, represents a vital component of the global carbon cycle management (Lal, 2008). Its significance in climate change mitigation is paramount; by facilitating the removal of CO_2 from the atmosphere and its subsequent storage in terrestrial, oceanic, or geological sinks, carbon sequestration provides a means to potentially decelerate or even reverse the accumulation of greenhouse gases, thereby mitigating the intensity of global warming effects.

Land use dynamics play a pivotal role in modulating carbon sequestration processes. The diverse mosaic of terrestrial ecosystems - encompassing forests, grasslands, agricultural lands, wetlands, and urban areas - exhibits significant heterogeneity in carbon sequestration capacity (Pan et al., 2011). Sharma et al. (2023) reported that converting natural ecosystems (forests, grasslands) to agricultural land typically results in SOC loss and different ecosystems have varying capacities for carbon storage, important for determining sequestration potential. The anthropogenic manipulation of land cover and land use directly influences the global carbon cycle, simultaneously affecting both carbon emissions and sequestration rates. This intricate interplay between land use and carbon dynamics underscores the necessity for nuanced understanding and strategic management of terrestrial ecosystems in the context of climate change mitigation. Moreover, carbon sequestration increases with increasing topographic gradient. This suggests that higher elevation areas or steeper slopes may have greater potential for carbon storage (He et al., 2023).

The impact of land use changes on carbon sequestration is multifaceted and often non-linear. For instance, the conversion of primary forests to agricultural land frequently results in substantial carbon emissions, depleting both above-ground biomass and soil organic carbon pools (Don et al., 2011). Conversely, reforestation initiatives or the implementation of sustainable agricultural practices, such as conservation tillage or agroforestry, can enhance terrestrial carbon sinks (Smith et al., 2008). Urban development, while traditionally associated with increased carbon emissions, can potentially contribute to sequestration through judicious urban planning, incorporation of green infrastructure, and utilization of carbon-sequestering construction materials (Churkina et al., 2020).

At the organismal level, carbon sequestration efficiency exhibits considerable variation across plant species and functional types. Arboreal species, characterized by substantial biomass accumulation and extended lifespans, are generally regarded as highly effective carbon sinks. A mature tree can sequester several tons of CO_2 over its lifetime, with sequestration rates varying based on species, age, and environmental conditions (Nowak & Crane, 2002). However, the sequestration potential of terrestrial ecosystems extends beyond arboreal components. Grasslands, for example, allocate a significant proportion of their carbon belowground, sequestering it in extensive root systems and recalcitrant soil organic matter fractions (Conant et al., 2017). Similarly, certain agricultural crops and management practices can contribute substantially to soil carbon sequestration, enhancing both climate mitigation potential and soil health (Paustian et al., 2016).

The efficacy of plants in carbon sequestering is contingent upon a complex interplay of factors, including growing rate, lifespan, and the fate of the captured carbon post-senescence. While rapid-growing species may exhibit high short-term carbon uptake rates, the long-term sequestration benefit can be limited if the captured carbon is swiftly re-released into the atmosphere through decomposition or combustion processes (Körner, 2017). Therefore, a comprehensive understanding of the carbon sequestration potential across diverse plant types and ecosystems is imperative for developing effective and sustainable land use strategies to combat climate change.

Ngiwngam Subdistrict is an exemplary model of agricultural landscapes in central Thailand, making it an ideal site for studying land use patterns and their environmental impacts. Although predominantly characterized by rice paddies, the subdistrict features diverse land use types, including tree plantations, orchards, and natural vegetation, facilitating comparative analyses of carbon sequestration and oxygen release. Located in a transitional zone between lowland agriculture and upland forests, Ngiwngam offers insights into landscape-level carbon management strategies. The region's significance as an agricultural hub underscores the need to balance food production with ecosystem services and climate change mitigation. Given the limited data on land use patterns and environmental impacts in Ngiwngam, this study is crucial for local and regional planning. Additionally, like many agricultural areas in Southeast Asia, Ngiwngam is vulnerable to climate change, making it essential to understand its carbon dynamics for developing adaptive strategies. The subdistrict also presents opportunities for optimizing land use to enhance carbon sequestration while maintaining agricultural productivity, positioning it as a vital case study for sustainable landscape management.

The researchers are particularly interested in studying the carbon sequestration potential of Ngiwngam Subdistrict, Mueang Phitsanulok District, Phitsanulok Province, specifically within the areas under local administrative organizations that are members of the Local Resource Base initiative. This study aims to enhance knowledge and gain insights that complement the researchers' academic field of study. The data obtained will elucidate the carbon sequestration capacity of the area. Furthermore, this information will provide governmental agencies with a robust foundation for policy-level decision-making at the provincial scale, particularly in developing strategies for promoting plant cultivation. Such strategies would enable local farmers to optimize land use while simultaneously conserving resources and sustainably maintaining forest ecosystems.

Methodology

1. Study Area

The research was conducted in Ngiwngam Subdistrict, Mueang District, Phitsanulok Province, encompassing a total land area of 6,054.72 hectares. This region falls under the purview of the Plant Genetic Conservation Project initiated under the royal patronage of Her Royal Highness Princess Maha Chakri Sirindhorn. The primary objective of this study was to quantify carbon sequestration in above-ground biomass, root systems, and understory vegetation within the administrative boundaries of the local government organization in Ngiwngam.

The selection of this study area is significant due to its participation in a royal conservation initiative, which provides a unique context for examining carbon sequestration in a managed landscape. The research aims to contribute to the understanding of carbon dynamics in diverse land use types within a local administrative unit, potentially informing both conservation strategies and climate change mitigation policies at the sub-district level.

By focusing on multiple components of the ecosystem (above-ground biomass, root systems, and understory vegetation), this study adopts a comprehensive approach to assessing carbon stocks. This multifaceted examination is crucial for accurately estimating the total carbon sequestration potential of the area and understanding the distribution of carbon across different Landuse land cover (LULC). The findings from this localized study have the potential to provide valuable insights into carbon sequestration patterns in similar ecological and administrative contexts, thereby contributing to the broader body of knowledge on terrestrial carbon dynamics in Thailand. The LULC data was obtained from Land development department (LDD) of Thailand on 2023

2. Field Sampling

Filed sampling was surveyed in May 2023. The study employed a systematic sampling approach to assess carbon sequestration across the study area, following established protocols (Pearson et al., 2007). The following methods were implemented:

1) Tree sampling: Fifteen 40x40 meter quadrats were randomly established across the study area. Within each quadrat, all tree species were identified and measured. For each tree, the diameter at breast height (DBH, measured at 1.3 meters above ground level), total height, and crown diameter were recorded (MacDicken, 1997).
2) Rice and Litter Sampling: Sixty 1x1 meter subplots were randomly placed within the larger quadrats to sample understory vegetation and surface litter, following the methodology outlined by Ravindranath and Ostwald (2008). These samples were collected to estimate carbon storage in understory biomass and forest floor litter.
3) Biomass Processing

Understory vegetation samples were oven-dried at 80°C for 48 hours or until a constant weight was achieved, as per standard protocols (Nelson & Sommers, 1996). The dry weight of the biomass (DW) was determined to biomass quantity.

3. Data Analysis

1) Tree biomass Estimation

Biomass components, including stem (WS), branch (WB), and leaf (WL) biomass, were estimated using species-specific allometric equations (Table 1) which related to land use type, following the approach recommended by Chave et al. (2014). Aboveground biomass (AGB) was calculated as the sum of these components (AGB = WS + WB + WL). Belowground biomass (RB), primarily comprising root biomass, was estimated using the widely accepted equation developed by Cairns et al. (1997): $RB = \exp(-1.0587 + 0.8836 \times \ln(AGB))$.

This comprehensive approach to biomass estimation allows for a more accurate assessment of carbon stocks across different tree components (Picard et al., 2012), providing a robust foundation for ecosystem carbon accounting. The study encompassed a diverse array of land use types, focusing on various agroforestry systems and plantations. The selected sites included orchards of tropical fruit trees such as Longan (*Dimocarpus longan*), Guava (*Psidium guajava*), Rose Apple (*Syzygium jambos*), Rambutan (*Nephelium lappaceum*), Tamarind (*Tamarindus indica*), Jackfruit (*Artocarpus heterophyllus*), Mango (*Mangifera indica*), and Santol (*Sandoricum koetjape*). Additionally, the research incorporated plantations of economically significant species like Bamboo (*Bambusa vulgaris*), Yang-na (*Dipterocarpus alatus*), Eucalyptus (*Eucalyptus* spp.), Rubber (*Hevea brasiliensis*), and Teak (*Tectona grandis*).

The study also included gardens of Lemon (*Citrus limon*), Neem (*Azadirachta indica*), Banana (*Musa* spp.), Papaya (*Carica papaya*), and Coconut (*Cocos nucifera*). This diverse selection of land use types provides a comprehensive representation of common agroforestry practices and plantation systems in the region, allowing for a thorough assessment of carbon sequestration potential across various vegetation structures (Roshetko et al., 2007; Nair et al., 2009).

Table 1 Allometric equation of each tree

Landuse	**Species**	**Stem (WS)**	**Branch (WB)**	**Leaf (WL)**	**ref**
Longan garden	*Dimocarpus longan*	$0.0396\ (DBH^2h)^{0.9326}$	$0.006003\ (DBH^2h)^{1.027}$	$[(28/\ WS+WB)+0.025]^{-1}$	Ogawa et al. (1965)
Guava garden	*Psidium guajava*				
Rambutan garden	*Nephelium lappaceum*				
Tamarind orchard	*Tamarindus indica*				
Mango orchard	*Mangifera indica*				
Rubber plantation	*Hevea brasiliensis*				
Teak	*Tectona grandis*				
Rose apple garden	*Syzygium jambos*				
bamboo garden	*Bambusa vulgaris*	$AGB = 0.2219DBH^{2.2749}$			Suwannapinunt et al., 1983
Jackfruit orchard	*Artocarpus heterophyllus*	$0.2903(DBH^2h)$ 0.9815	$0.11920WS^{1.059}$	$0.09146\ (WS+WB)^{0.7266}$	Zheng et al.,2008
Lemon garden	*Citrus limon*				
Santol Garden	*Sandoricum koetjape*	$0.0439\ (DBH^2h)^{0.8666}$	$0.0307\ (DBH^2h)^{0.8434}$	$0.0056\ (DBH^2h)^{0.9568}$	Ogawa et al. (1965)
Yang-na	*Dipterocarpus alatus*	$0.0509\ (DBH^2h)^{0.919}$	$0.00893\ (DBH^2h)^{0.977}$	$0.0140\ (DBH^2h)^{0.669}$	Ogawa et al. (1965)
Eucalyptus garden	*Eucalyptus* spp.	$0.0305\ (DBH^2h)^{0.9862}$	$0.0008\ (DBH^2h)^{1.2698}$	$0.0003\ (DBH^2h)^{1.1666}$	Treepatanasuwan et al. (2008
Neem Garden	*Azadirachta indica*	$0.0410\ (DBH^2h)^{0.9148}$	$0.0018\ (DBH^2h)^{1.1037}$	$0.0023\ (DBH^2h)^{0.9388}$	Viriyabuncha et al. (2004)
Teak plantation	*Tectona grandis*	$0.0439\ (DBH^2h)^{0.8666}$	$0.0307\ (DBH^2h)^{0.8434}$	$0.0056\ (DBH^2h)^{0.9568}$	Treepatanasuwan et al. (2008
banana plantation	*Musa* spp.	$AGB = 0.0303\ (DBH)^{2.1345}$			Arifin (2001)
Papaya Garden	*Carica papaya*	AGB =10(-1.625+2.63log(DBH))			Arifin (2001)
Coconut Garden	*Cocos nucifera*	AGB = 0.666 + 12.82 (h) 0.5(ln h)-			peason et al

2) **Carbon Stock Calculation**

Carbon stocks for various biomass components were calculated using the following equations: Carbon stocks = Biomass x CF Where CF is the carbon fraction of dry matter, assumed to be 0.47 IPCC (2006) guidelines.

3) **Carbon Sequestration and Oxygen Release Estimation**

CO_2 sequestration and Oxygen release was calculated using the molecular weight ratio of CO_2 to C (44/12) and O_2 to C (32/12), as described by IPCC (2003): CO2 sequestration (t c/ha) = Carbon stock (t c/ha) x 44/12 and O2 release (t c/ha) = Carbon stock (t c/ha) x 32/12

Results

1. Land use land cover

The land use patterns in Ngiwngam have been comprehensively analyzed. The subdistrict is characterized by a lowland area with structured land consolidation. The majority of the land is dedicated to agricultural purposes, benefiting from river systems and irrigation canals that facilitate year-round agricultural activities. The total land area of the subdistrict encompasses 6,054.72 hectares. A detailed land use classification revealed 20 distinct categories, showcasing the diversity of agricultural and vegetation types in the region. These categories, listed in descending order of area coverage, are as shown in **Figure 1.**

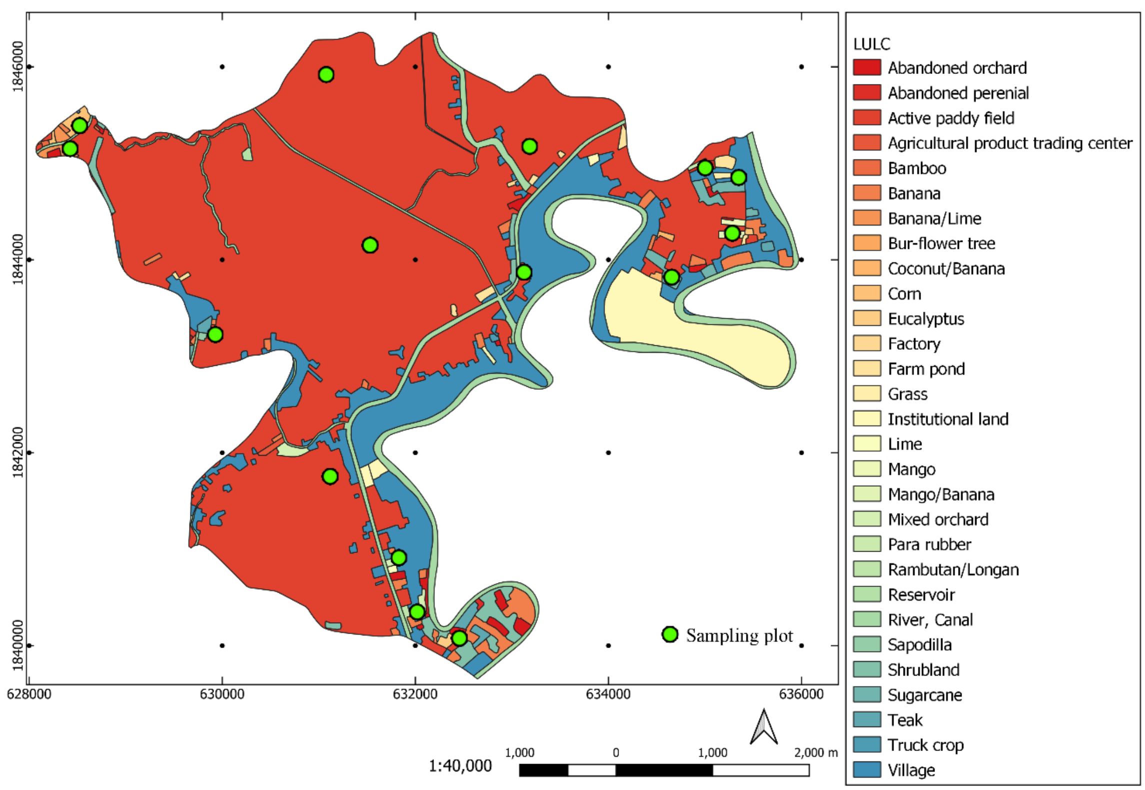

Figure 1 Land use land cover of Ngiwngam

This detailed land use classification provides valuable insights into the agricultural landscape and vegetation cover of Ngiwngam Subdistrict. The predominance of rice paddies, accounting for over 97% of the total area, underscores the significance of rice cultivation in the local agricultural economy. The presence of diverse fruit orchards, plantations, and mixed cropping systems reflects the adaptation of agricultural practices to local environmental conditions and market demands. Such comprehensive land use data is crucial for informed decision-making in land management, agricultural policy formulation, and sustainable development planning at the subdistrict level (Lambin et al., 2001; Turner et al., 2007).

2. Tree diversity

The study of tree species diversity in Ngiwngam was conducted using a systematic sampling method. Fifteen plots, each measuring 40x40 meters, were established across the study area. The survey revealed a total of 18 tree species belonging to 13 families, with an aggregate count of 3,701 individual trees. Analysis of species abundance indicated a clear dominance of certain species within the study area. The five most prevalent tree species were Banana, Mango, Teak, Neem, and Bamboo. The all of tree species data was shown in **Table 2.**

Table 2. Tree species in Ngiwngam

id	Species	Tree (individual)	Scientific name	Family name
1	Banana	2,091	*Musa* app.	MUSACEAE
2	Mango	2,73	*Mangifera indica*	ANACARDIACEAE
3	Teak	240	*Tectona grandis*	VERBENACEAE
4	Neem	176	*Azadirachta indica*	MELIACEAE
5	Bamboo	152	*Bambusa tulda*	POACEAE
6	Rubber tree	152	*Hevea brasiliensis*	EUPHORBIACEAE
7	Lime	131	*Citrus aurantifolia*	RUTACEAE
8	Eucalyptus	109	*Eucalyptus citriodora* Hook	MYRTACEAE
9	Rambutan	68	*Nephelium lappaceum*	SAPINDACEAE
10	Papaya	64	*Carica papaya*	CARICACEAE
11	Jackfruit	48	*Artocarpus heterophyllus*	MORACEAE
12	Longan	44	*Mangifera caesia*	ANACARDIACEAE
13	Tamarind	44	*Tamarindus indica*	FABACEAE
14	Coconut	36	*Cocos nucifera*	PALMAE
15	Santol	24	*Sandoricum koetjape*	MELIACEAE
16	Yangna	16	*Dipterocarpus alatus*	DIPTEROCARPACEAE
17	Rose apple	12	*Syzygium samarangense*	MYRTACEAE
18	Guava	8	*Psidium guajava*	MYRTACEAE

Notably, banana trees constituted the majority of the surveyed population, accounting for approximately 56.5% of the total tree count. This significant predominance of banana trees suggests a strong agricultural influence on the local vegetation structure, likely due to its economic importance in the region. The presence of commercially valuable species such as mango, teak, and bamboo among the top five most abundant trees further underscores the interplay between natural vegetation and agricultural practices in shaping the arboreal landscape of Ngiwngam Subdistrict. These findings provide valuable insights into the current composition and distribution of tree species in the study area, offering a foundation for further ecological analyses and informed decision-making in local forest management and conservation efforts.

3. Biomass Estimation

Table 3 investigates into biomass quantity and its relationship to land use patterns in Ngiwngam has yielded significant results. The study estimated an average total biomass of 189.39 t/ha across the area. Among the various land use categories, five stood out for their exceptionally high biomass quantities: Eucalyptus plantations led with 1,797.50 t/ha, followed by Bamboo (466.78 t/ha), Abandoned perennial trees (452.77 t/ha), Teak plantations (235.59 t/ha), and Rambutan/Longan orchards (193.01 t/ha). These land use types also demonstrated correspondingly high carbon stock values of 898.75, 233.39, 226.39, 117.80, and 96.50 t/ha, respectively. In contrast, the study identified five land use categories with notably low biomass quantities: Vegetable crops and Rice paddies (both at 4.44 t/ha), Coconut/Banana plantations (3.25 t/ha), Natural grasslands (2.88 t/ha), and Corn fields (2.63 t/ha). These findings underscore the substantial variability in biomass accumulation across different land use types in the study area.

The total accumulation biomass for the entire study area was estimated at 36,536.68 t. The five land use categories contributing the most to the total biomass were: Rice paddy field 20,443.68 t, Grasslands interspersed with shrubs and thickets 3,809.90 t, Abandoned orchard 3,300.38 t, Eucalyptus 3,163.61 t, and Teak plantations 1,636.50 t

These results provide a detailed assessment of biomass distribution across various land use types in the study area, demonstrating significant variability in biomass accumulation. The data highlights the importance of perennial vegetation, particularly abandoned or degraded trees and teak plantations, which contribute substantially to biomass stocks. This contrasts with agricultural lands such as vegetable crops and rice paddies, which, despite their extensive coverage, contribute relatively little to total biomass. The findings underscore the potential of certain land use practices to enhance carbon sequestration and emphasize the need for sustainable management strategies in agricultural and natural landscapes. The substantial biomass in abandoned or degraded perennial trees and fruit trees suggests an opportunity for land restoration efforts to further enhance carbon storage.

Table 3 the biomass and carbon stock in study area

id	LULC	Accumulation biomass (t)	biomass (t/ha)	Carbon stock (t/ha)
1	Eucalyptus	3,163.61	1,797.50	898.75
2	Bamboo	149.37	466.78	233.39
3	Abandoned perennial	796.88	452.77	226.39
4	Teak	1,960.14	235.59	117.80
5	Rambutan/Longan	247.05	193.01	96.50
6	Abandoned orchard	3,300.38	182.54	91.27
7	Shrubland	3,809.90	126.66	63.33
8	Mixed orchard	456.94	73.23	36.61

9	Coconut/Banana	388.71	59.25	29.63
10	Para rubber	46.21	57.77	28.88
11	Mango/Banana	82.69	43.07	21.53
12	Banana	1,408.21	29.63	14.82
13	Banana/lime	154.64	29.29	14.64
14	Mango	49.58	22.13	11.07
15	Lime	5.36	8.38	4.19
16	Rice paddy field	20,443.68	3.47	1.74
17	Sugarcane	62.35	3.12	1.56
18	Truck crop	2.57	1.61	0.80
19	Grass	1.65	1.03	0.51
20	Corn	6.75	0.88	0.44
Summation		36,536.68	3,787.71	1,893.86
Average		1,826.83	189.39	94.69

4. Carbon Sequestration and Oxygen Release Estimation

Our study examined carbon sequestration and oxygen release rates across 20 different land use and land cover (LULC) types in the study area (**Table 4**). The results reveal significant variations in these ecosystem services among different land uses, with implications for climate change mitigation and local air quality. The total carbon sequestration across all LULC types was calculated at 6,944.14 tonnes per hectare (t/ha), with an average of 347.21 t/ha. Notably, there was a wide range in sequestration rates, spanning from 1.61 t/ha to 3,295.42 t/ha. The top five LULC types for carbon sequestration were: Eucalyptus plantations (3,295.42 t/ha), Bamboo stands (855.76 t/ha), Abandoned perennial vegetation (830.08 t/ha), Teak plantations (431.92 t/ha), and Rambutan/Longan orchards (353.85 t/ha)

Eucalyptus plantations demonstrated an exceptionally high carbon sequestration rate, more than three times that of the next highest category. This underscores the potential of fast-growing tree species for rapid carbon capture. Conversely, the lowest carbon sequestration rates were observed in: Rice paddy fields (6.36 t/ha), Sugarcane fields (5.72 t/ha), Truck crops (2.95 t/ha), Grass (1.89 t/ha), and Corn fields (1.61 t/ha). These results highlight the relatively low carbon sequestration potential of annual crops and grasslands compared to perennial woody vegetation.

The study also quantified oxygen release, which closely mirrored carbon sequestration patterns. Total oxygen release across all LULC types was 5,050.28 t/ha, with an average of 252.51 t/ha. The top five oxygen releasing LULC types were estimated same carbon sequestration as Eucalyptus plantations (2,396.67 t/ha), Bamboo stands (622.37 t/ha), Abandoned perennial vegetation (603.70 t/ha), Teak plantations (314.12 t/ha), and Rambutan/Longan orchards (257.34 t/ha) There is a strong positive correlation between carbon sequestration and oxygen release across all LULC types. This relationship is expected due to the stoichiometric balance in photosynthesis, where CO2 uptake is directly linked to O2 production.

The results demonstrate that tree-based systems, particularly fast-growing species like Eucalyptus and Bamboo, offer the highest potential for both carbon sequestration and oxygen release. Abandoned perennial vegetation also shows high rates, suggesting that allowing natural regeneration of woody vegetation can significantly contribute to these ecosystem services.

In contrast, annual cropping systems and grasslands show much lower rates of both carbon sequestration and oxygen release. This highlights a potential trade-off between agricultural production and climate regulation services. The intermediate values observed in mixed orchards and plantation crops like rubber and banana indicate that agroforestry systems might offer a balanced approach, providing both ecosystem services and agricultural products.

These findings have important implications for land use planning and climate change mitigation strategies in the region. They suggest that increasing the area under tree cover, whether through commercial plantations, agroforestry, or natural regeneration, could significantly enhance the landscape's capacity for carbon sequestration and oxygen production.

Table 4 Carbon sequestration and oxygen release estimation in study area

id	LULC	Carbon sequestration (t/ha)	oxygen release (t/ha)
1	Eucalyptus	3,295.42	2,396.67
2	Bamboo	855.76	622.37
3	Abandoned perennial	830.08	603.70
4	Teak	431.92	314.12
5	Rambutan/Longan	353.85	257.34
6	Abandoned orchard	334.66	243.39
7	Shrubland	232.21	168.88
8	Mixed orchard	134.25	97.64
9	Coconut/Banana	108.63	79.01
10	Para rubber	105.91	77.02
11	Mango/Banana	78.96	57.42
12	Banana	54.33	39.51
13	Banana/lime	53.70	39.05
14	Mango	40.58	29.51
15	Lime	15.36	11.17
16	Rice paddy field	6.36	4.63
17	Sugarcane	5.72	4.16
18	Truck crop	2.95	2.14
19	Grass	1.89	1.37
20	Corn	1.61	1.17
Summation		6,944.14	5,050.28
Average		347.21	252.51

Discussion

Our findings on carbon sequestration and biomass distribution across different land use types offer significant insights for land use planning strategies. For instance, the superior performance of Eucalyptus plantations in carbon sequestration (3,295.42 t/ha) compared to other land use types suggests that strategic incorporation of fast-growing tree species into the landscape could substantially enhance the region's carbon sink capacity. The comprehensive analysis of land use patterns, tree species diversity, biomass estimation, and ecosystem services in Ngiwngam provides valuable insights into the complex interplay between agricultural practices, vegetation dynamics, and environmental services. This discussion will explore the implications of our findings, contextualize them within the broader scientific literature, and consider their significance for sustainable land management and climate change mitigation strategies.

The predominance of rice paddies, covering over 97% of the total area, underscores the critical role of rice cultivation in the local agricultural economy. This monoculture dominance is consistent with the broader agricultural landscape of Thailand, where rice is a staple crop and a significant export commodity (Sirisupluxana et al., 2017). However, the extensive coverage of a single crop type raises concerns about biodiversity, ecosystem resilience, and long-term sustainability. The diversity of other land use types, including various fruit orchards and plantations, suggests attempts at agricultural diversification. This aligns with global trends towards more diverse agricultural landscapes, which can enhance ecosystem services and economic resilience (Kremen & Miles, 2012). The presence of mixed cropping systems, albeit in smaller proportions, indicates potential pathways for increasing agricultural diversity and sustainability in the region.

The survey of tree species diversity revealed a total of 18 species from 13 families, with a clear dominance of banana trees. This finding reflects the strong agricultural influence on the local vegetation structure. The prevalence of commercially valuable species such as mango, teak, and bamboo among the most abundant trees further emphasizes the interconnection between economic priorities and vegetation composition. The dominance of banana trees (56.5% of the total count) is particularly noteworthy. While bananas are an important crop with significant economic value, their prevalence raises questions about the overall ecological balance and biodiversity of the area. High abundance of a single species can increase vulnerability to pests and diseases, potentially threatening both agricultural productivity and ecosystem stability (Altieri et al., 2015). The presence of teak and neem among the top five most abundant species is encouraging from both economic and ecological perspectives. Teak is a valuable timber species with high carbon sequestration potential (Kenzo et al., 2014), while neem is known for its multiple uses in agriculture and medicine, as well as its ecological benefits (Lokanadhan et al., 2012). The inclusion of these species in the landscape suggests opportunities for agroforestry systems that could enhance both economic returns and ecosystem services.

The biomass estimation results reveal significant variability across different land use types, with implications for carbon sequestration and climate change mitigation strategies. The exceptionally high biomass quantities observed in Eucalyptus plantations (1,797.50 t/ha) align with previous studies highlighting the rapid growth and high biomass accumulation potential of Eucalyptus species (Forrester et al., 2010). However, it is crucial to consider the ecological implications of large-scale Eucalyptus plantations, including potential impacts on water resources and biodiversity (Ferraz et al., 2013). The high biomass quantities in bamboo stands (466.78 t/ha) and abandoned perennial vegetation (452.77 t/ha) underscore the carbon sequestration potential of these land use types. Bamboo has gained attention as a fast-growing, renewable resource with significant carbon sequestration capabilities (Song et al., 2011). The high biomass in abandoned perennial vegetation suggests that natural regeneration processes can contribute substantially to carbon storage, highlighting the potential benefits of allowing some agricultural lands to revert to natural vegetation (Chazdon et al., 2016). The low biomass quantities observed in annual crops such as rice paddies, vegetable crops, and corn fields (ranging from 2.63 to 4.44 t/ha) highlight a critical challenge in balancing food production with climate change mitigation objectives. These findings align with global patterns where annual cropping systems generally have lower biomass and carbon sequestration potential compared to perennial vegetation (Lal, 2004).

The analysis of carbon sequestration and oxygen release rates across different land use types provides crucial insights into the climate regulation services of the landscape. The wide range in sequestration rates (1.61 to 3,295.42 t/ha) emphasizes the significant impact that land use decisions can have on the carbon balance of the region.

The exceptional performance of Eucalyptus plantations in both carbon sequestration (3,295.42 t/ha) and oxygen release (2,396.67 t/ha) aligns with their high biomass accumulation.

This finding supports the potential role of fast-growing tree plantations in rapid carbon capture strategies (Paquette & Messier, 2010). However, it is essential to balance these benefits against potential ecological drawbacks and consider the long-term sustainability of such plantations.

The high sequestration rates observed in bamboo stands, abandoned perennial vegetation, and teak plantations offer promising avenues for enhancing the carbon sink capacity of the landscape. These findings support the argument for integrating more perennial vegetation and agroforestry systems into agricultural landscapes as a strategy for climate change mitigation (Jose & Bardhan, 2012). The low carbon sequestration and oxygen release rates in annual cropping systems highlight a significant challenge in reconciling food production with climate regulation services. This trade-off is a central issue in sustainable land management and requires innovative approaches to increase the carbon storage potential of agricultural lands without compromising food security (Smith et al., 2013).

In Ngiwngam, the average total biomass is 189.39 t/ha, with Eucalyptus plantations showing the highest biomass at 1,797.50 t/ha. This level of biomass is comparable to findings from other regions in Southeast Asia. For instance, a study conducted in mixed agricultural landscapes in central Vietnam reported an average biomass of 172.5 t/ha (Chazdon & Guariguata, 2016), indicating a similar capacity for biomass accumulation in these agricultural systems. However, the Eucalyptus plantations in Ngiwngam demonstrate a notably higher biomass than the average of 1,250 t/ha reported for similar plantations in Sumatra (Forrester et al., 2010). This disparity may be attributed to several factors, including differences in plantation age, management practices, soil fertility, and local climatic conditions.

In terms of carbon sequestration, Ngiwngam's total carbon sequestration rate of 6,944.14 t/ha across all land use types exceeds the average of 5,500 t/ha reported for agricultural landscapes in northern Thailand (Don et al., 2011). This suggests that Ngiwngam Subdistrict may possess above-average carbon sequestration potential compared to other regions, highlighting its significance in regional carbon management strategies. Such findings align with broader observations across Southeast Asia, where land use practices significantly influence carbon dynamics. For example, studies have shown that agroforestry systems and well-managed tree plantations can enhance carbon storage capabilities (Jose & Bardhan, 2012; Roshetko et al., 2007).

Overall, the results from Ngiwngam Subdistrict underscore the potential for strategic land use planning to optimize biomass and carbon sequestration while maintaining agricultural productivity. This comparative analysis emphasizes the importance of local conditions and management practices in determining the effectiveness of carbon sequestration strategies across different agricultural landscapes in Southeast Asia.

Implications for Sustainable Land Management and Climate Change Mitigation

The findings of this study have several important implications for sustainable land management and climate change mitigation strategies in Ngiwngam Subdistrict and similar agricultural landscapes:

1. Diversification of Agricultural Systems: The dominance of rice paddies, while economically important, presents risks in terms of biodiversity loss and limited ecosystem services. Encouraging a more diverse agricultural landscape, including the integration of

tree-based systems and agroforestry, could enhance both ecological resilience and economic stability (Tscharntke et al., 2012).

2. Promotion of Perennial Vegetation: The high biomass and carbon sequestration potential of perennial vegetation, including abandoned orchards and tree plantations, suggests that increasing the cover of woody perennials could significantly enhance the carbon sink capacity of the landscape. This could be achieved through targeted reforestation, agroforestry initiatives, and policies that incentivize the maintenance of tree cover on agricultural lands (Chazdon et al., 2016).
3. Sustainable Management of High-Performing Species: While Eucalyptus plantations show exceptional performance in terms of biomass accumulation and carbon sequestration, their widespread adoption should be approached cautiously. Balancing the carbon benefits with potential ecological impacts requires careful planning and management strategies (Ferraz et al., 2013).
4. Enhancement of Carbon Storage in Agricultural Systems: Given the low carbon sequestration rates in annual cropping systems, there is a need for practices that enhance soil organic carbon and above-ground biomass in these systems. Conservation agriculture, cover cropping, and the integration of trees into agricultural landscapes are potential strategies to address this challenge (Lal, 2004).
5. Leveraging Natural Regeneration: The high biomass and carbon sequestration potential of abandoned perennial vegetation highlights the value of natural regeneration processes. Policies that allow for and incentivize the natural recovery of degraded or abandoned agricultural lands could provide a cost-effective approach to enhancing carbon sinks (Chazdon & Guariguata, 2016).
6. Balancing Multiple Ecosystem Services: The study underscores the need to consider multiple ecosystem services in land use planning. While carbon sequestration is crucial for climate change mitigation, other services such as biodiversity conservation, water regulation, and food production must also be considered in a holistic approach to landscape management (Bennett et al., 2009).
7. Policy Implications: The findings suggest a need for policies that incentivize land use practices that enhance carbon sequestration and other ecosystem services. This could include payments for ecosystem services, carbon credits for agroforestry and reforestation initiatives, and support for sustainable agricultural practices that increase soil carbon storage (Pagiola et al., 2005).

Conclusion

This study highlights the significant carbon sequestration potential of Ngiwngam Subdistrict, with an average total biomass of 189.39 t/ha and a total carbon sequestration rate of 6,944.14 t/ha across diverse land use types. Eucalyptus plantations emerged as the most effective in biomass accumulation, indicating their suitability for enhancing carbon storage in agricultural landscapes. These findings suggest that strategic land use planning, including the expansion of tree cover and the implementation of agroforestry practices, could substantially enhance carbon sequestration and improve ecosystem services in the region.

Recommendations for Future Research and Policy:

1. Targeted Reforestation: Identify areas within Ngiwngam Subdistrict that are suitable for reforestation with native tree species to maximize biodiversity and carbon storage.
2. Agroforestry Initiatives: Promote agroforestry systems that integrate trees with crops to optimize land use while enhancing carbon sequestration and soil health.
3. Longitudinal Studies: Conduct long-term monitoring of biomass and carbon dynamics to assess the effectiveness of different land management practices over time.
4. Policy Development: Encourage local policymakers to incorporate findings into land use policies that prioritize sustainable practices aimed at increasing carbon sinks while supporting agricultural productivity.

By adopting these strategies, Ngiwngam Subdistrict can play a pivotal role in regional efforts to mitigate climate change through enhanced carbon management practices. This revised conclusion succinctly summarizes your study's key findings while providing clear recommendations for future research and policy initiatives related to carbon sequestration and land use management.

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