CHAPTER IV
RESULTS AND DISCUSSION

4.1 Ground Truth Data

4.1.1 Ground Truth Records

The field data were collected between April 2023 and July 2024 in the Banlaem planted mangrove forest, located in Nakhon Si Thammarat, Thailand (**Table 4.1**). The forest was found to contain relatively few species (**Figure 4.1**). *Rhizophora* species generally functioned as edge species, primarily distributed along upland boundaries, while grey mangrove (*A. marina*) was more commonly found in interior areas. However, within the study plots, the *Rhizophora* species often coexisted with *A. marina*. No study plots contained single species, *Rhizophora* species, except for those dominated by seedlings. The mangrove trees appeared to form three distinct composition types: 1) a mixture of *A. marina* and *Rhizophora* spp. in plots 1, 2, 7, 13–22, and 31–36; 2) *A. marina* in plots 3–6, 8–12, and 23–30; and 3) predominantly seedlings, with *R. mucronata* dominant in plots 37–48. The overall tree density was 4,386±4,732 mangrove trees/ha, with an average DBH of 6.32±3.84 cm, H of 6.15±3.78 m and a basal area of 8.76±7.40 m^2/ha, respectively.

Table 4.1 The ground truth records in the Banlaem mangrove forest.

Plot	Species Occurrence			Tree Density (No/ ha)	Mean H (m)	Mean DBH (cm)	BA (m^2/ ha)
	R. mucronata	*R. apiculata*	*A. marina*				
1	✓	×	✓	4,355	8.29	7.61	21.42
2	✓	×	✓	2,535	6.95	8.64	16.16
3	×	×	✓	1,690	11.71	7.61	8.02
4	×	×	✓	2,015	7.33	7.83	10.28
5	×	×	✓	3,250	7.08	7.28	14.34
6	×	×	✓	3,770	5.65	8.07	12.08
7	✓	×	✓	2,340	6.88	7.17	13.72
8	×	×	✓	2,340	6.40	7.17	10.81
9	×	×	✓	1,300	5.41	6.27	6.01
10	×	×	✓	845	5.49	6.55	3.65
11	×	×	✓	780	5.09	6.79	3.27
12	×	×	✓	1,365	5.40	6.85	5.51
13	✓	×	✓	2,665	8.06	7.89	13.34
14	✓	×	✓	3,055	10.38	8.58	19.01
15	✓	×	✓	2,340	8.14	9.44	17.85
16	✓	×	✓	2,015	9.12	11.62	22.33
17	✓	×	✓	1,430	9.34	10.41	13.17
18	✓	×	✓	1,950	8.64	9.26	14.43
19	✓	×	✓	3,965	7.97	8.57	23.64
20	✓	×	✓	2,795	8.86	8.53	16.68
21	✓	×	✓	2,210	9.52	8.35	13.34
22	✓	×	✓	1,690	8.74	9.13	11.48
23	×	×	✓	2,080	6.46	8.26	11.69
24	×	×	✓	2,145	6.18	7.15	8.67
25	×	×	✓	1,690	9.40	10.50	15.72
26	×	×	✓	455	4.50	9.71	3.48
27	×	×	✓	260	3.53	9.12	1.37
28	×	×	✓	455	4.70	7.98	2.37
29	×	×	✓	390	4.40	8.70	2.58
30	×	×	✓	130	4.25	7.64	0.60
31	✓	×	✓	3,315	12.38	8.52	19.31
32	✓	×	✓	1,755	11.87	8.83	11.74
33	✓	×	✓	2,210	10.73	9.02	15.15
34	✓	✓	✓	1,820	9.77	10.53	17.06
35	✓	✓	✓	1,430	9.17	8.08	7.60
36	✓	×	✓	1,690	15.50	9.89	12.64
37	✓	×	×	10,000	1.00	0.00	0.00
38	✓	×	×	10,000	0.66	0.00	0.00
39	✓	×	×	20,000	0.71	0.00	0.00
40	×	×	✓	10,000	1.10	0.00	0.00
41	✓	×	×	10,000	1.20	0.00	0.00
42	✓	×	×	10,000	0.71	0.00	0.00
43	✓	×	×	10,000	0.35	0.00	0.00
44	✓	×	×	10,000	0.95	0.00	0.00
45	×	×	✓	10,000	0.96	0.00	0.00
46	✓	×	×	20,000	1.05	0.00	0.00
47	✓	×	×	10,000	1.30	0.00	0.00
48	✓	×	×	10,000	1.91	0.00	0.00
		Mean		**4,386**	**6.15**	**6.32**	**8.76**
		SD		**4,732**	**3.18**	**3.84**	**7.40**

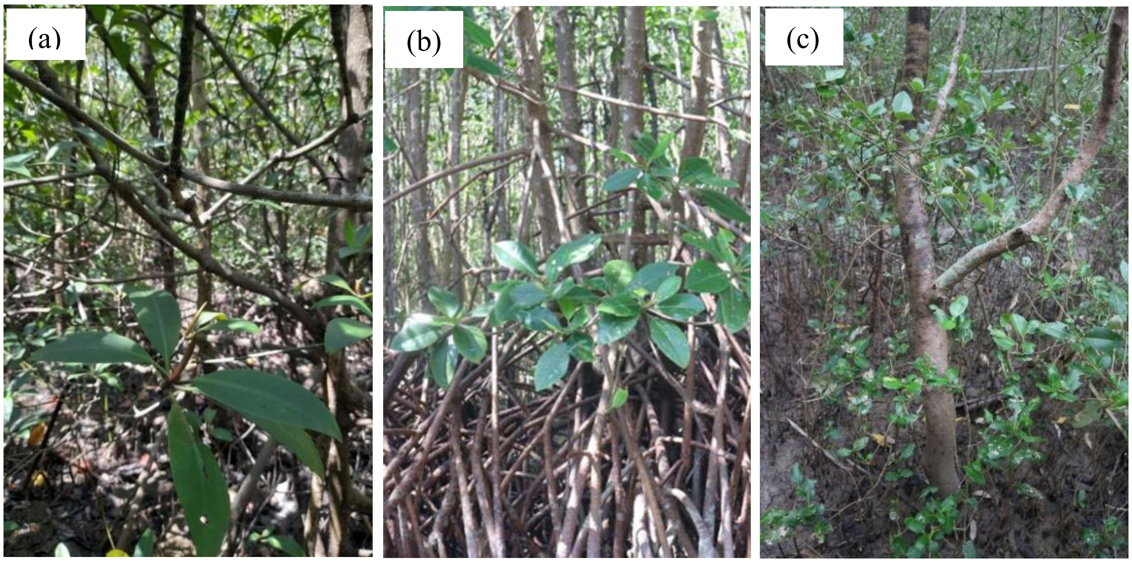

Figure 4.1 The mangrove tree species found in the study area: a) *R. apiculata*; b) *R. mucronata*; and c) *A. marina.*

4.1.2 Biodiversity

The mangrove biodiversity in the Banlaem community was limited due to its low species richness (*S*), with only three species from two genera being recorded in this study (**Table 4.3**). Two species (loop-root mangroves), *R. mucronata* and *R. apiculata*, belong to the family Rhizophoraceae, while the third species, *A. marina* (grey mangrove), is part of the family Acanthaceae. The biodiversity indices further reflect the limited diversity of the mangroves in Banlaem. Simpson's index (*1-D*), Shannon-Wiener index (*H*), and evenness index (*J*) showed values ranging from 0.00 to 0.50 (0.11±0.17), 0.00 to 0.69 (0.17±0.25), and 0.00 to 1.00 (0.25±0.36), respectively (**Table 4.2**). Plot 17 demonstrated the highest diversity with the *1-D*, H, and *J* of 0.50, 0.69, and 1.00, respectively. In contrast, the plots that were dominated by a single species exhibited the lowest levels of diversity.

Table 4.2 Diversity indices recorded in the Banlaem mangrove forest.

Plot	Diversity Indices		
	1-D	*H*	*J*
1	0.49	0.69	0.99
2	0.14	0.27	0.39
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.24	0.34	0.49
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.00	0.00	0.00
12	0.00	0.00	0.00
13	0.05	0.11	0.17
14	0.12	0.24	0.34
15	0.15	0.29	0.41
16	0.27	0.44	0.64
17	0.50	0.69	1.00
18	0.44	0.64	0.92
19	0.06	0.14	0.21
20	0.30	0.48	0.69
21	0.46	0.65	0.94
22	0.20	0.36	0.52
23	0.00	0.00	0.00
24	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.00	0.00	0.00
27	0.00	0.00	0.00
28	0.00	0.00	0.00
29	0.00	0.00	0.00
30	0.00	0.00	0.00
31	0.04	0.10	0.14
32	0.35	0.53	0.76
33	0.42	0.61	0.87
34	0.30	0.56	0.81
35	0.24	0.49	0.70
36	0.50	0.69	1.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.00	0.00	0.00
40	0.00	0.00	0.00
41	0.00	0.00	0.00
42	0.00	0.00	0.00
43	0.00	0.00	0.00
44	0.00	0.00	0.00
45	0.00	0.00	0.00
46	0.00	0.00	0.00
47	0.00	0.00	0.00
48	0.00	0.00	0.00
Mean	**0.11**	**0.17**	**0.25**
SD	**0.17**	**0.25**	**0.36**

Table 4.3 List of mangrove tree species found in the Banlaem mangrove forest.

Order	Family	Genus	Scientific name
Malpighiales	Rhizophoraceae	*Rhizophora*	*R. mucronata*
Malpighiales	Rhizophoraceae	*Rhizophora*	*R. apiculata*
Lamiales	Acanthaceae	*Avicennia*	*A. marina*

4.1.3 Aboveground Biomass and Carbon Stock

The AGB and AGC stocks in the Banlaem mangrove ecosystem varied across different study plots (**Figure 4.2**). Overall, AGB ranged from 0 to 179.78 (with an average of 56.30±51.81) tons/ha, while AGC ranged from 0 to 89.89 (with an average of 28.15±25.90) tons/ha. The highest AGC stock was observed in the plot with the largest average DBH, specifically plot 16 (DBH = 11.62±2.52 cm), dominated by *A. marina* and *R. mucronata*. In contrast, the lowest AGC stock was recorded in plots with very small DBH values (plots 37–48, DBH ≤ 5 cm), located along the seafront (small-mangrove group). When comparing study plots with DBH ≥ 5 cm based on species composition (**Figure 4.3**), it was found that plots containing a mix of *A. marina* and *Rhizophora* species had significantly higher AGB (43.4–180, averaging 108±33 tons/ha) and AGC (21.7–89.9, averaging 53.8±16.7 tons/ha). These values were higher than those in *A. marina*-only plots, which had an AGB of 3.2–102 (38.6±27.9) tons/ha and an AGC of 1.6–51.0 (19.3±14.0) tons/ha ($t_{34} = -6.68$, $p < 0.001$).

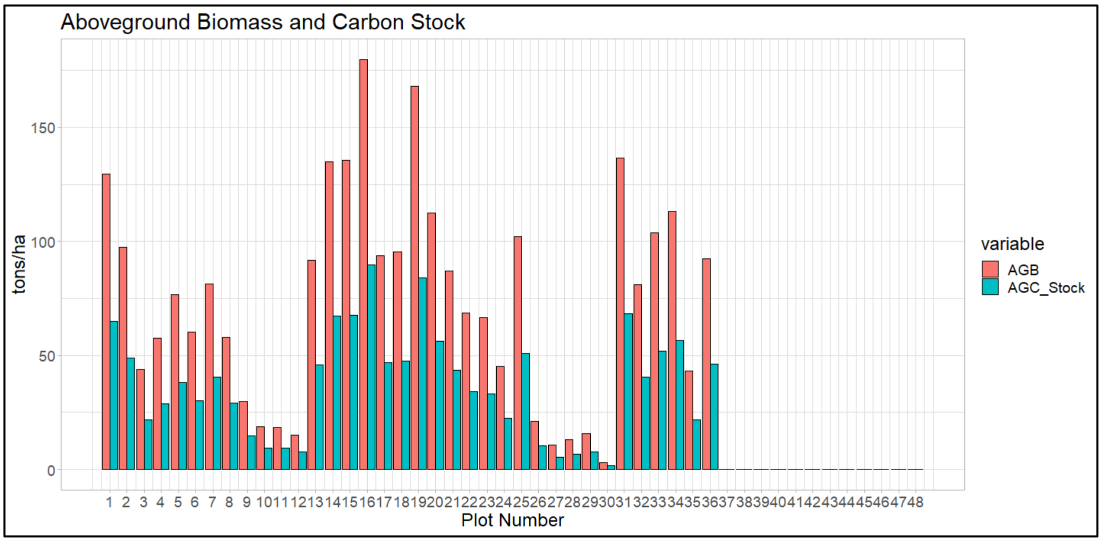

Figure 4.2 The AGB and AGC stock in each study plot of the Banlaem mangrove forest.

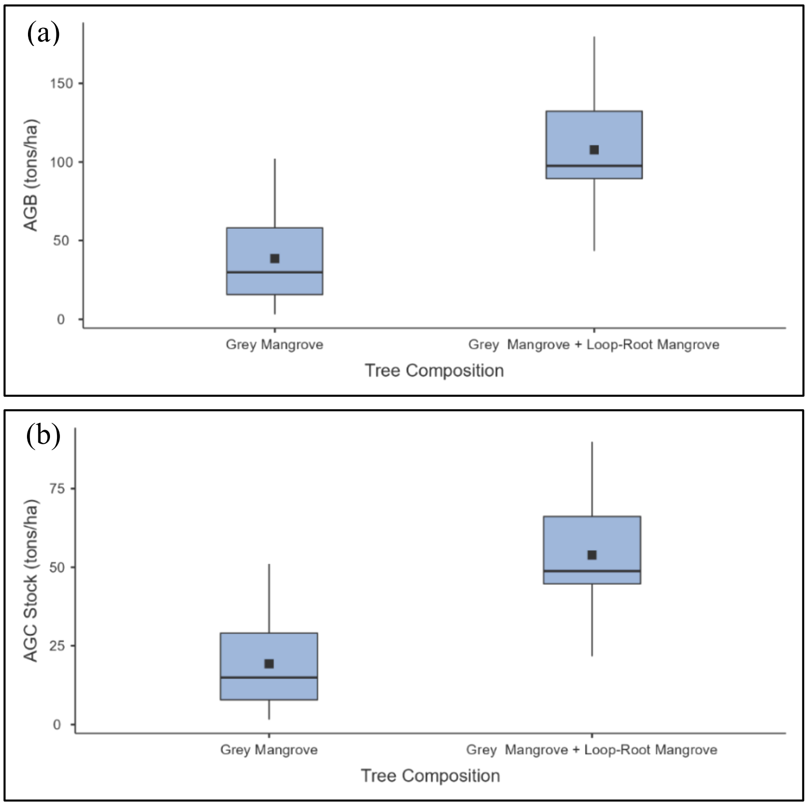

Figure 4.3 The boxplots of the AGB and ABC stocks: a) represents AGB; and b) represents AGC stock in the Banlaem mangrove based on tree composition.

4.1.4 Discussion on The Ground Truth Data

This study offers the first evaluation of AGB and AGC stock along with its biodiversity in the Banlaem mangrove forest, located in Nakhon Si Thammarat, southern Thailand. The results indicate a relatively low species diversity (*S* = 3) compared to other studies on planted mangrove ecosystems in Thailand. Only *R. mucronata* was actively planted in Banlaem, but tidal currents have naturally dispersed propagules of other species (Minmun, personal communication, June 23, 2024). In contrast, the Ranong Biosphere Reserve (RBR) in southern Thailand's Ranong province recorded four mangrove species across three genera (*Rhizophora*, *Bruguiera*, and *Ceriops*) (Macintosh and Ashton, 2023). Additionally, the DBH of mangroves in the RBR (15.12 ± 7.34 cm) is significantly larger than the DBH of those in Banlaem (6.32 ± 3.84 cm). This contributes to the lower AGB in Banlaem (ranging from 0 to 179.78 ton/ha) compared to the RBR, where AGB ranged from 117.78 to 336.41 tons/ha. Notably, the lowest AGB (0 ton/ha) in Banlaem was found in mangrove seedlings, while the highest AGB in the RBR (336.41 ton/ha) was recorded in mixed-species conservation areas (Macintosh and Ashton, 2023). Mangrove biodiversity is positively correlated with both biomass and carbon storage, and carbon stock evaluations typically use allometric equations based on DBH (Bai, Meng, Gou, Lyu, Dai, and Diao et al., 2021). Therefore, the smaller DBH and low species diversity (*1-D* = 0.11 ± 0.17, *H* = 0.17 ± 0.25, *J* = 0.25 ± 0.36) in Banlaem contributes to reduced carbon storage. A study conducted by the Sirinart Rajini Ecosystem Learning Center in Prachuap Khiri Khan Province indicated that a mangrove species richness (*S* = 6) was higher than in Banlaem mangrove forest, although the AGB was somewhat lower (ranging from 0 to 159.63 tons per hectare) (Sribut, Sunthornhao, and Diloksumpun, 2020). This suggests that species richness alone is not a definitive predictor of AGB or AGC stock. Other factors, such as latitude, tidal range, and heavy metal pollution, also influence mangrove biomass (Wang, Singh, Wang, Xiao, and Guan, 2021). Future research could explore how these and other factors affect biomass and carbon stocks in the Banlaem mangroves.

This study found that the composition of mangrove species affects the AGB and AGC stocks in the Banlaem mangrove forest (**Figure 4.3**). Specifically, the presence of *A. marina* and *Rhizophora* species results in higher AGB compared to areas dominated solely by *A. marina*. This observation supports previous research indicating that *Rhizophora* species generally exhibit greater biomass than *Avicennia* species (Sribut et al., 2020), and that mixed-species plots have higher biomass than those dominated by a single species (Macintosh and Ashton, 2023). This difference may be attributed to the higher wood density of *R. mucronata* and *R. apiculata*, which contributes to greater biomass compared to *A. marina* in this study (Zanne et al., 2009).

In the Banlaem mangrove forest, an evaluation of mangrove AGB by age revealed no apparent correlation between stand age and AGB or AGC stocks. Notably, the presence of *Rhizophora* species appears to contribute to higher AGB levels, even in younger mangrove plots. Age of the mangrove tree is a factor that contributes to AGB and AGC stock in a mangrove forest. However, stand age showed no clear influence on AGB or AGC stocks in the Banlaem mangrove forest. A study conducted in Lamongan, Indonesia, showed a positive correlation between mangrove age and AGB (Asadi, Rr, Adam, Novianti, and Isdianto 2017). The highest AGB was recorded at the site with 100-year-old mangroves (302.24 tons/ha), followed by 70-year-old (288.12 tons/ha), 20-year-old (98.62 tons/ha), and 15-year-old (60.01 tons/ha) sites. Notably, *Rhizophora* sp. was present at all study sites (Asadi et al., 2017). The Banlaem mangrove forest is around 30 to 40 years old and may continue to accumulate AGB and AGC stock. *Rhizophora* sp. could play a crucial role in carbon sequestration in this forest, as observed in the Lamongan study. Moreover, the Banlaem mangrove area has expanded significantly from 56.16 ha in 1995 to 527.55 ha in 2023 (Pungpa and Chumkiew, 2025). Ongoing monitoring of carbon stocks in the Banlaem mangrove forest is essential for the sustainable management of this blue carbon ecosystem due to its rapid spatial expansion.

4.2 AGB Model Development and Validation

4.2.1 Model Development and Validation

Various vegetation indices (NDVI, SAVI, GNDVI) and CHM, derived from remote sensing (UAV), were used to generate regression models to estimate mangrove AGB. Overall, the results showed that combining different vegetation indices (including CHM) improved the accuracy of the prediction models, with R^2 values ranging from 0.124 to 0.577 and *RMSE* values between 27.5 and 39.5 tons/ha. Using a single index resulted in lower accuracy, with R^2 values ranging from 0.070 to 0.108 and *RMSE* values between 39.2 and 40.7 tons/ha. The optimum single index for generating mangrove AGB was NDVI, which had an R^2 = 0.108 and an *RMSE* of 39.2 tons/ha, with a p = 0.08. The most accurate AGB model (model 11) in this study was derived from combining multiple indices (NDVI, SAVI, GNDVI, CHM), yielding an R^2 of 0.577, an *RMSE* = 27.5 tons/ha, and a $p < 0.001$ (**Table 4.4; Figure 4.4**).

Model 11, which exhibited the highest predictive accuracy, was selected for comparison between its estimated AGB and the observed AGB values. The Omnibus ANOVA test in Jamovi revealed a significant statistical relationship between the UAV-predicted and observed AGB values ($F_{(1, 28)}$ = 38.1, $p < .001$), suggesting that the association is not likely due to random chance. The predicted AGB from this model was 65.71 ± 32.63 tons/ha, which overestimated the ground truth value (56.30 ± 51.81 tons/ha); however, there was no significant difference between the two measurements (t_{76} = 0.89, p = 0.19). It can be concluded that the model 11 (UAV-based measurement) is highly effective in estimating AGB in the Banlaem mangrove forest. This model is suitable for application in monitoring mangrove AGB and AGC stocks in this area.

Moreover, this study demonstrates the influence of different plant compositions, including (1) monogenous *A. marina* and (2) a mixture of *A. marina* and *Rhizophora* spp., on mangrove AGB model development (**Table 4.5; Table 4.6**). Overall, the results showed that combining different vegetation indices (including CHM) improved the accuracy of the prediction models. For the homogenous *A. marina* plots, the optimum model was Model No. 22, with an R^2 = 0.579, an *RMSE* = 17.6 tons/ha, and a $p < 0.025$ (**Figure 4.5**). For the mixture of *A. marina* and *Rhizophora* spp. plots, the optimum model was Model No. 33, with an R^2 = 0.223, an *RMSE* = 27.1 tons/ha, and a *p* = 0.69 (**Figure 4.6**). Additionally, using a single index resulted in lower accuracy.

Finally, residual plots were generated to evaluate the fit of these models. The analysis revealed that the residuals were randomly distributed around the horizontal axis without any discernible pattern, suggesting that the models successfully captured the relationship between the independent and dependent variables (**Figure 4.4; Figure 4.5; Figure 4.6**).

Table 4.4 The AGB model development in this study using all plots.

Variable	Model No.	Equation	*R*	R^2	*p*-value	*RMSE* (tons/ha)
NDVI	1	AGB = 58.5+51.7(NDVI)	0.329	0.108	0.08	39.2
SAVI	2	AGB = 58.5+34.5(SAVI)	0.329	0.108	0.08	39.9
GNDVI	3	AGB = 60.8+46.4(GNDVI)	0.301	0.091	0.11	40.3
CHM	4	AGB = 35.05+5.68(CHM)	0.265	0.070	0.16	40.7
NDVI, SAVI	5	AGB = 55.9-25,212.4(NDVI)+16,877(SAVI)	0.352	0.124	0.17	39.5
NDVI, GNDVI	6	AGB = -14.5+2,152.1(NDVI)-2,063.8(GNDVI)	0.695	0.483	<0.001	30.4
NDVI, CHM	7	AGB = 37.62+43.68(NDVI)+4.08(CHM)	0.377	0.142	0.13	39.1
SAVI, GNDVI	8	AGB = -15.2+1,446.6(SAVI)-2,076.9(GNDVI)	0.697	0.486	<0.001	30.3
SAVI, CHM	9	AGB = 37.61+29.19(SAVI)+4.08(CHM)	0.377	0.142	0.17	39.1
GNDVI, CHM	10	38.77+38.12(GNDVI)+4.24(CHM)	0.356	0.127	0.16	39.5
NDVI, SAVI, GNDVI, CHM	11	AGB = -51.68+5.53 (CHM)-40,122.32 (NDVI)+28,315.69 (SAVI) -2185.20(GNDVI)	0.759	0.577	<0.001	27.5

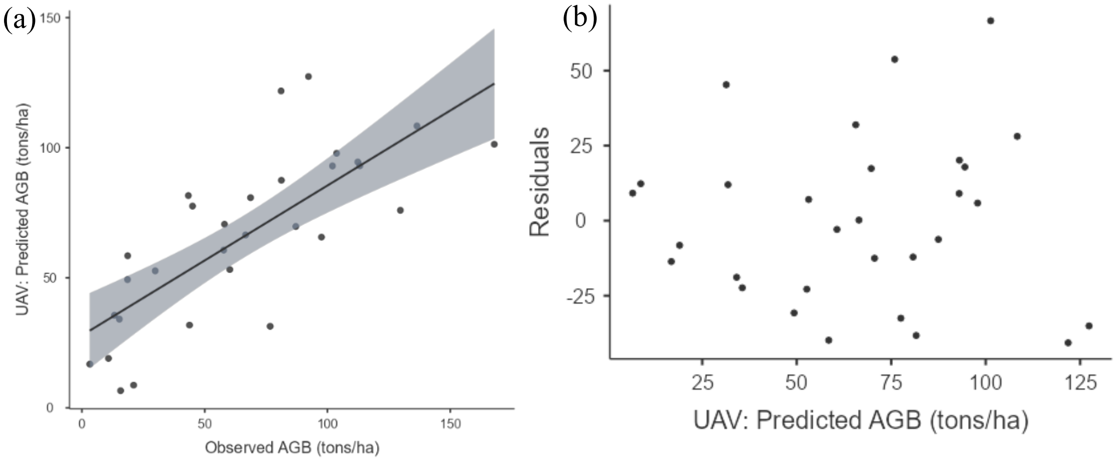

Figure 4.4 The most accurate AGB model (Model 11), generated from all plots: a) represents the regression model; and b) its residual plot.

Table 4.5 The AGB model development in using single species plots (*A. marina*).

Variable	Model No.	Equation	*R*	R^2	*p*-value	*RMSE* (tons/ha)
NDVI	12	AGB = 38.9-13.6(NDVI)	0.123	0.015	0.64	26.9
SAVI	13	AGB = 38.95-9.1(SAVI)	0.122	0.015	0.64	26.9
GNDVI	14	AGB = 38.6-14.3(GNDVI)	0.134	0.018	0.61	26.8
CHM	15	AGB = 8.44+5.78(CHM)	0.517	0.267	0.03	23.2
NDVI, SAVI	16	AGB = 37.0-20,783.9(NDVI)+13,876.1(SAVI)	0.237	0.056	0.67	26.3
NDVI, GNDVI	17	AGB = 14.8+841.8(NDVI)-818.8(GNDVI)	0.326	0.106	0.46	25.6
NDVI, CHM	18	AGB = 5.72-28.29(NDVI)+6.43(CHM)	0.573	0.329	0.06	22.2
SAVI, GNDVI	19	AGB = 14+580.9(SAVI)-845.4(GNDVI)	0.333	0.111	0.44	25.5
SAVI, CHM	20	AGB = 5.73-18.88(SAVI)+6.42(CHM)	0.573	0.329	0.06	22.2
GNDVI, CHM	21	4.7-28.54(GNDVI)+6.47(CHM)	0.579	0.335	0.06	22.1
NDVI, SAVI, GNDVI, CHM	22	AGB = -37.39+7.24(CHM) -38,161.85 (NDVI)+ 26,310.11(SAVI) -1,196.66(GNDVI)	0.761	0.579	0.025	17.6

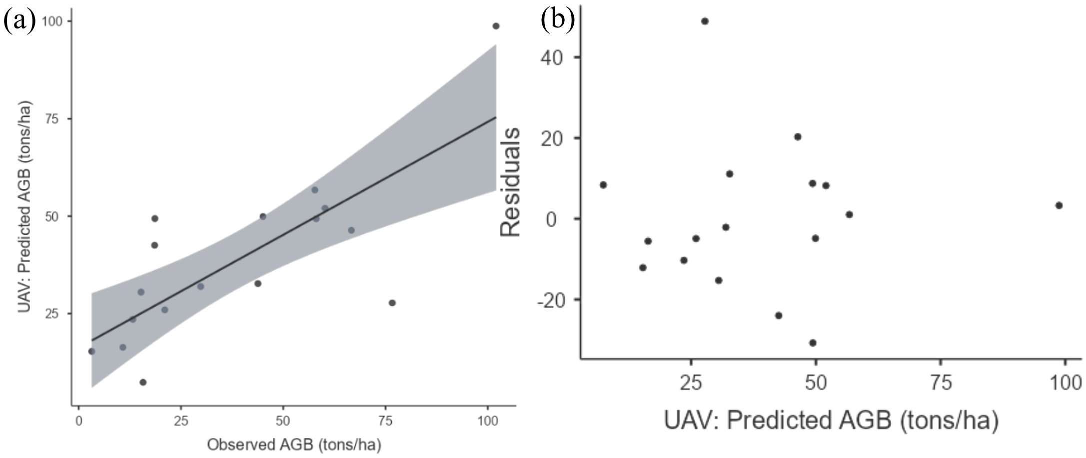

Figure 4.5 The most accurate AGB model (Model 22), generated from *A. marina* plots; a) represents the regression model; and b) its residual plot.

Table 4.6 The AGB model development in this study using coexisting plots (*A. marina* and *Rhizophora* spp).

Variable	Model No.	Equation	*R*	R^2	*p*-value	*RMSE* (tons/ha)
NDVI	23	AGB = 99.27-6.46(NDVI)	0.047	0.002	0.88	30.7
SAVI	24	AGB = 99.27-4.31(SAVI)	0.047	0.002	0.88	30.7
GNDVI	25	AGB = 99.91-4.9(GNDVI)	0.036	0.001	0.91	30.7
CHM	26	AGB = 198.02-6.55(CHM)	0.233	0.054	0.44	29.9
NDVI, SAVI	27	AGB = 108+77,459(NDVI)-51,739(SAVI)	0.230	0.053	0.76	29.9
NDVI, GNDVI	28	AGB = 22.7+1,738.2(NDVI)-1,695.1(GNDVI)	0.368	0.135	0.48	28.6
NDVI, CHM	29	AGB = 140.99+21.26(NDVI)-8.17 (CHM)	0.273	0.075	0.68	29.6
SAVI, GNDVI	30	AGB = 22.8+1,157.3(SAVI)-1,689.5(GNDVI)	0.366	0.134	0.49	28.6
SAVI, CHM	31	AGB = 140.98+14.19(SAVI)-8.17(CHM)	0.273	0.075	0.67	29.6
GNDVI, CHM	32	141.64+19.18(GNDVI)-8.04(CHM)	0.268	0.072	0.69	29.6
NDVI, SAVI, GNDVI, CHM	33	AGB = 74.99-7.65(CHM)+51,586.19(NDVI)-33,400.63(SAVI) -1,532.38(GNDVI)	0.472	0.223	0.689	27.1

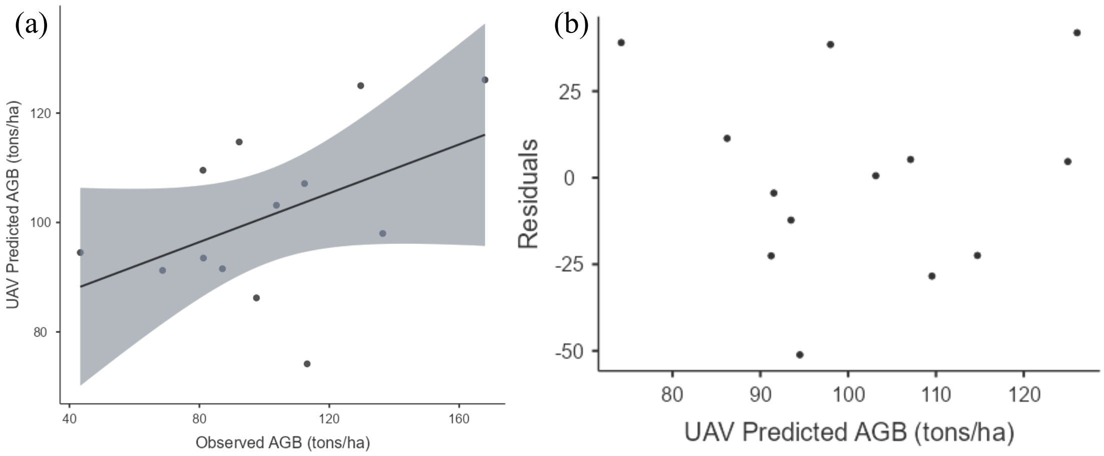

Figure 4.6 The most accurate AGB model (Model 33), from coexisting of *A. marina and Rhizophora spp.* plots: a) represents the regression model; and b) its residual plot.

4.2.2 Discussion on AGB Model

In examining AGB models for the Bamlaem mangrove forest, the integration of evaluated variables, including VIs and CHM, was found to significantly enhance prediction accuracy. The most effective models, Model 11 and Model 22, combined NDVI, SAVI, GNDVI, and CHM to estimate mangrove AGB, achieving an R^2 of approximately 0.58. Unlike prior research in Thailand, this study represents the first application of UAV imagery combined with VIs and CHM for estimating mangrove biomass and carbon storage. A study conducted in Ranong province, southern Thailand, employed medium-resolution (ASTER) and high-resolution (GeoEye-1) satellite data alongside machine learning techniques to model mangrove biomass, as reported by (Jachowski et al., 2013). The optimal AGB model from this research reached an R^2 value of 0.66 (Jachowski et al., 2013). In comparison, the combined model (Model 11) developed for the Banlaem mangrove exhibited slightly lower performance, with an R^2 value of 0.58. Moreover, the use of UAVs equipped with VIs and the height model, has been reported in other Southeast Asian countries. In Quang Ninh Province, Vietnam, a model utilizing NDVI and UAV-derived tree height data achieved high accuracy in estimating mangrove AGB, with an R^2 = 0.83 and an *RMSE* = 0.04 tons/ha (Ngo et al., 2023). Additionally, in Komodo National Park, Indonesia, multisource remote sensing data combined with machine learning techniques yielded an optimal model for mangrove AGB estimation, achieving an R^2 = 0.76 (Rijal et al., 2023). These findings are consistent with prior research (Nguyen et al., 2021), which indicated that integrating various VIs enhances model performance. The diverse age structures or mixed species compositions may reduce approach accuracy (Nguyen et al., 2019). Thus, in this study, models developed within homogeneous *A. marina* plots exhibited higher accuracy compared to those applied to mixed species plots containing both *A. marina* and *Rhizophora* species.

Despite its contributions, this study faced certain limitations. Specifically, some plots (plots 13-18) were excluded from the analysis of VIs derived from UAV data due to their location within a no-fly zone near an airport. Additionally, the UAV-derived height model demonstrated a low correlation with AGB. The dense canopy of the mangroves may have contributed to signal interference from the UAV. To enhance model accuracy in future research, incorporating LiDAR data, which provides distinct advantages for examining the vertical structure of mangroves (Tian, Zhang, Huang, Huang, Tao, and Zhou et al., 2022), could be beneficial.

4.3 Impacts on the Banlaem Community

To findings in this study reveal the ability of the Banlaem mangrove forest as the carbon sink and underscore the potential of UAV data in estimating mangrove biomass and carbon stocks. The proposed methodological framework and mathematical models, particularly Models 11 and 22 (**Table 4.4; Table 4.5**), offer a reproducible approach for evaluating carbon stocks not only in the Banlaem mangrove forest but also in other regions of Thailand and tropical mangrove ecosystems with similar species compositions. This study aligns with the Thai government's emission reduction targets, which include goals for carbon neutrality by 2050 and achieving net-zero greenhouse gas (GHG) emissions by 2065; to support these targets, Thailand has revised its Nationally Determined Contributions (NDC) strategy to increase the GHG emissions reduction goal from 25% to 40% by 2030 (ONEP, 2022).

Ultimately, with the presence of a voluntary market mechanism in Thailand, this study offers valuable insights for land managers in making informed decisions regarding harvesting, tree planting, and habitat conservation in this promising area. This approach fosters community engagement in sustainable management and carbon offset initiatives.

Notably, the Banlaem community hosts approximately 300-400 tourists and students each month who visit the mangrove forest to participate in tree planting activities (Minmun, personal communication, June 23, 2024). This study could enhance the community's understanding of the growing importance of carbon storage in mangroves and facilitate the collection of statistical data to assess the impact of mangrove planting on greenhouse gas reduction.

Additionally, the study found that the combination of grey and loop-root mangroves in this area leads to higher carbon stocks compared to stands of only grey mangroves (**Figure 4.3**). This finding may inform authorities as they develop mangrove plantation plans and management strategies to support blue carbon management in the region.

4.4 Limitations and Possible Applications of the AGB Model

The AGB model in this study was developed based on the specific characteristics of the Banlaem mangrove forest, which may limit its effectiveness when applied to mangroves with different characteristics. Mangrove forests with higher species diversity and more complex structures may require advanced modeling approaches instead of relying solely on linear relationships. It is recommended to apply the modeling approach used in this study to mangrove areas that share similar characteristics. Nevertheless, the modeling approach proposed in this study may apply to adjacent mangrove ecosystems that exhibit comparable features. For instance, a study conducted at the Mangrove Forest Resource Development and Learning Center 2 (Srimoh and Markphan, 2024), in Nakhon Si Thammarat, identified higher species diversity, with six mangrove species recorded. Despite this diversity, the *Avicennia* marina and *Rhizophora* species remained dominant. The study, which relied on field-based methods, reported a carbon stock of 29.69 tons/ha, comparable to the 28.15 ± 25.90 tons/ha recorded in Banlaem. The similarity in dominant species and carbon storage capacity between the two sites suggests that the modeling approach developed in this study could be effectively applied to the Mangrove Forest Resource Development and Learning Center 2 for monitoring purposes. This application would help overcome challenges related to difficulties in field data collection