Journal of Environmental & Earth Sciences
https://journals.bilpubgroup.com/index.php/jees

ARTICLE

Assessing Carbon Sequestration and Biomass Distribution across Diverse Land Use Types in Ban Krang Subdistrict, Phitsanulok Province

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ABSTRACT

This study investigates carbon dioxide (CO_2) sequestration and biomass distribution across various plant components and land use types in Ban Krang Subdistrict, Mueang District, Phitsanulok Province, with the goal of enhancing carbon management strategies. Field surveys were conducted using 14 plots of 40 × 40 meters to quantify biomass and estimate CO_2 sequestration across different vegetation types. The findings reveal an average CO_2 sequestration of 122.81 ton ha^{-1}, with aboveground biomass, particularly stems, contributing the most to carbon storage. Notably, abandoned perennial crops and mixed perennial crops demonstrated the highest sequestration rates, at 657.94 ton ha^{-1} and 613.00 ton ha^{-1}, respectively. In contrast, agricultural lands such as rice paddies and cassava plantations exhibited the lowest sequestration rates, though rice paddies contributed the highest total CO_2 sequestration, amounting to 61,119.71 tons, due to their extensive area. The study highlights the critical role of diverse and dense vegetation, particularly perennial crops, in maximizing carbon sequestration. It also underscores the potential for improving carbon storage in agricultural lands through better land management practices. The results suggest that targeted strategies should prioritize high-sequestration land use types while also enhancing carbon storage in low-sequestration areas. By optimizing land use and management practices, the region can significantly increase its carbon storage capacity, contributing to climate change mitigation and promoting long-term

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ARTICLE INFO
Received: 30 August 2024 | Revised: 19 October 2024 | Accepted: 23 October 2024 | Published Online: 2 December 2024
DOI: https://doi.org/10.30564/jees.v7i1.7169

CITATION
Panumonwatee, G., Premprasit, R., Pampasit. S., 2024. Assessing Carbon Sequestration and Biomass Distribution across Diverse Land Use Types in Ban Krang Subdistrict, Phitsanulok Province. Journal of Environmental & Earth Sciences. 7(1): 214–224.
DOI: https://doi.org/10.30564/jees.v7i1.7169

ecological sustainability. These insights are crucial for formulating effective carbon management strategies in Ban Krang Subdistrict, as well as in other comparable regions.

Keywords: Carbon Sequestration; Biomass Distribution; Land Use

1. Introduction

The exponential increase in atmospheric greenhouse gas concentrations, particularly carbon dioxide (CO_2), has driven anthropogenic climate change, posing an unprecedented threat to global ecosystems and human societies. This sustained rise in global average surface temperature has triggered a cascade of interconnected environmental disruptions, including accelerated sea-level rise, intensified extreme weather events, and significant disturbances to agricultural systems and biodiversity. In response to this escalating climate crisis, carbon sequestration has emerged as a critical mitigation strategy, offering a potential means to slow the accumulation of atmospheric CO_2 [1].

Land-use dynamics are pivotal in modulating carbon sequestration processes. The diverse mosaic of terrestrial ecosystems, such as forests, grasslands, agricultural lands, wetlands, and urban areas, exhibits considerable variability in carbon sequestration potential [2]. Human-driven land-use changes exert a direct influence on the global carbon cycle, simultaneously affecting carbon emissions and sequestration rates. This complex interaction between land-use patterns and carbon dynamics underscores the need for a nuanced understanding and strategic management of terrestrial ecosystems in the context of climate change mitigation. The effects of land-use changes on carbon sequestration are multifaceted and often non-linear. For instance, the conversion of primary forests to agricultural land typically results in substantial carbon emissions, reducing both above-ground biomass and soil organic carbon reserves [3]. Conversely, reforestation efforts or the adoption of sustainable agricultural practices, such as conservation tillage and agroforestry, can enhance terrestrial carbon sinks [4]. Urban development, though traditionally associated with increased carbon emissions, may also contribute to carbon sequestration through innovative urban planning, green infrastructure, and the use of carbon-sequestering building materials [5].

Carbon sequestration, a key component of global carbon cycle management, refers to the process of capturing atmospheric CO_2 and storing it in long-term reservoirs. This mechanism plays a crucial role in climate change mitigation by removing CO_2 from the atmosphere and depositing it in terrestrial, oceanic, or geological sinks, potentially slowing or reversing the accumulation of greenhouse gases and mitigating global warming [6]. The efficiency of carbon sequestration varies significantly across plant species and functional types. Trees, with their substantial biomass accumulation and long lifespans, are recognized as highly effective carbon sinks, with mature trees sequestering several tons of CO_2 over their lifetime. Sequestration rates vary depending on species, age, and environmental conditions [7]. However, carbon sequestration potential is not limited to arboreal species. Grasslands, for example, allocate a significant portion of their carbon belowground, storing it in extensive root systems and in stable soil organic matter fractions [8]. Similarly, certain agricultural crops and management practices can significantly contribute to soil carbon sequestration, enhancing both climate mitigation potential and soil health [9].

The Plant Genetic Conservation Project under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn (RSPG) is an initiative aimed at preserving Thailand's rich botanical heritage. The project encompasses various activities, including the conservation of plant genetic resources in natural forest areas, the survey and collection of plant species endangered by environmental changes, the cultivation and preservation of collected species in suitable and protected areas, and the sustainable use of these genetic resources. The project's multifaceted approach addresses key aspects of plant biodiversity conservation, including in-situ conservation of indigenous plant genetic material within natural forest ecosystems, systematic documentation and collection of species at risk of extinction due to environmental disturbances, ex-situ conservation through the cultivation and maintenance of species in secure locations, and the sustainable use of plant genetic resources with an emphasis on both conservation and practical application.

The researchers are particularly interested in assessing the carbon sequestration potential in Ban Krang Subdistrict, Mueang Phitsanulok District, Phitsanulok Province, specifically within areas under the jurisdiction of local administrative organizations participating in the RSPG. This study aims to enhance scientific knowledge and generate insights relevant to the researchers' academic field. The data obtained will elucidate the area's carbon sequestration capacity, providing a foundation for policy-level decision-making at the provincial level. Specifically, the information will assist governmental agencies in developing strategies to promote sustainable plant cultivation practices. Such strategies could enable local farmers to optimize land use while conserving natural resources and maintaining forest ecosystems. The research seeks to contribute to a deeper understanding of carbon dynamics across diverse land-use types within a local administrative unit, potentially informing both conservation strategies and climate change mitigation policies at the subdistrict level.

2. Materials and Methods

2.1. Study Area

The research was conducted in Ban Krang Subdistrict, Mueang Phitsanulok District, Phitsanulok Province, covering a total area of 12,212.19 hectares (approximately 122 km²). The primary objective was to quantify carbon sequestration in above-ground biomass, root systems, and understory vegetation within the local government administrative boundaries in Ban Krang.

This study area was chosen for its participation in the Plant Genetic Conservation Project, initiated under the royal patronage of Her Royal Highness Princess Maha Chakri Sirindhorn. This involvement provides a unique opportunity to examine carbon sequestration in a managed landscape. By assessing multiple ecosystem components—above-ground biomass, below-ground biomass, and understory vegetation—the study takes a comprehensive approach to evaluating carbon stocks. This multifaceted analysis is crucial for accurately estimating the area's total carbon sequestration potential and understanding how carbon is distributed across various land use and land cover (LULC) types. The 23 distinct LULC types studied include rice paddies, lowlands, sugarcane, teak, natural grasslands, corn, bananas, mangoes, abandoned fruit trees, vegetables, shrubland, cassava, abandoned trees, ornamental plants, bamboo, mixed tree species, coconut and banana plantations, eucalyptus, abandoned farmland, guavas and rose apples, limes, and coconut groves (**Figure 1**).

2.2. Field Sampling

Field data collection was conducted in June 2023 using a systematic sampling approach to assess carbon sequestration across the study area, adhering to well-established protocols [10]. The following methods were implemented:

2.2.1. Tree Sampling

Fifteen 40 × 40 meter quadrats were systematic randomly established throughout the study area. Within each quadrat, all tree species were identified, and their biometric parameters were 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, following the guidelines set by MacDicken [11].

The number of sampling plots was determined using the sample size equation [12] shown in Equation (1):

$$N = \left(\frac{z^2 \times s^2}{E^2} \times 10{,}000 \right)/1{,}600 \approx 12 \quad (1)$$

Where:

N = number of plots
Z = confidence level (1.96 for 95% confidence)
s = standard deviation (≈114.5 ton ha^{-1})
E = margin of error (10% of the average biomass)

The results showed that the number of plots used in the study (15 plots) exceeded the theoretically required number (12 plots), ensuring sufficient data collection.

2.2.2. Understory and Litter Sampling

Sixty 1 × 1 meter subplots were randomly placed within the larger quadrats to sample understory vegetation and surface litter, following the methodology outlined by Ravindranath and Ostwald [13]. These samples were collected to estimate carbon storage in understory biomass and forest floor litter (UB).

2.2.3. Biomass Processing

Understory and Litter samples were oven-dried at 80 °C for 48 hours or until a constant weight was achieved, in accordance with standard protocols [14]. The dry weight of the biomass (DW) was subsequently determined to quantify biomass quantity.

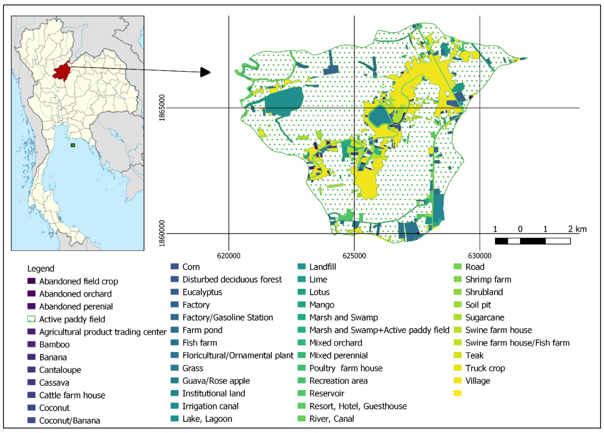

Figure 1. The map of study and LULC distribution.

2.3. Data Analysis

2.3.1. Tree Biomass Estimation

The estimation of biomass components, including stem (WS), branch (WB), and leaf (WL) biomass, was performed using species-specific allometric equations (refer to **Table 1**), tailored to different land use types in accordance with the methodology recommended by Chave et al.[15]. Aboveground biomass (AGB) was derived by summing these individual components (AGB = WS + WB + WL). For belowground biomass (RB), which predominantly consists of root biomass, the estimation followed the widely recognized equation proposed by Cairns et al.[16]: $RB = \exp(-1.0587 + 0.8836 \times \ln(AGB))$.

This integrated approach to biomass estimation enhances the accuracy of carbon stock assessments across various tree components (Picard et al., 2012)[17], thereby providing a reliable basis for ecosystem carbon accounting. The study was conducted across a diverse range of land use types, with a particular emphasis on different agroforestry systems and plantations. The selected sites included orchards of tropical fruit trees such as. Mango (*Mangifera indica*), Guava (*Psidium guajava*), Rose Apple (*Syzygium jambos*), Plum Mango (*Bouea macrophylla*), Jackfruit (*Artocarpus heterophyllus*), and Santol (*Sandoricum koetjape*).

Additionally, the research incorporated plantations of economically significant species like Bamboo (*Bambusa vulgaris*), Yang-na (*Dipterocarpus alatus*), Eucalyptus (*Eucalyptus spp.*), Black Rosewood (*Afzelia xylocarpa*), Pradu (*Pterocarpus macrocarpus*), and Teak (*Tectona grandis*).

The study also included gardens of Lemon (*Citrus limon*), Neem (*Azadirachta indica*), Banana (*Musa spp.*), Agarwood (*Aquilaria crassna*), 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[18, 19].

2.3.2. Carbon Stock Calculation

Carbon stocks for various biomass components were calculated using the following equations: Carbon stocks = Biomass × CF Where CF is the carbon fraction of dry matter, assumed to be 0.47 IPCC[1] guidelines.

2.3.3. Carbon Sequestration

The quantification of carbon dioxide (CO_2) sequestration can be derived from the total carbon content through stoichiometric analysis. The CO_2 molecule comprises one carbon atom and two oxygen atoms, with respective atomic masses of 12u and 16u. The molecular mass ratio of CO_2 to C is calculated from the molecular mass of CO_2 (44u, derived from one carbon atom at 12u plus two oxygen atoms at 16u each) divided by the atomic mass of carbon (12u), yielding a conversion factor of 3.67 (44/12 = 3.67). Therefore, the mass of sequestered CO_2 can be determined by multiplying the tree's carbon mass by this conversion factor of 3.67, which accounts for the complete molecular structure of carbon dioxide relative to its carbon component.

3. Results

3.1. Biomass Estimation

Ban Krang Subdistrict, Mueang District, Phitsanulok Province, is primarily characterized by lowland areas. It is predominantly utilized for agricultural purposes, with rice farming being the most common practice. This agricultural activity is supported by an irrigation system that allows for year-round cultivation. The green or agricultural area amounts is 9,683 ha or approximately 80% of the total area, and land use is distributed across 22 distinct types as shown in **Figure 1**, including rice paddies, lowland, sugarcane, teak, natural grassland, corn, bananas, mangoes, abandoned orchards, vegetables, mixed grassland/shrubland, cassava, abandoned perennial crops, ornamental plants, bamboo, mixed perennial crops, coconut/banana, eucalyptus, abandoned fields, guava/rose apple, lime, coconut.

Table 1. Allometric equation of each tree.

Land Use	Species	Stem (WS)	Branch (WB)	Leaf (WL)	Reference
Teak	*Tectona grandis*	$0.0396 (DBH^2h)^{0.9326}$	$0.006003(DBH^2h)^{1.027}$	$[(28/WS + WB) + 0.025]^{-1}$	Ogawa et al. [20]
Black Rosewood	*Afzelia xylocarpa*				
Pradu	*Pterocarpus macrocarpus*				
Mango orchard	*Mangifera indica*				
Rose apple garden	*Syzygium jambos*				
Guava garden	*Psidium guajava*				
Agarwood	*Aquilaria crassna*				
White Popinac	*Leucaena leucocephala*				
bamboo garden	*Bambusa vulgaris*	$AGB = 0.2219DBH^{2.2749}$			Suwannapinunt et al. [21]
Jackfruit orchard	*Artocarpus heterophyllus*	$0.2903(DBH^2h)^{0.9815}$	$0.11920WS^{1.059}$	$0.09146 (WS + WB)^{0.7266}$	Zheng et al. [22]
Lemon garden	*Citrus limon*				
Plum Mango	*Bouea macrophylla*				
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. [21]
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. [21]
Eucalyptus garden	*Eucalyptus spp.*	$0.0305 (DBH^2h)^{0.9862}$	$0.0008 (DBH^2h)^{1.2698}$	$0.0003 (DBH^2h)^{1.1666}$	Treepatana-suwan et al. [23]
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. [24]
banana plantation	*Musa spp.*	$AGB = 0.0303 (DBH)^{2.1345}$			Arifin [25]
Coconut Garden	*Cocos nucifera*	AGB = 0.666 + 12.82 (h) 0.5(ln h)			Peason & Brown [26]

Table 2 shows a survey conducted using 14 plots, each measuring 40 × 40 meters, identified 17 tree species belonging to 12 families. A total of 2,334 individual trees were recorded across the study area. The five most common species were bamboo, banana, eucalyptus, mango, and lime, with respective counts of 739, 573, 203, 172, and 140 trees, respectively. The biomass results were visualized to illustrate the spatial distribution, as presented in **Figure 2**.

The study of biomass distribution across various plant components in Ban Krang (**Table 3**), revealed a total average biomass of 71.25 ton ha^{-1}. The aboveground biomass constituted the largest portion at 57.25 ton ha^{-1}, followed by stem biomass at 37.38 ton ha^{-1}, branch biomass at 13.06 ton ha^{-1}, root biomass at 9.00 ton ha^{-1}, understory and litter biomass at 5.00 ton ha^{-1}, and leaf biomass at 4.13 ton ha^{-1}. The total biomass in the study area amounted to 57,556.55 ton. The understory and litter component comprised the largest portion at 45,354.54 ton, followed by aboveground biomass at 10,530.79 ton, stem biomass at 6,697.87 ton, branch biomass at 2,455.04 ton, root biomass at 1,671.22 ton, and leaf biomass at 951.26 ton.

Analysis of biomass distribution across different land use types in the study area showed an average biomass of 71.25 ton ha^{-1}. The five land use types with the highest biomass density were: abandoned perennial crops (381.75 ton ha^{-1}), mixed perennial crops (355.69 ton ha^{-1}), grassland interspersed with shrubs/scrub (240.63 ton ha^{-1}), teak plantations (204.44 ton ha^{-1}), and eucalyptus plantations (130.50 ton ha^{-1}). Conversely, the five land use types with the lowest biomass density were: rice paddies (4.63 ton ha^{-1}), abandoned fields (4.50 ton ha^{-1}), natural grasslands (4.13 ton ha^{-1}), cassava plantations (3.25 ton ha^{-1}), and ornamental plant gardens (3.06 ton ha^{-1}).

Table 2. The number of individual trees in study area.

ID	Species	Scientific Name	Family Name	Amount (Trees)
1	Bamboo	*Bambusa tulda*	POACEAE	739
2	Eucalyptus	*Eucalyptus citriodora Hook*	MYRTACEAE	203
3	Plum Mango	*Bouea macrophylla*	ANACARDIACEAE	32
4	Agarwood	*Aquilaria crassna*	THYMELAEACEAE	15
5	Neem	*Azadirachta indica*	MELIACEAE	59
6	Black Rosewood	*Afzelia xylocarpa*	FABACEAE	11
7	White Popinac	*Leucaena leucocephala*	FABACEAE	12
8	Jackfruit	*Artocarpus heterophyllus*	MORACEAE	15
9	Yang-na	*Dipterocarpus alatus*	DIPTEROCARPACEAE	125
10	Teak	*Tectona grandis*	VERBENACEAE	80
11	Rose Apple	*Syzygium samarangense*	MYRTACEAE	27
12	Guava	*Psidium guajava*	MYRTACEAE	12
13	Lime	*Citrus aurantifolia*	RUTACEAE	140
14	Padauk	*Pterocarpus macrocarpus*	FABACEAE	12
15	Banana	*Musa × paradisiaca*	MUSACEAE	573
16	Coconut	*Cocos nucifera*	PALMAE	107
17	Mango	*Mangifera indica*	ANACARDIACEAE	172
		Total		**2,334**

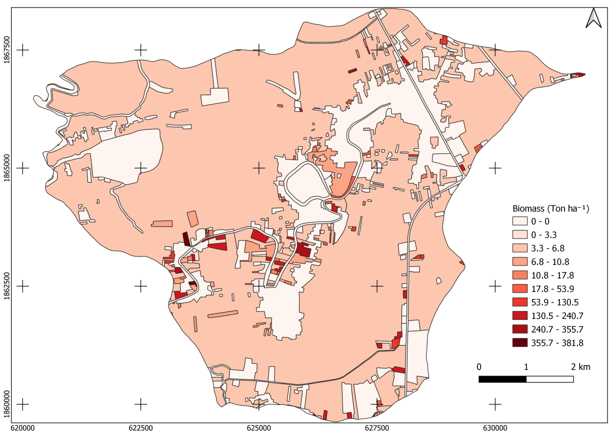

Figure 2. The spatial distribution of biomass.

Regarding the total biomass distribution across land use types in the study area, the five types with the highest total biomass were: rice paddies (35,465.98 ton), lowland areas (8,359.09 ton), teak plantations (5,298.73 ton), grassland interspersed with shrubs/scrub (2,579.80 ton), and abandoned perennial crops (1,588.17 ton). The five land use types with the lowest total biomass were: guava/rose apple orchards (8.55 ton), coconut/banana plantations (6.93 ton), lime orchards (6.26 ton), melon fields (3.64 ton), and abandoned fields (2.16 ton). These findings highlight the significant variation in biomass distribution across different plant components and land use types in the study area, providing valuable insights for carbon stock assessments and land management strategies.

3.2. Carbon Sequestration Estimation

The study of carbon dioxide sequestration across various plant components in Ban Krang Subdistrict, Mueang District, Phitsanulok Province, revealed a total average CO_2 sequestration of 122.81 ton ha^{-1}. The aboveground components exhibited the highest sequestration at 98.63 ton ha^{-1}, followed by stem at 64.44 ton ha^{-1}, branches at 22.56 ton ha^{-1}, roots at 15.56 ton ha^{-1}, understory and litter at 8.56 ton ha^{-1}, and leaves at 7.13 ton ha^{-1}.

The total CO_2 sequestration in the study area amounted to 99,189.11 ton. The understory and litter component comprised the largest portion at 78,160.99 ton, followed by aboveground biomass at 18,148.05 ton, stem at 11,542.67 ton, branches at 4,230.85 ton, roots at 2,880.07 ton, and leaves at 1,639.34 ton. Analysis of CO_2 sequestration across different land use types in the study area showed an average of 122.81 ton ha^{-1}. The five land use types with the highest CO_2 sequestration were: abandoned perennial crops (657.94 ton ha^{-1}), mixed perennial crops (613.00 ton ha^{-1}), grassland interspersed with shrubs/scrub (414.75 ton ha^{-1}), teak plantations (352.31 ton ha^{-1}), and eucalyptus plantations (224.88 ton ha^{-1}). Conversely, the five land use types with the lowest CO_2 sequestration were: rice paddies (8.00 ton ha^{-1}), abandoned fields (7.75 ton ha^{-1}), natural grasslands (7.13 ton ha^{-1}), cassava plantations (5.63 ton ha^{-1}), and ornamental plant gardens (5.25 ton ha^{-1}).

Table 3. Comparative analysis of biomass density and total biomass across LULC types in Ban Krang.

ID	LULC	Area (ha)	WS (ton)	WB (ton)	WL (ton)	AGB (ton)	RB (ton)	UB (ton)	Total Biomass (ton)	Biomass (ton ha^{-1})
1	Rice paddies	7,668	-	-	-	-	-	35,465.98	35,465.98	4.63
2	Lowland areas	1,779	-	-	-	-	-	8,359.09	8,359.09	4.70
3	Teak plantations	25.92	2,364.31	1,305.37	759.19	4,476.71	744.56	77.46	5,298.73	204.43
4	mixed grass-land/shrubland	10.72	1,599.53	475.04	31.22	2,207.18	314.50	58.12	2,579.80	240.65
5	Aandoned perennial crops	4.16	975.19	325.70	42.64	1,343.53	217.16	27.48	1,588.17	381.77
6	mangoes	12.8	1,075.16	182.89	36.17	1,294.21	234.14	42.97	1,571.33	122.76
7	Sugarcrane	86.56	-	-	-	-	-	871.86	871.86	10.07
8	abandoned orchards	11.2	326.22	18.29	7.37	494.77	68.92	40.08	603.78	53.91
9	mixed perennial crops	1.6	294.86	124.37	69.20	488.43	76.51	4.20	569.14	355.71
10	bananas	15.84	-	-	-	119.64	-	73.09	192.73	12.17
11	corn	18.08	-	-	-	-	-	113.02	113.02	6.25
12	Eucalyptus	0.64	44.49	20.03	3.12	67.63	13.44	2.43	83.50	130.47
13	natural grassland	18.72	-	-	-	-	-	77.38	77.38	4.13
14	vegetables	11.04	-	-	-	-	-	75.05	75.05	6.80
15	cassava	8.8	-	-	-	-	-	28.82	28.82	3.28
16	bamboo	3.04	11.14	2.32	2.09	15.55	-	9.73	25.28	8.32
17	coconut	0.48	-	-	-	10.67	-	2.93	13.60	28.33
18	ornamental plants	3.84	-	-	-	-	-	11.74	11.74	3.06
19	guava/rose apple	0.48	4.69	0.73	0.14	5.56	1.15	1.84	8.55	17.81
20	coconut/banana	0.64	-	-	-	3.81	-	3.12	6.93	10.82
21	lime	0.48	2.19	0.29	0.13	2.98	0.80	2.48	6.26	13.04
23	abandoned fields	0.48	0.10	0.01	-	0.12	0.04	2.00	2.16	4.49
	Total	**9,683**	**6,698**	**2,455**	**951**	**10,531**	**1,671**	**45,351**	**57,553**	**1,628**

Regarding the total CO_2 sequestration across land use types in the study area, the aggregate amount was 141,496.37 ton. The five types with the highest total CO_2 sequestration were: rice paddies (61,119.71 ton), lowland areas/rice paddies (14,405.51 ton), teak plantations (9,131.48 ton), grassland interspersed with shrubs/scrub (4,445.86 ton), and abandoned perennial crops (2,736.95 ton).

The study of carbon dioxide sequestration across various plant components in Ban Krang Subdistrict, Mueang District, Phitsanulok Province, revealed a total average CO_2 sequestration of 122.81 ton ha^{-1}. The aboveground components exhibited the highest sequestration at 98.63 ton ha^{-1}, followed by stem at 64.44 ton ha^{-1}, branches at 22.56 ton ha^{-1}, roots at 15.56 ton ha^{-1}, understory and litter at 8.56 ton ha^{-1}, and leaves at 7.13 ton ha^{-1}.

The total CO_2 sequestration in the study area amounted to 99,189.11 ton. The understory and litter component comprised the largest portion at 78,160.99 ton, followed by aboveground biomass at 18,148.05 ton, stem at 11,542.67 ton, branches at 4,230.85 ton, roots at 2,880.07 ton, and leaves at 1,639.34 ton. Analysis of CO_2 sequestration across different land use types in the study area showed an average of 122.81 ton ha^{-1}. The five land use types with the highest CO_2 sequestration were: abandoned perennial crops (657.94

ton ha^{-1}), mixed perennial crops (613.00 ton ha^{-1}), grassland interspersed with shrubs/scrub (414.75 ton ha^{-1}), teak plantations (352.31 ton ha^{-1}), and eucalyptus plantations (224.88 ton ha^{-1}). Conversely, the five land use types with the lowest CO_2 sequestration were: rice paddies (8.00 ton ha^{-1}), abandoned fields (7.75 ton ha^{-1}), natural grasslands (7.13 ton ha^{-1}), cassava plantations (5.63 ton ha^{-1}), and ornamental plant gardens (5.25 ton ha^{-1}).

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The analysis across different land use types shows substantial differences in CO_2 sequestration potential. Abandoned perennial crops and mixed perennial crops exhibited the highest sequestration rates at 657.94 ton ha^{-1} and 613.00 ton ha^{-1}, respectively. These findings indicate that areas with diverse and long-lived vegetation types are particularly effective in sequestering CO_2. The high sequestration rates in these land use types could be attributed to the dense biomass and the extended life cycle of perennial plants, which allow for sustained carbon storage.

On the other hand, land use types such as rice paddies, abandoned fields, and cassava plantations showed the lowest sequestration rates, ranging from 5.25 to 8.00 ton ha^{-1}. This disparity highlights the lower carbon storage potential of agricultural and disturbed lands, likely due to factors such as soil disturbance, lower biomass density, and shorter plant life cycles. In terms of total CO_2 sequestration, rice paddies stood out with the highest aggregate amount at 61,119.71 tons, despite their low per hectare sequestration rate. This can be attributed to the extensive area covered by rice paddies in the study region. Similarly, lowland areas, teak plantations, and grasslands interspersed with shrubs also contributed significantly to the total sequestration due to their widespread presence.

However, it is noteworthy that while certain land use types like abandoned perennial crops and mixed perennial crops had high per hectare sequestration rates, their total contribution to CO_2 sequestration was relatively lower. This indicates that while these land uses are efficient at carbon storage on a per hectare basis, their limited spatial extent reduces their overall impact. The findings from this study have important implications for land management and carbon sequestration strategies in the region. Promoting land use types with high sequestration potential, such as mixed perennial crops and abandoned perennial crops, could enhance the overall carbon sequestration in the area. Conversely, improving the management of low-sequestration land use types, like rice paddies and cassava plantations, could further optimize carbon storage across the landscape.

Overall, this study underscores the critical role of vegetation and land use in carbon sequestration. It highlights the need for targeted strategies to maximize CO_2 capture, particularly in areas with high sequestration potential, to mitigate climate change and enhance ecological sustainability.

4. Discussion

The findings of this study on carbon dioxide (CO_2) sequestration and biomass distribution across various plant components and land use types in Ban Krang Subdistrict, Mueang District, Phitsanulok Province, provide valuable insights into the region's carbon storage potential. The study area, characterized predominantly by agricultural land, reveals significant variation in CO_2 sequestration and biomass distribution, which is crucial for developing effective land management strategies aimed at enhancing carbon capture and storage.

The study revealed that the aboveground biomass, particularly the stems, played a dominant role in CO_2 sequestration, with an average of 98.63 ton ha^{-1}. This finding aligns with previous research indicating that aboveground biomass, especially in forested areas, is a major contributor to carbon storage due to its substantial mass and longevity [15]. The significant sequestration by the stems underscores the importance of maintaining mature and structurally robust vegetation for carbon management strategies.

Interestingly, despite the lower per hectare sequestration, the understory and litter components contributed the largest portion of the total CO_2 sequestration in the study area, amounting to 78,160.99 tons. This outcome highlights the critical role of ground-level and litter biomass, which, although often overlooked, serves as a substantial carbon sink, particularly in ecosystems with dense understory vegetation [27].

The results of this study highlight the marked differences in carbon sequestration potential among various land use types, particularly emphasizing the contrast between rice paddies and perennial crops. Rice paddies, while contributing the highest total CO_2 sequestration—amounting to 61,119.71 tons due to their extensive area—exhibit lower per-hectare sequestration efficiency compared to perennial crops. In contrast, abandoned perennial crops and mixed perennial crops demonstrate significantly higher sequestration rates, recorded at 657.94 tons ha^{-1} and 613.00 tons ha^{-1}, respectively. This indicates that although rice paddies cover a larger area and thus contribute substantially to overall carbon storage, the efficiency of carbon capture per unit area is considerably greater in perennial systems.

These findings suggest that land management strategies should prioritize the enhancement of perennial crop systems to optimize carbon sequestration. The critical role of diverse and dense vegetation in maximizing carbon storage becomes evident, as perennial crops not only sequester more carbon per hectare but also support richer biodiversity. Implementing sustainable agricultural practices within rice paddies, such as integrating agroforestry or cover cropping techniques, could improve their carbon sequestration potential.

The analysis of CO_2 sequestration across different land use types revealed significant disparities [28]. Abandoned perennial crops and mixed perennial crops showed the highest sequestration rates, which can be attributed to the dense and diverse vegetation typical of these land use types [29]. These results are consistent with studies that emphasize the carbon sequestration potential of perennial vegetation due to its longer life cycle and higher biomass density [30].

Conversely, agricultural land use types, such as rice paddies and cassava plantations, exhibited the lowest CO_2 sequestration rates. This is likely due to factors such as frequent soil disturbance, lower biomass density, and the short-lived nature of these crops, which limit their carbon storage potential [31]. However, the extensive area covered by rice paddies in the region resulted in the highest total CO_2 sequestration, underscoring the impact of land area on total carbon sequestration, even for low-density vegetation types.

These findings have significant implications for land management and climate change mitigation strategies in Ban Krang Subdistrict. The high sequestration rates observed in perennial crop areas suggest that promoting the cultivation of mixed perennial crops and maintaining abandoned perennial lands could be effective strategies for enhancing carbon sequestration in the region. Furthermore, improving the management of low-sequestration agricultural lands, such as by incorporating agroforestry practices or enhancing soil carbon storage, could further optimize carbon capture across the landscape [4].

The study also underscores the importance of considering both biomass distribution, and land use when developing carbon management strategies. By identifying land use types with high sequestration potential, policymakers and land managers can target specific areas for conservation or reforestation efforts to maximize carbon storage and contribute to global climate change mitigation goals. Overall, this study advocates for targeted land management approaches that focus on high-sequestration land use types while simultaneously enhancing carbon storage in areas with lower sequestration rates, like rice paddies. By optimizing land use and management practices, it is possible to significantly increase carbon storage capacity in the region, contributing to climate change mitigation efforts and promoting long-term ecological sustainability.

5. Conclusions

This study provides critical insights into the carbon sequestration potential across various land use types in Ban Krang Subdistrict, Phitsanulok Province. Our findings reveal an average CO_2 sequestration rate of 122.81 tons ha^{-1}, indicating the significant capacity of the region to act as a carbon sink. Notably, abandoned perennial crops and mixed perennial crops exhibited the highest sequestration rates at 657.94 tons ha^{-1} and 613.00 tons ha^{-1}, respectively, demonstrating their effectiveness in capturing atmospheric carbon compared to other land uses. Conversely, while rice paddies contributed the highest total CO_2 sequestration—amounting to 61,119.71 tons due to their extensive area—their per-hectare efficiency remains lower than that of perennial systems. This highlights the need for targeted management strategies that prioritize high-sequestration land use types while also enhancing carbon storage in lower-performing areas such as rice paddies. The study underscores the importance of diverse and dense vegetation in maximizing carbon sequestration, suggesting that improved land management practices could significantly increase carbon storage capacity in agricultural lands. By optimizing land use and implementing sustainable agricultural practices, it is possible to enhance the region's contribution to climate change mitigation efforts.

Author Contributions

G.P. conceptualized and formulated the research methodology, conducted statistical analyses, interpreted the empirical findings, and prepared the original draft of the manuscript. R.P. executed field sampling protocols and contributed to primary data acquisition. S.P. provided project supervision, critical academic oversight, and substantive intellectual contributions throughout the research implementation. All authors participated in manuscript revision, critically reviewed the intellectual content, and approved the final version for submission. G.P. serves as the corresponding author for this publication.

Funding

This research was financially supported by the 2023 Fundamental Fund of Thailand Science Research and Innovation (TSRI) under the project titled "The Carbon Dioxide Storage in Local Administration Organization Phitsanulok province Database Partner Plant Genetic Conservation Project Under the Royal Initiation of Her Highness Princess Maha Chakri Siridhorn" (Grant No. 4366604).

Institutional Review Board Statement

Not applicable as this study did not involve human subjects or medical research requiring ethical review.

Informed Consent Statement

Not applicable as this study did not involve human subjects.

Data Availability Statement

The raw data supporting the conclusions of this article, including biomass measurements, carbon stock calculations, and land use classification data collected from Ban Krang Subdistrict, Phitsanulok Province, are available from the corresponding author upon reasonable request.

Acknowledgments

The authors would like to express their sincere gratitude to Naresuan University for providing the institutional support and research infrastructure necessary to conduct this comprehensive study on carbon sequestration and biomass distribution. Special thanks are extended to the Faculty of Agriculture Nature Resources and Environment and the Department of Natural Resources and Environment for their academic guidance and resources. We are deeply appreciative of the local authorities and community members of Ban Krang Subdistrict, Phitsanulok Province, for their cooperation and assistance during field research and data collection. Their local knowledge and support were instrumental in the successful completion of this research.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

[1] Intergovernmental Panel on Climate Change, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, MA, USA.

[2] Pan, Y., Birdsey, R.A., Fang, J., et al., 2011. A Large and Persistent Carbon Sink in the World's Forests. Science. 333(6045), 988–993. DOI: https://doi.org/10.1126/science.1201609

[3] Don, A., Schumacher, J., Freibauer, A., 2011. Impact of Tropical Land-Use Change on Soil Organic Carbon Stocks – A Meta-Analysis. Global Change Biology. 17(4), 1658–1670. DOI: https://doi.org/10.1111/j.1365-2486.2010.2336.x

[4] Smith, P., Martino, D., Cai, Z., et al., 2008. Greenhouse Gas Mitigation in Agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences. 363(1492), 789–813. DOI: https://doi.org/10.1098/rstb.2007.2184

[5] Churkina, G., Organschi, A., Reyer, C.P.O., et al., 2020. Buildings as a global carbon sink. Nature Sustainability. 3(4), 269–276. DOI: https://doi.org/10.1038/

s41893-019-0462-4

[6] Lal, R., 2008. Carbon Sequestration. Philosophical Transactions of the Royal Society B: Biological Sciences. 363(1492), 815−830. DOI: https://doi.org/10.1098/rstb.2007.2185

[7] Nowak, D.J., Crane, D.E., 2002. Carbon Storage and Sequestration by Urban Trees in the USA. Environmental Pollution. 116(3), 381−389. DOI: https://doi.org/10.1016/S0269-7491(01)00214-7

[8] Conant, R.T., Cerri, C.E.P., Osborne, B.B., et al., 2017. Grassland Management Impacts on Soil Carbon Stocks: A New Synthesis. Ecological Applications. 27(2), 662−668. DOI: https://doi.org/10.1002/eap.1473

[9] Paustian, K., Lehmann, J., Ogle, S., et al., 2016. Climate-Smart Soils. Nature. 532(7597), 49−57. DOI: https://doi.org/10.1038/nature17174

[10] Pearson, T., Walker, S., Brown, S., 2007. Sourcebook for Land Use, Land-Use Change and Forestry Projects. Winrock International and the World Bank Biocarbon Fund. World Bank Group: Washington, DC, USA.

[11] MacDicken, K.G., 1997. A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects. Winrock International Inst. for Agricultural Development, Forest Carbon Monitoring Program: Arlington, VA, USA.

[12] Lowman, M.D., Schowalter, T.D., Franklin, J.F., 2012. Methods in Forest Canopy Research. University of California Press: Berkeley, CA, USA.

[13] Ravindranath, N.H., Ostwald, M., 2008. Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects. Springer Science & Business Media: New York, NY, USA.

[14] Nelson, D.W., Sommers, L.E., 1996. Total Carbon, Organic Carbon, and Organic Matter. Methods of Soil Analysis: Part 3 Chemical Methods. 5, 961−1010.

[15] Chave, J., Réjou-Méchain, M., Búrquez, A., et al., 2014. Improved Allometric Models to Estimate the Aboveground Biomass of Tropical Trees. Global Change Biology. 20(10), 3177−3190.

[16] Cairns, M.A., Brown, S., Helmer, E.H., et al., 1997. Root biomass allocation in the world's upland forests. Oecologia. 111(1), 1−11.

[17] Picard, N., Saint-André, L., Henry, M., 2012. Manual for building tree volume and biomass allometric equations: from field measurement to prediction. FAO, Food and Agricultural Organization of the United Nations: Roma, Italy.

[18] Roshetko, J.M., Lasco, R.D., Angeleas, M.S.D., 2007. Smallholder agroforestry systems for carbon storage. Mitigation and Adaptation Strategies for Global Change. 12, 219−242. DOI: https://doi.org/10.1007/s11027-005-9010-9

[19] Nair, P.K.R., Kumar, B.M., Nair, V.D., 2009. Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science. 172, 10−23. DOI: https://doi.org/10.1002/jpln.200800030

[20] Ogawa, H., Yoda, K., Ogino, K., 1965. Comparative ecological studies on three main types of forest vegetation in Thailand. II plant Biomass. Nature and life in southeast Asia. 4, 49−80.

[21] Suwannapinunt, W., 1983. A study on the biomass of Thyrsostachys siamensis Gamble Forest at Hin-Lap, Kanchanaburi. Journal of Bamboo Research. 2(2), 82−101.

[22] Zheng, D., Yang, Q.Y., Wu, S.H., et al., 2008. China's Ecogeographical Regionalization Research. The Commercial Press: Beijing, China.

[23] Treepatanasuwan, P., Diloksumpun, S., Sathaporn, D., et al., 2008. Carbon Sequestration in Biomass of Some Tree Species Planted at Phu Phan Royal Development Study Center, Sakon Nakhon Province. Research Report. Department of National Parks, Wildlife and Plant Conservation: Bangkok, Thailand.

[24] Viriyabuncha, C., Rattanapornjaroe, W., Mangklararat, J., et al., 2004. Biomass and Growth of Some Economic Tree Species for Carbon Storage Estimation in Forest Plantation. In Proceedings of the Conference on Climate Change in Forestry: Forests and Climate Change, Bangkok, Thailand, 16−17 August 2004.

[25] Arifin J., 2001. Estimasicadangan C pada berbagaisistem penggunaan lahan di Kecamatan Ngantang, Malang. Skripsi-S1. Unibraw: Malang, Indonesia.

[26] Pearson, T., Brown, S., 2005. Guide de mesure et de suivi du carbone dans les forêts et prairies herbeuses. Winrock International. 11−35.

[27] Ketterings, Q.M., Wibowo, T.T., van Noordwijk, M., et al., 2001. Farmers' Perspectives on Slash-and-Burn as a Land Clearing Method for Small-Scale Rubber Producers in Sepunggur, Jambi Province, Sumatra, Indonesia. Forest Ecology and Management. 146(1−3), 145−158.

[28] Crews, T.E., Rumsey, B.E., 2017. What Agriculture Can Learn from Native Ecosystems in Building Soil Organic Matter: A Review. Sustainability. 9(4), 578. DOI: https://doi.org/10.3390/su9040578

[29] Monti, A., Zatta, A., 2009. Root Distribution and Soil Carbon Sequestration of Different Perennial and Annual Bioenergy Crops. Agricultural Ecosystems & Environment. 132(3−4), 329−339. DOI: https://doi.org/10.1016/j.agee.2009.04.007

[30] De Deyn, G.B., Cornelissen, J.H.C., Bardgett, R.D., 2008. Plant Functional Traits and Soil Carbon Sequestration in Contrasting Biomes. Ecology Letters. 11(5), 516−531.

[31] Lal, R., 2004. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science. 304(5677), 1623−1627.