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Estimation of aboveground carbon stock in service area of Ubon Ratchathani Zoo, Ubon Ratchathani province, Northeastern Thailand

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Abstract Results found a total of 200 trees of 22 species which belongs to from 16 families. The most common family was Dipterocarpaceae with 129 trees, including *Shorea roxburghii* G. Don (40% of total trees), *Dipterocarpus alatus* Roxb. (17% of total trees), and *Dipterocarpus intricatus* Dyer (7% of total trees). The total aboveground biomass and total carbon storage for all trees were 52,337.3 kg (200.1 kg rai^{-1}) and 24,598.5 kg (.246 ton), respectively. A total of carbon dioxide absorption for the study site was 85.4 t-CO_2 or 60.6 t-CO_2 ha^{-1} (9.7 t-CO_2 rai^{-1}). It is provided an important data for climate mitigation policy i.e., carbon credit policy and carbon credit trading in the future. This study is firstly estimated of carbon storage by trees growing in the service area of National Zoo in Northeastern Thailand.

Keywords: Climate change, Biomass, Carbon storage, Ubon Ratchathani Zoo, Carbon credit

Introduction

Among any other factors related to climate change such as the fast-growing industries and agricultural areas, greenhouse effect is the main driver of climate change worldwide (Kabir *et al.,* 2023). The increasing concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHG) in the Earth's atmosphere is the largest contributor to global warming todate (Letcher, 2020; Kabir *et al.,* 2023). The atmospheric CO_2 can be absorbed by trees and other plants through photosynthesis and consequently accumulated in living and dead organisms (i.e., plants), especially in the form of woody biomass (Paul *et al.,*

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2022). Both natural and plantation forests typically serve as a significant carbon sink. Therefore, deforestation releases the stored CO_2 back into the atmosphere which leads to the greenhouse effect and global warming. Regarding to the international agreement, known as the Kyoto Protocol (KP), which was initiated in 1997 as a part of the United Nations Framework Convention on Climate Change (UNFCCC), the main gold of the KP was to reduce the GHG emissions from the industrial sector (i.e. industrialized countries or deleloped nations) by 5.2% compared to the base year in 1990 (United Nations, 1998; Sotoodeh, 2021). The KP estrablished the carbon markets as the economic mechanisms to reduce or limit GHG emissions, including mandatory or compliance carbon market (CCM) and voluntary carbon market (VCM) (United Nations, 1998). In 2015, the signed of the Paris Agreement (PA) (known as COP 21) provide a roadmap for nations to reach carbon neutrality (or climate neutrality) by 2050 and allow carbon credit trading between developed and developing countries (UNFCCC, 2015). A carbon credit is referred to by a variety of terms such as carbon offsets, carbon allowances, or carbon counterbalancing, which is considered as a powerful tool in controlling the GHG emissions and reductions through the so-called carbon trading systems or carbon pricing machanisms (Alam and Jain, 2020), and is also regarded as one of the most effective tools for climate change mitigation (IPCC, 2023; Vilkov and Tian, 2023).

Thailand locates in the center of mainland Southeast Asia. Carbon credit trading in Thailand is under the domestic VCM. Thailand Voluntary Emission Reduction Program (T-VER) and Thailand Voluntary Emission Trading Scheme (Thailand V-ETS) have been launched and implemented since 2009 by the Thailand Greenhouse Gas Management Organization (TGO) (TGO, 2021). Both public and private sectors in Thailand are thus required to participate in the VCM in order to meet the PA targets in the future. The zoo industry is considered as one of important sectors for Thailand economic. Zoos provide not only entertainment but also education, conservation and research (Carr and Cohen, 2015). Thailand's zoos generate income of over 1 billion Thai bahts (THB) in the past few years (The Zoological Park Organization of Thailand, 2022). Ubon Ratchathani Zoo is one of the biggest zoo in Thailand. The zoo locates in the capital city of Ubon Ratchathani province, which is known as one of the biggest provinces in Northeastern Thailand and plays pivotal role in conserving of local ecosystems and biodiversity of the natural areas in the city that having rapid expansion of infrastructure. The zoo is situated in the area of Dong Fa Huan national reserved forest and comprises of a wide variety of tree species with various shapes and sizes. Because the carbon is mainly stored in trees and soils in forests, measuring forest ecosystem carbon storage or carbon sequestration rates are fundamental basis for estimating the the absorption of CO_2 by plants and essential for reducing carbon emission (Salas Macías *et al.,* 2017). Previouse studies have shown plant biomass carbon storage in several areas in Thailand such as the Ban Mae Chiang Rai Lum Community Forest Management in Northern Thailand (Thammanu *et al.,* 2021) and the Sakaerat Environmental Research Station in Northeastern Thailand (Pungpa *et al.,* 2023). However, none of these studies focused on estimating carbon storage in Thailand's zoos, especially the zoo in northeastern Thailand. The objective was to assess aboveground biomass and carbon storage of trees growing in service area of Ubon Ratchathani Zoo.

Materials and methods

Study site

The study site situated in Ubon Ratchathani Zoo which locates within Dong Fa Huan national reserved forest (15^{O}17'10" N, 104^{O} 48'25" E) of Ubon Ratchathani province in Northeastern Thailand, with an area of 194.72 ha (1,217 rai) in total (Figure 1.). The zoo area is divided into three parts, including service area or service zone, animal display and exhibition zone, and natural forest zone for nature trails ranging from 318 to 1,464 m. The zoo serves as essential natural areas in the big city and provide not only recreation but also environmental services to society. According to the changes in land use and infrastructure development in the zoo, the service zone is primarily selected in this study as it might be mostly linked to infrastructure planning in the near future compared to other zone (i.e., natural forest zone or protected forest area). A total of 1.90 ha (11.89 rai) of the service area within the zoo was studied.

Data collection

In-the-field data collection was conducted between January and May 2023. All species of trees in the service area (Figure 2.) were recorded and indentified to their species. Individual tree characteristics such as diameter at breast height (DBH), tree height (H), and tree position were collected using diameter tape, laser rangefinder/hypsometer (Nikon Forestry Pro II), and Global Positioning System (GPS), repectively. The distribution of trees at the site was created using the Geographic Information System (GIS) software.

Data analysis

Tree species density i.e. the number of trees per unit area, was calculated using the formula as follow:

$$\text{Density (D)} = \frac{\text{Total number of such plant species}}{\text{Total sample plot area unit of the study}}$$

The estimation of aboveground biomass (AGB) was calculated using the allometric equation in Table 1.

(a

(b

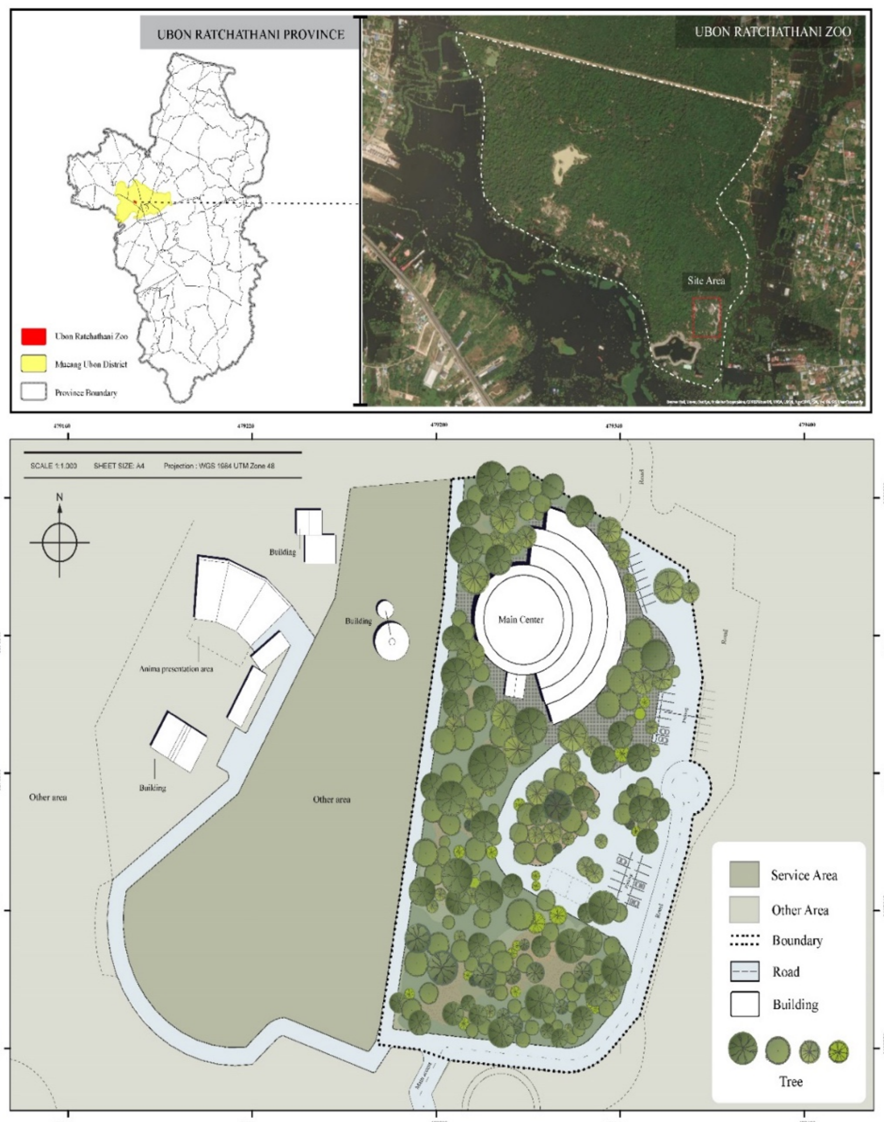

Figure 1. The study area in Ubon Ratchathani province (a) and the study site at Ubon Ratchathani Zoo showing the boundary of service area (or service zone) and other zones (b)

Table 1. The allometric equations for the estimation of aboveground biomass used in this study

Forest types/Tree species	Equations and parameters	References
Dry evergreen forest and Montane evergreen forest	$W_S = 0.0509\ (D^2H)^{0.919}$ $W_B = 0.00893\ (D^2H)^{0.977}$ $W_L = 0.0140\ (D^2H)^{0.669}$ $W_T = W_S + W_B + W_L$	Tsutsumi *et al.* (1983)
Tropical evergreen rain forest or tropical rain forest	$W_S = 0.0396\ (D^2H)^{0.9326}$ $W_B = 0.006003\ (D^2H)^{1.027}$ $W_L = (28/\ (W_S+W_B+0.025))^{-1}$ $W_T = W_S + W_B + W_L$	Ogawa *et al.* (1965)
Deciduous dipterocarp forest and mixed deciduous forest	$W_S = 0.0396\ (D^2H)^{0.933}$ $W_B = 0.00349\ (D^2H)^{1.030}$ $W_L = (28/\ (W_S+W_B+0.025))^{-1}$ $W_T = W_S + W_B + W_L$	Ogawa *et al.* (1965)

Remarks: W_S =Stem biomass (kg.), W_B =Branch biomass of branches (kg.), W_L =Leaf biomass (kg.), W_T =Total biomass (kg.), D =Diameter at breath height (m.) and H =Tree height (m.)

Figure 2. Trees growing within the service area in Ubon Ratchathani Zoo

Results

Resulrs showed that the girth and DBH of all trees within service zone were averaged 82.8 cm and 26.4 cm, respectively (Table 2.). The total aboveground biomass for all trees was 52,337.3 kg (200.1 kg rai^{-1}). Total carbon storage for all trees in the service zone were 52,337.3 kg (200.1 kg rai^{-1}) and 24,598.5 kg

(24.6 ton). A total of carbon dioxide absorption for the study site was 85.4 t-CO_2 or 60.6 t-CO_2 ha^{-1} (9.7 t-CO_2 rai^{-1}).

Table 2. Plant community characteristics and carbon stored in trees growing within the service area of Ubon Ratchathani Zoo

Parameters	Summary of results
Total area	1.90 ha or 11.89rai
Number of trees	200 trees
Number of families	16 families
Number of species	22species
Average girth	82.8 cm
Average DBH	26.4 cm
Average H	9.7 m
Tree density	6.7 stem rai^{-1}
	42 1.stem ha^{-1}
Sum of stem biomass (W_S)	40,838.6 kg
Sum of branch biomass (W_B)	10,236.9 kg
Sum of leaf biomass (W_L)	1,261.8 kg
Total aboveground biomass	52,338.3 kg or 200.1 kg rai^{-1}
Total carbon	24,598.5 kg
	0.246 t
Average total carbon per tree	122.0 kg
	0.12 t
CO_2 absorption	85.4 t-CO_2
	9.7 t-CO_2 rai^{-1} or 60.6 t-CO_2 ha^{-1}

Species composition, characteristics, and density of trees

The distribution of trees within the service zone was shown in Figure 1(b). It is indicated a total of 200 trees of 22 species from 16 families (Table 3). The most common family was Dipterocarpaceae with 129 trees, including *Shorea roxburghii* G. Don (40% of total trees), *Dipterocarpus alatus* Roxb. (17% of total trees), and *Dipterocarpus intricatus* Dyer (7% of total trees).

The trees with the greatest and smallest girth belonged to *Ficus benjamina* L. (260.0 cm) and *Millettia brandisiana* Kurz (16.5 cm), respectively. The average height of all trees in the service zone was 9.7 m. *Dipterocarpus intricatus* Dyer was the highest tree in the service zone with approximately 16.5 m height.

Tree density of the studied area was 42.1 stem ha^{-1} or 6.7 stem rai^{-1} (Table 4). It is noted that the service area generaly covers with building and other infrastructure. The top five dominant tree species in the service area were *Shorea roxburghii* G. Don (42.1 stem ha^{-1}), *Dipterocarpus alatus* Roxb. (18.4 stem ha-

$^{-1}$), *Parinari anamensis* (9.5 stem ha^{-1}), *Dipterocarpus intricatus* Dyer (7.4 stem ha^{-1}), and *Pterocarpus macrocarpus* Kurz and *Carallia brachiate* (Lour.) Merr. (5.8 stem ha^{-1}), respectively.

Table 3. Summary of species composition in this study

No. of families	Families	No. of species	Sciencetific name	Abundance (stems)	Percentage (%)
1	Dipterocarpaceae	1	*Shorea roxburghii* G. Don	80	40.0
		2	*Dipterocarpus intricatus* Dyer	14	7.0
		3	*Dipterocarpus alatus* Roxb.	35	17.5
2	Chrysobalanaceae	4	*Parinari anamensis*	18	9.0
3	Rhizoophoraceae	5	*Carallia brachiate* (Lour.) Merr.	11	5.5
4	Leguminosae	6	*Pterocarpus macrocarpus* Kurz	11	5.5
5	Burseraceae	7	*Canarium subulatum* Guillaumin	6	3.0
6	Fabaceae	8	*Millettia brandisiana* Kurz	1	0.5
		9	*Peltophorum dasyrhachis*	3	1.5
		10	*Butea monosperma* (Lam.) Taub.	1	0.5
7	Annonaceae	11	*Melodorum fruticosum* Lour	3	1.5
		12	*Xylopia vielana*	1	0.5
8	Connaraceae	13	*Ellipanthus tomentosus Kurz* var. tomentosus	4	2.0
9	Myrtaceae	14	*Syzygium cumini*	**3**	1.5
10	Moraceae	15	*Artocarpus lacucha*	1	0.5
		16	*Ficus benjamina* L.	1	0.5
11	Anacardiaceae	17	*Mangifera pentandra*	2	1.0
12	Ochnaceae	18	*Ochna integerrima* (Lour.) Merr.	1	0.5
13	Tiliaceae	19	*Microcos tomentosa* Smith.	1	0.5
14	Myristcaceae	20	*Knema globularia* (Lam.) Warb.	1	0.5
15	Leguminosae - Papilionoideae.	21	*Dalbergia cultrata* Graham ex Benth.	1	0.5
16	Irvingiaceae	22	*Irvingia malayana*	1	0.5
		Total		**200**	**100**

Table 4. The tree density in the service zone of Ubon Ratchathani Zoo

No.	Sciencetific name	Density (stem/rai)	Density (stem/ha)
1	*Dipterocarpus alatus* Roxb.	2.9	18.4
2	*Peltophorum dasyrhachis*	0.3	1.6
3	*Melodorum fruticosum* Lour	0.3	1.6
4	*Irvingia malayana*	0.1	0.5
5	*Ficus benjamina* L.	0.1	0.5
6	*Xylopia vielana*	0.1	0.5
7	*Knema globularia* (Lam.) Warb.	0.1	0.5
8	*Syzygium cumini*	0.3	1.6
9	*Shorea roxburghii* G. Don	6.7	42.1
10	*Dipterocarpus intricatus* Dyer	1.2	7.4
11	*Carallia brachiate* (Lour.) Merr.	0.9	5.8
12	*Ochna integerrima* (Lour.) Merr.	0.1	0.5
13	*Microcos tomentosa* Smith.	0.1	0.5
14	*Canarium subulatum* Guillaumin	0.5	3.2
15	*Ellipanthus tomentosus Kurz* var. tomentosus	0.3	2.1
16	*Pterocarpus macrocarpus* Kurz	0.9	5.8
17	*Parinari anamensis*	1.5	9.5
18	*Butea monosperma* (Lam.) Taub.	0.1	0.5
19	*Dalbergia cultrata* Graham ex Benth.	0.1	0.5
20	*Artocarpus lacucha*	0.1	0.5
21	*Mangifera pentandra*	0.2	1.1
22	*Millettia brandisiana* Kurz	0.1	0.5
	Average	**0.8**	**4.8**

The aboveground biomass and total carbon storage

Five top species with the highest value of aboveground biomass are found to be *Shorea roxburghii* G. Don (15,964.7 kg), *Dipterocarpus alatus* Roxb. (14,580.5 kg) *Parinari anamensis* (4,752.3 kg) *Pterocarpus macrocarpus* Kurz (4,582.1 kg), and *Dipterocarpus intricatus* Dyer (4,068.5 kg) (Table 5. and Figure 3.).

Table 5. Estimating the aboveground biomass of all species in the service area of Ubon Ratchathani Zoo

No.	**Sciencetific name**	**Sum of stem biomass (kg)**	**Sum of branch biomass (kg)**	**Sum of leaf biomass (kg)**	**Total aboveground biomass (kg)**	**Total aboveground biomass (kg rai^{-1})**
1	*Dipterocarpus alatus* Roxb.	10,919.6	3,399.0	261.9	14,580.5	1,226.3
2	*Peltophorum dasyrhachis*	745.8	225.4	19.9	991.0	83.3
3	*Melodorum fruticosum* Lour	109.2	29.2	4.9	143.3	12.1
4	*Irvingia malayana*	99.5	28.2	3.5	131.2	11.0
5	*Ficus benjamina* L.	1,033.7	339.1	19.1	1,392.0	117.1
6	*Xylopia vielana*	74.7	20.8	2.8	98.3	8.3
7	*Knema globularia* (Lam.) Warb.	154.3	55.2	6.3	215.8	18.2
8	*Syzygium cumini*	512.6	186.6	20.4	719.6	60.5
9	*Shorea roxburghii* G. Don	12,777.9	2,727.1	459.7	15,964.7	1,342.7
10	*Dipterocarpus intricatus* Dyer	3,225.3	751.2	92.0	4,068.5	342.2
11	*Carallia brachiate* (Lour.) Merr.	972.7	193.4	38.7	1,204.7	101.3
12	*Ochna integerrima* (Lour.) Merr.	60.2	11.4	2.5	74.1	6.2
13	*Microcos tomentosa* Smith.	14.2	2.3	0.6	17.1	1.4
14	*Canarium subulatum* Guillaumin	995.0	217.0	34.1	1,246.1	104.8
15	*Ellipanthus tomentosus Kurz* var. tomentosus	399.1	84.1	14.5	497.6	41.9
16	*Pterocarpus macrocarpus* Kurz	3,636.4	834.8	110.9	4,582.1	385.4
17	*Parinari anamensis*	3,791.0	831.5	129.8	4,752.3	399.7
18	*Butea monosperma* (Lam.) Taub.	83.1	16.2	3.4	102.7	8.6
19	*Dalbergia cultrata* Graham ex Benth.	290.8	64.7	9.8	365.2	30.7
20	*Artocarpus lacucha*	112.6	22.7	4.4	139.7	11.7
21	*Mangifera pentandra*	827.5	196.7	22.4	1,046.6	88.0
22	*Millettia brandisiana* Kurz	3.6	0.5	0.2	4.3	0.4
	Total	**40,838.6**	**10,236.9**	**1,261.8**	**52,337.3**	**200.1**

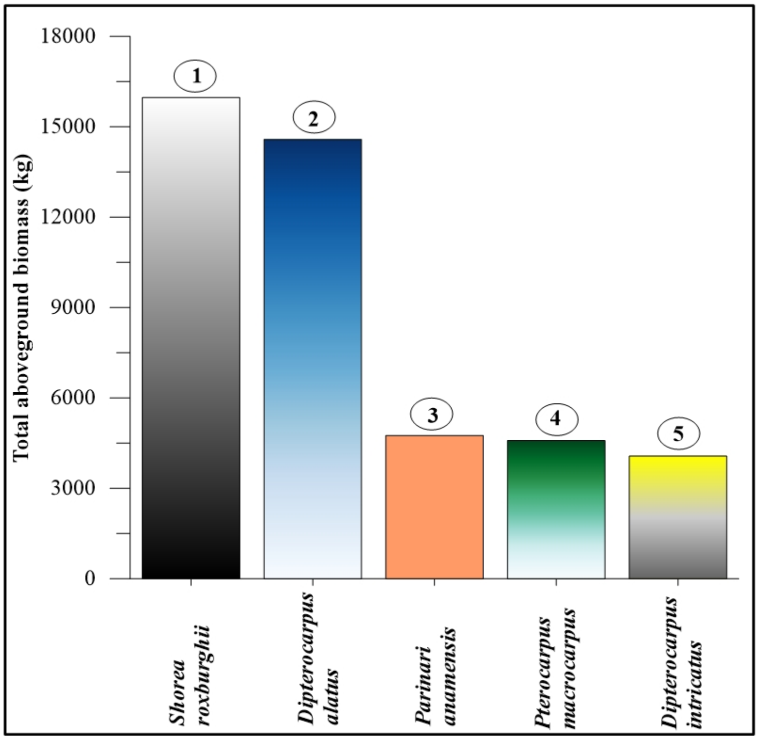

Figure 3. Five top species with the highest value of total carbon storage

Five top species with the highest value of total carbon are shown to be *Ficus benjamina* L. (654.2 kg rai^{-1} or 0.654 ton rai^{-1}), *Mangifera pentandra* (245.9 kg rai^{-1} or 0.246 ton rai^{-1}), *Dipterocarpus alatus* Roxb. and *Pterocarpus macrocarpus* Kurz (159.8 kg rai^{-1} or 0.196 ton rai^{-1}), *Dalbergia cultrata* Graham ex Benth. (171.7 kg rai^{-1} or 0.172 ton rai^{-1}), and *Peltophorum dasyrhachis* (155.3 kg rai^{-1} or 0.155 ton rai^{-1}) (Table 6).

Table 6. Estimating the carbon storage by all plant species in the service area of Ubon Ratchathani Zoo

No.	**Sciencetific name**	**Total carbon**		**Average of total carbon**	
		(kg)	**(ton)**	**(kg/stem)**	**(ton/stem)**
1	*Dipterocarpus alatus* Roxb.	6,852.9	6.853	195.8	0.196
2	*Peltophorum dasyrhachis*	465.8	0.466	155.3	0.155
3	*Melodorum fruticosum* Lour	67.3	0.067	22.4	0.022
4	*Irvingia malayana*	61.7	0.062	61.7	0.062

Table 6. (Con.)

No.	Sciencetific name	Total carbon (kg)	(ton)	Average of total carbon (kg/stem)	(ton/stem)
5	*Ficus benjamina* L.	654.2	0.654	654.2	0.654
6	*Xylopia vielana*	46.2	0.046	46.2	0.046
7	*Knema globularia* (Lam.) Warb.	101.4	0.101	101.4	0.101
8	*Syzygium cumini*	338.2	0.338	112.7	0.113
9	*Shorea roxburghii* G. Don	7,503.4	7.503	93.8	0.094
10	*Dipterocarpus intricatus* Dyer	1,912.2	1.912	136.6	0.137
11	*Carallia brachiate* (Lour.) Merr.	566.2	0.566	51.5	0.051
12	*Ochna integerrima* (Lour.) Merr.	34.8	0.035	34.8	0.035
13	*Microcos tomentosa* Smith.	8.0	0.008	8.0	0.008
14	*Canarium subulatum* Guillaumin	585.7	0.586	97.6	0.098
15	*Ellipanthus tomentosus Kurz* var. tomentosus	233.9	0.234	58.5	0.058
16	*Pterocarpus macrocarpus* Kurz	2,153.6	2.154	195.8	0.196
17	*Parinari anamensis*	2,233.6	2.234	124.1	0.124
18	*Butea monosperma* (Lam.) Taub.	48.3	0.048	48.3	0.048
19	*Dalbergia cultrata* Graham ex Benth.	171.7	0.172	171.7	0.172
20	*Artocarpus lacucha*	65.7	0.066	65.7	0.066
21	*Mangifera pentandra*	491.9	0.492	245.9	0.246
22	*Millettia brandisiana* Kurz	2.0	0.002	2.0	0.002
	Sum or average	**24,598.5**	**24.599**	**0.122**	**200.1**

The total amount of carbon dioxide absorption per unit area varied from 0.022 t-CO_2 ha-1 (*Millettia brandisiana* Kurz) to 14.462 t-CO_2 ha-1 (*Shorea roxburghii* G. Don) as shown in Table 7. Five top species with the highest amount of carbon dioxide absorption are shown to be *Shorea roxburghii* G. Don (2.314 t-CO_2 rai-^{1} or 14.462 t-CO_2 ha^{-1}), *Dipterocarpus alatus* Roxb. (2.113 t-CO_2 rai-^{1} or 13.208 t-CO_2 ha^{-1}), *Ficus benjamina* L. (1.127 t-CO_2 rai-^{1} or 7.047 t-CO_2 ha^{-1}), *Mangifera pentandra* (0.848 t-CO_2 rai-^{1} or 5.298 t-CO_2 ha^{-1}), and *Parinari anamensis* (0.689 t-CO_2 rai-^{1} or 4.305 t-CO_2 ha^{-1}) (Figure 4.).

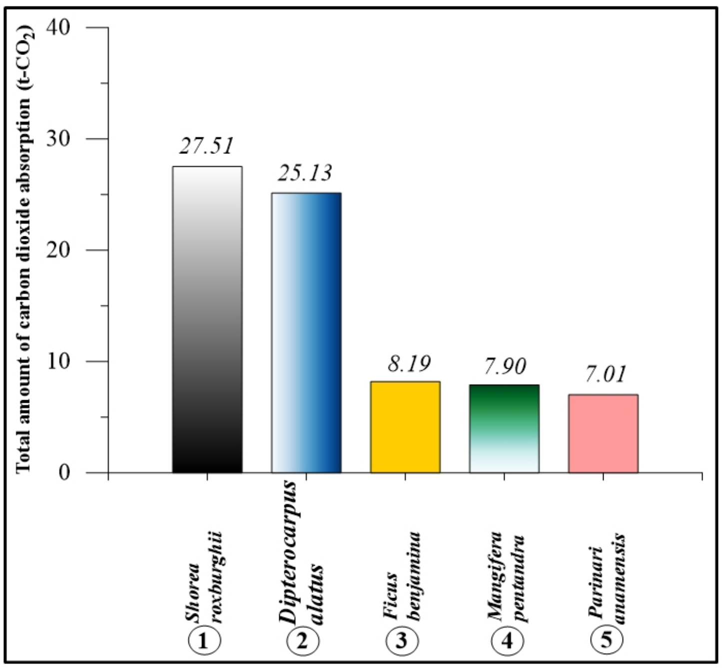

Figure 4. Five top species with the highest amount of carbon dioxide absorption

Table 7. Estimating the amount of carbon dioxide absorption by all plant species in the service area of Ubon Ratchathani Zoo

No.	Sciencetific name	Total amount of carbon dioxide absorption	Total amount of carbon dioxide absorption per unit area	
		t-CO_2	**t-CO_2 rai^{1-}**	**t-CO_2 ha^{1-}**
1	*Dipterocarpus alatus* Roxb.	25.127	2.113	13.208
2	*Peltophorum dasyrhachis*	1.708	0.144	0.898
3	*Melodorum fruticosum* Lour	0.247	0.021	0.130

Table 7. (Con.)

No.	Sciencetific name	Total amount of carbon dioxide absorption	Total amount of carbon dioxide absorption per unit area	
		t-CO_2	t-CO_2 rai[1-]	t-CO_2 ha[1-]
4	*Irvingia malayana*	0.029	0.106	0.664
5	*Ficus benjamina* L.	0.307	1.127	7.047
6	*Xylopia vielana*	0.022	0.080	0.497
7	*Knema globularia* (Lam.) Warb.	0.372	0.031	0.196
8	*Syzygium cumini*	1.240	0.104	0.652
9	*Shorea roxburghii* G. Don	27.512	2.314	14.462
10	*Dipterocarpus intricatus* Dyer	7.011	0.590	3.686
11	*Carallia brachiate* (Lour.) Merr.	2.076	0.175	1.091
12	*Ochna integerrima* (Lour.) Merr.	0.128	0.011	0.067
13	*Microcos tomentosa* Smith.	0.029	0.002	0.015
14	*Canarium subulatum* Guillaumin	2.147	0.181	1.129
15	*Ellipanthus tomentosus Kurz* var. tomentosus	0.858	0.072	0.451
16	*Pterocarpus macrocarpus* Kurz	7.896	0.664	4.151
17	*Parinari anamensis*	8.190	0.689	4.305
18	*Butea monosperma* (Lam.) Taub.	0.177	0.015	0.093
19	*Dalbergia cultrata* Graham ex Benth.	0.081	0.296	1.849
20	*Artocarpus lacucha*	0.031	0.113	0.707
21	*Mangifera pentandra*	0.231	0.848	5.298
22	*Millettia brandisiana* Kurz	0.001	0.003	0.022
	Sum or average	**85.421**	**9.699**	**60.617**

Discussion

The estimation of aboveground carbon stock is the most critical step for tracking changes in the the quantity of carbon stored in different land use and land cover types as well as providing the information which can be further used to buy and sell carbon credits. Previous works have shown the potential of natural forest areas for carbon credit trading, including the Ban Mae Chiang Rai Lum Community Forest Management in Northern Thailand (Thammanu *et al.,* 2021) and the Sakaerat Environmental Research Station in Northeastern Thailand (Pungpa *et al.,* 2023). In addition, many studies have shown that the green areas (i.e., service areas) in cities or urbanized areas also serve as important places for carbon storages and carbon sinks, for examples in Thailand (Suthampaeng and Boonyanuphap, 2020) and other countries (Zhao *et al.,* 2023). Because different land cover classes and area sizes, the amount of CO_2 absorbtion in our study cannot be copared to other previous studies due to their studied scales. The area of Ubon Ratchathani Zoo is not only the palce for recreation and eduation but also provide valuable ecosystem services in relation to carbon sequestration and storage. Our results provided an important data for climate mitigation policy (i.e., carbon credit policy) and carbon credit trading of Ubon Ratchathani Zoo and other similar areas in the future.

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