Generating site-specific allometric equations for aboveground and belowground biomass of mangroves in Siargao Island, Surigao del Norte, Mindanao, Phillipines

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Abstract. The application of allometric equations for quantifying mangrove forests aboveground and belowground biomass is an essential step related to efforts of climate change adaptation. Generalized allometric equations have been applied for estimating biomass and carbon storage of mangrove forests. However, adopting a generalized allometric equation to estimate the biomass generates uncertainty due to the variation in the environment, species and zonation. Therefore, formulating site-specific allometric equations is important to accurately quantify the biomass. Siargao Island is considered to have the largest continuous stand of mangrove with an estimated 9,000 ha of fair condition mangrove forests. This study was aimed to formulate site-specific allometric equations for mangroves in Siargao Island, Mindanao, Philippines using destructive method.

Key Words: carbon stock, climate change, growth, multi-species.

Introduction. Mangrove ecosystem has proven to provide a wide array of economic and ecological services. It supports local fishery, livelihood to fisherfolk (Primavera 2000; Ingwall 2005; Walters et al 2008; Hogarth 2015) and fish breeding grounds (Brander et al 2012), produces wooden products (Da Silva et al 1993; Brander et al 2012; Abino et al 2014), protects coastal community from storm surge (Lee et al 2014) and sequesters atmospheric carbon.

The carbon storage function of mangroves has been considered as a cost-effective way in mitigating the impacts of climate change (Alongi 2012). One way to estimate the carbon content is through conversion of the mangrove biomass value (Lasco & Pulhin 2003). The traditional way of measuring mangrove biomass is through tree harvest yet deemed to be destructive, laborious, time-consuming and expensive. Thus, several researches had focused on generating allometric equation to measure mangrove biomass to avoid tree destruction.

Allometric equations are statistically generated equations through regression using dependent variable and independent variables which are mangrove measurements such as diameter at breast height, tree height and crown diameter. It has been highly regarded as equally convenient and helpful especially in filling in the gaps of mangrove research. However, it may overestimate or underestimate the biomass as the independent variables or mangrove measurements in the used allometric equation vary depending on species, age of tree, site quality, climate, and stocking of tree stands (Zianis & Mencuccini 2004). Furthermore, mangrove measurements also vary in terms of genetic and environmental factors across wide geographic regions (Kusmana et al 2018). With this, certain allometric equations may not fit to a certain mangrove stand. It is therefore wise to formulate an allometric equation which is site specific for the accuracy of results (Nugroho 2014) and to refine the present biomass estimates for mangroves which are hugely important in the light of carbon trading.

Siargao Island is considered to have the largest contiguous stand of mangrove, supporting 31 species within a vast estimated 9,000 ha of fair condition mangrove forests (Long & Giri 2011). It was declared as a mangrove reserve in 1981 according to the Presidential Proclamation No. 2152. Because of this, formulating site-specific allometric equations is important to accurately quantify the aboveground and belowground biomass of mangroves thus its carbon stocks. So far, only one study has been conducted on allometric equation in Siargao Island and the study was focused on *Rhizophora apiculata* (Makinano-Santillan et al 2019). The result of this study could be used for future monitoring of the mangrove ecosystem in the area. This study was aimed to formulate site-specific allometric equations for mangroves in Siargao Island, Mindanao, Philippines using destructive method.

Material and Method

Study area. Siargao is a teardropped-shaped small island located at the northeastern coast of Mindanao (9.8482°N, 126.0458°E). It is composed of 48 islets, divided by nine municipalities which are all covered with mangroves (Figure 1). There were eight coastal barangays that were chosen as sampling stations because of its dense mangrove forest. The sampling stations were in Del Carmen, Bitoon, Antipolo, Dayaohay, Pilaring, Asinan, Centro and Salvacion.

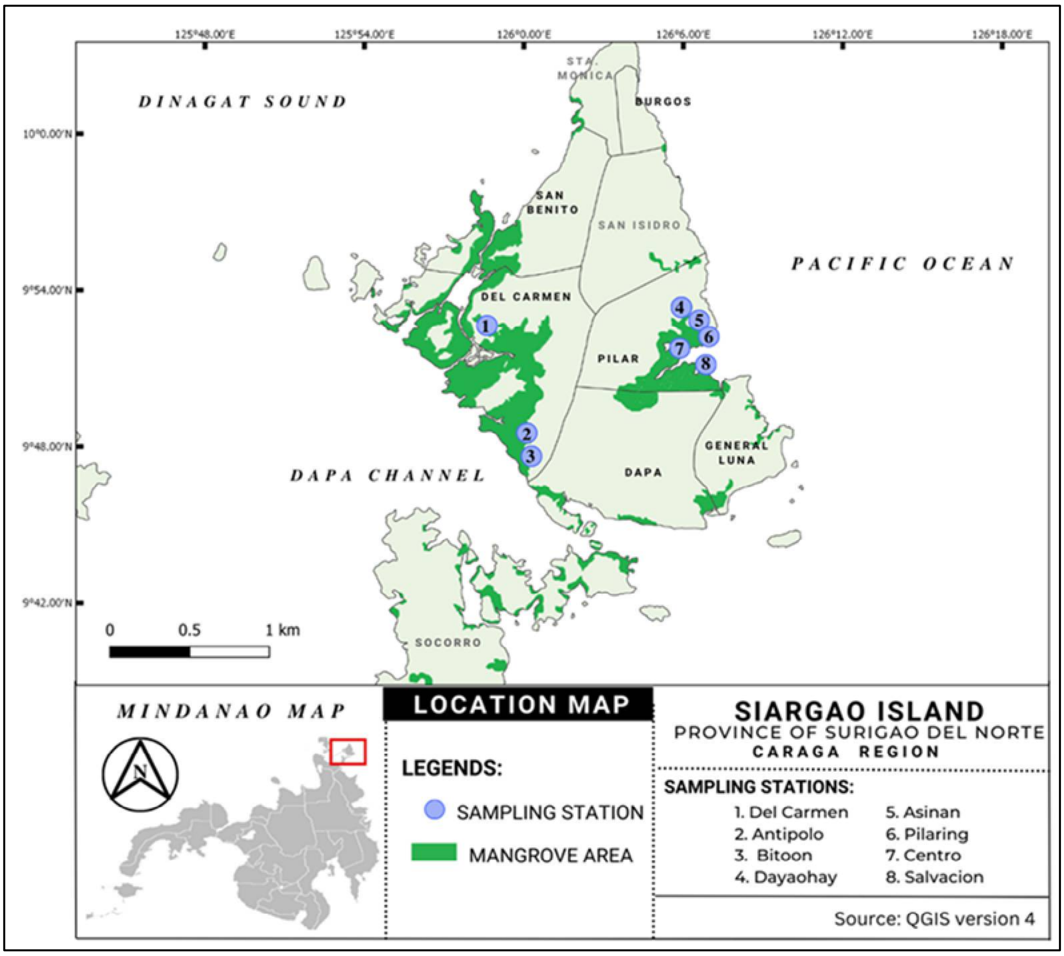

Figure 1. Map of the study area and location of the mangrove sampling stations.

Collection of mangrove trees and measurement of diameter at breast height (DBH), basal area (BA), height (H), crown width (CW), crown length (CL) and crown area (CA). The sampling was conducted from April to June 2021. A total of 38 mangrove trees were randomly selected from eight sampling stations and used for allometric purposes. One to four trees per mangrove species that were live, single or multi-stemmed and had no sign of damage were selected and harvested. Likewise, only trees with sizes achievable for harvesting were prioritized. The girth or DBH was measured using a tape measure and was calculated using the formula: circumference / 3.1416. Likewise, the basal area (BA) was computed using the following formula: 3.1416 (DBH) $^2/_4$ (English et al 1997). The height of trees was measured using the trigonometric techniques (Saliu et al 2021). For crown area, the crown length and width was measured using a tape measure. The CW is the widest diameter of the crown while CL is the diameter perpendicular to the CW. The crown area was computed using the formula of Kauffman & Donato (2012):

$$\text{Elliptical crown area} = [W_1 * (W_2 / 2)]^2 * 3.1416$$

where: W_1 = the crown length (m);
W_2 = the crown width (m).

Determination of fresh and dry weight. The small trees (with DBH that ranged from 3.5 to 19 cm) were cut using a battery operated chainsaw and axe for splitting hardwood. The parts of the tree such as leaves, branches and trunk were separately cut, collected and weighed. For those large trees (with DBH that ranged from 20.6 to 69.7 cm), only the upper part of the tree was cut due to the big size of the trunk. However, in order to calculate the total fresh weight of the whole trunk, the Smalian's formula was used (Lang'at et al 2009):

$$\text{Log volume (cm}^3) = [(B+b)/2]\ L$$

where: B = the area of the base of the felled (or cut) and stump (or remaining) trunk;
b = the area of the tip of the felled and stump trunk;
L = the length of the felled or stump trunk.

After the measurement (base, tip and length) of the trunk, the fresh weight of the remaining trunk was calculated based on simple ratio and proportion (Wang et al 2017):

$$FW_2 = \frac{FW_1 * V_2}{V_1}$$

where: FW_2 = the fresh weight of the remaining trunk or stump;
FW_1 = the fresh weight of the felled (or cut) trunk;
V_1 = the volume of the felled trunk;
V_2 = the volume of the remaining trunk or stump.

The parts of the tree such as leaves, branches and trunk were weighed separately and the weight of the leaves, branches and trunk served as the fresh weight. The roots (prop roots and pneumatophores) were counted first and they were collected and weighed. Counting was done inside a trench (125 cm x 20 cm x 10 cm) with some modification (Komiyama et al 2000). The prop roots along with its secondary and/or tertiary roots were counted as one (Coronado-Molina et al 2004).

In terms of dry weight, about 100 grams of subsample from each part (leaves, branch, trunk and roots) were oven-dried at 110°C for 48 hours. Dry to fresh weight ratio was calculated to determine the dry mass of the whole tree compartments such as leaves, branches, trunk and roots (Komiyama et al 2005; Kairo et al 2008). The total dry weight (D_1) in grams of the tree compartments was determined based on the formula:

$$D_1 = (D_2 * F_1) / F_2$$

where: D_1 = the total dry weight of each tree compartment (leaves, branch, trunk and roots);
F_1 = the total fresh weight of each of the tree compartments (leaves, branch, trunk and roots);
D_2 = the oven-dried weight of the 100 grams subsample of leaves, branch, trunk and roots;
F_2 = the initial subsample of 100 grams of leaves, branch, trunk and roots.

Statistical analysis and calculation of allometric equation. All the independent variables such as diameter at breast height, basal area, height, crown width, crown length, crown area, and number of roots were tested against its dependent variables through multiple linear regression analysis. Independent variables which significantly correlated with the dependent variables were included in the models. The allometric equation best fit for the data was chosen based upon the R, R^2, significance of the coefficient factors and ANOVA model. To test the regression model accuracy, the actual biomass was tested against the computed above ground biomass using the generated formulas. To determine whether it was significant or not, the Independent *t*-test was used for the actual biomass versus the calculated biomass ($p < 0.05$).

Results and Discussion. The multiple linear regression analysis was the best technique used to formulate the allometric growth model of mangroves in Siargao Island. For the above-ground biomass (AGB) equation-1, the regression model includes all corresponding independent factors. The R value = 0.87 pointed out a high degree of correlation between dependent and independent variables (Table 1). An R^2 = 0.76 indicated 76% of the predictive factors correlated to the overall AGB and the equation yielded highly significant value of p = 0.00. Comparing the actual and predicted values, there was no significant difference (Independent t-test, p = 1.0) implying that the AGB equation-1 developed in this study is accurate (Table 2). The regression model for below-ground biomass (BGB) resulted to a significant value (p = 0.05), R = 0.91 and R^2 = 0.83, signifying high degree of correlation and 83% fraction of the predictive factor to correlate with the BGB. No significant difference was found between the actual values of the BGB and the predicted values implying that the BGB equation-2 is accurate.

Table 1

The allometric growth equation model of mangroves in Siargao Island represented by above-ground biomass (AGB), below-ground biomass (BGB) and total tree biomass (TTB) derived from multiple regression analysis (MRA)

Growth parameter	*Equation*	*R*	*R^2*	*P*	*Analysis*
AGB	y = 0.20 (DBH) - 0.089 (H) + 1.418 (CW) + 1.362 (CL) + 0.008 (BA) + 0.090 (CA) + 0.554	0.87	0.76	0.00	Significant
BGB	y = -0.0107 (NR) + 1.6509	0.91	0.83	0.05	Significant
TTB	y = 0.191 (DBH) - 0.045 (H) + 1.5 (CW) + 1.373 (CL) + 0.008 (BA) + 0.089 (CA) - 0.007 (NR) + 1.10	0.87	0.76	0.00	Significant
TTB	y = 0.012 (BA) + (0.13) CA + 7.586	0.87	0.75	0.00	Significant

Table 2

Statistical analysis (*t-test*) of the actual above-ground biomass (AGB), below-ground biomass (BGB) and total tree biomass (TTB) versus the predicted values of AGB, BGB and TTB of mangroves in Siargao Island

Source	*d.f.*	*t-statistics*	*p*	*Analysis*
AGB_1	74	-0.016	0.414	N.S.
BGB_2	74	-4.790	0.412	N.S.
TTB_3	74	-0.012	0.377	N.S.
TTB_4	74	-0.029	0.319	N.S.

Legend: N.S. = not significant.

For the total tree biomass, the TTB equation-3 model included all the independent factors. The R value = 0.87 indicated a high degree of correlation. The value of R^2 = 0.76 implies 76% of the predictive factors correlated to the total tree biomass and the equation was highly significant (p = 0.00). The result of the *t-test* between the actual and predicted values was not significant implying that the TTB equation 3 is accurate.

Also, this study generated a shorter equation which is more convenient as it only required two variables, the crown and the basal area. The TTB equation-4 was strongly significant (p = 0.00) and had a high degree of correlation (R = 0.87). A value of R^2 = 0.75 signified 75% of the predictive variables correlated to the dependent variable. Similar to the TTB equation 3, no significant difference was detected between the actual and predicted values suggesting that the equation is accurate.

Furthermore, the common allometric equation for the above-ground and belowground biomass $W_{agb} = 0.251_p D^{2.46}$; $W_R = 0.199_p^{0.899} D^{2.22}$ formulated by Komiyama et al (2005) was used to compute for the AGB and BGB of the mangroves in Siargao Island. The result was then statistically compared with the actual above ground biomass using t-test (Table 3). Results showed that there was a significant difference in the AGB that was derived from Komiyama's formula versus the actual and predictive AGB of this study. Similar result was seen with regard to the BGB. This result further suggests that it is essential to use site-specific biomass equation in assessing carbon stock in order to avoid overestimation of data. Moreover, in this study it was seen that the CW and CL have stronger correlation values compared to the DBH.

Table 3

Statistical analysis (*t-test*) of the actual and predicted above-ground biomass (AGB) of mangroves in Siargao Island versus the AGB formula of Komiyama et al (2005)

Source	*d.f.*	*t-statistics*	*p*	*Analysis*
AGB_a	74	0.427	0.001	Significant
AGB_P	74	2.427	0.001	Significant
BGB_a	74	2.916	0.000	Significant
BGB_p	74	2.903	0.000	Significant

Legend: *a* is actual; *p* is predicted.

Conclusions. The 4 allometric equations for above-ground biomass, below-ground biomass and total tree biomass (1 & 2) developed in this study were accurate when actual and predicted values were compared. This implies that the equations developed could be used for future assessment and monitoring of mangroves in Siargao in view of carbon trading as significant climate change mitigation opportunity. Moreover, formulation of site-specific allometric equation is highly recommended for a more precise quantification of mangrove tree biomass.

Acknowledgements. We would like to thank the DOST-ASTHRD for the scholarship and thesis grant and the Department of Marine Science, College of Science and Mathematics, MSU - Iligan Institute of Technology for all the support in the conduct of this research.

Conflict of interest. The authors declare that there is no conflict of interest.

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Received: 26 October 2023. Accepted: 17 December 2023. Published online: 07 January 2024.
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How to cite this article:
Elecho F. E. E., Orbita M. L. S., Lacuna M. L. D. G., Guihawan J. Q., Orbita R. R., 2024 Generating site-specific allometric equations for aboveground and belowground biomass of mangroves in Siargao Island, Surigao del Norte, Mindanao, Phillipines. AACL Bioflux 17(1):23-29.