Estimation of aboveground biomass using allometric relationship between DBH and height for mixed mangrove forest in Setiu Wetland, Terengganu, Malaysia

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Abstract. A study was conducted to determine aboveground biomass in a mixed mangrove forest in Setiu Wetland, Terengganu, Malaysia. A total of 22 plots were established, diameter breast height (DBH) and height of each of the trees were measured and recorded. A total of three species from Rhizophoraceae and eight species from the non-Rhizophoraceae family were recorded. The highest no. of species for Rhizophoraceae is Bruguiera cylindrica with 189 individuals, meanwhile for non-Rhizophoraceae is Heritiera littoralis with 36 individuals. Linear regression between DBH to height had been done for stem allometry analysis for each species with Avicennia lanata shows good fit ($r^2 = 0.906$). The total aboveground biomass was $5202.23 \text{ kg ha}^{-1}$. A. lanata recorded the highest (983.78 kg ha$^{-1}$) total aboveground biomass because of various ranges of DBH and height. Linear regression also had been done between aboveground biomass to DBH and height. Rhizophora apiculata (Rhizophoraceae) and Excoecaria agallocha (non-Rhizophoraceae) show the highest value of regression between aboveground biomass to DBH which are $r^2 = 0.925$ and $r^2 = 0.948$ while B. gymnorrhiza (Rhizophoraceae) and Xylocarpus granatum (non-Rhizophoraceae) show the highest value of regression between aboveground biomass to height with $r^2 = 0.806$ and $r^2 = 0.839$. Overall, non-Rhizophoraceae have higher aboveground biomass as compared to Rhizophoraceae.

1. Introduction
Mangroves are specialized plants that can be found commonly in tropical and subtropical tidal areas. They have unusual physical adaptation at waterlogged saline soils with different temperatures, salinity and moisture. Malaysia is the third-largest mangrove forest in the Asia-Pacific region after Indonesia and Australia, approximately has an area of 645,852 ha of mangrove area, which covers 2% of its land area [1]. Mangrove ecosystems get the least attention from scientific researchers and also receive less conservation effort made compare to other biological communities [2]. Mixed Mangrove Forest is the formation of all mangrove forest type which is not dominated by any specific species. Mangrove forest is divided into two groups which are Rhizophoraceae and non-Rhizophoraceae. Rhizophoraceae is the family for genera Rhizophora, Bruguiera and Ceriops which usually form dense jungle along tropical seacoasts. Rhizophoraceae have scalariform perforation plates and obvious scalariform intervacular pits extending the whole length of the vessels which are important in the production of good quality charcoal [3]. Non-Rhizophoraceae consists of the other mangrove species. Mangrove species in this family such as Excoecaria agallocha are not suitable to use as fuelwood because they will release too
pungent, poisonous smoke and also have blinding sap. The weight and number of remains of non-Rhizophoraceae are not dominant because they occur in bigger pieces compare to Rhizophoraceae. Non-Rhizophoraceae species produce tiny seeds that give serious problems in endorsing regeneration for nursery establishment [4]. Moreover, these species act as a complement to the mangrove ecosystem.

Mathematical relation such as allometric equation helps us in estimating and predicting the total aboveground biomass or the parts of the biomass from the plants. It is applied with independent variables such as trunk diameter, height and crown projection that can be measured during the sampling process. Allometric equation develops in three ways of sampling; destructive, non-destructive and literature data. Destructive sampling is applied by cutting off the trees while non-destructive sampling is applied by using the same equations to calculate and measure all the individual biomass of the trees from the leaves to the roots. Data from another literature might be used to develop equations too. Hairiah et al. [5] stated that allometric relationships are the scaling relationship that will show the effect to the ratio of different parts of tree when comparing small and large trees from the same species together. Allometric relationships can be envisaged when the construction of a tree body is based on biological or physical theories [6]. On top of that, the aboveground biomass of all vegetation including mangrove species can be predicted by using an allometric equation [7]. However, allometric relationships can be frailty as a tool. This is because they show various relationships due to diverse tree species and sites [6]. Furthermore, it is too painstaking for researchers to cut and weigh a lot of trees to create a series of allometric relationships for all tree species and sites. There must be a strong relationship between the parts measured and the other parameter of interest to develop an allometric relationship [8] and must know the factors that affect tree growth such as species and site location [9]. According to the research done before, two common variables that can be used are diameter breast height (DBH) and tree height. Studies done by Putz and Chan [10] and Ong et al. [11], show that DBH was taken as the only independent variable in the allometric equation. However, the tree height may help in the accuracy of biomass estimation [12]. According to Niklas et al. [13], the height of trees is restricted by the size range of basal stem diameter. They also stated that the recorded size of the height and stem diameter of trees such as the maximum size is important for further analysis which may help in ecological and evolutionary hypotheses. Measuring the aboveground biomass of mangroves by using allometric relations will show that the quantitative morphological characteristics of the trees such as DBH and height are linked together [14]. Aboveground biomass is all the living biomass above the soil such as stems, branches, seeds and foliage. The DBH of the trunk will show the size of the mangrove trees. The diameter-at-breast-height of the trees commonly will be measured 1.3 m above the soil surface as a standard because of the different sizes of mangrove biologists [15]. According to Kathiresan and Bingham [16], an accurate estimation of biomass requires in measuring the volumes for each tree. The rate of accumulation of biomass can be estimated by calculating the standing biomass from the parts of the trees such as leaves and stems. Field survey of mangrove biomass and productivity is difficult due to muddy soil conditions and the heavy weight of the wood.

Salinity and pH are the abiotic components in the mangrove ecosystem and are important as environmental parameters in mangrove research. Normally, mangrove vegetation is more abundant in lower salinities [17]. The seawater has an average salinity of 35 ppt and varies with estuarine depth. The pH of water is important to determine whether it is alkaline or acidic. The mangrove soils are usually neutral to slightly acidic because of the presence of sulphur-reducing bacteria and acidic clays.

This study is trying to focus on estimating the aboveground biomass of mixed mangrove forests in Setiu Wetland by using an allometric relationship between DBH and height. The mangrove species were separated into two groups which are Rhizophoraceae and non-Rhizophoraceae. There are insufficient information and lack of study about the allometric relationship of mangroves, so hopefully will be useful for future research especially in the allometric relationship between DBH and height in the Terengganu mangrove forest.
2. Methodology
The Setiu Wetland is situated 50 km northwest of Kuala Terengganu. According to WWF Malaysia [18], it is a part of the Setiu River Basin that covered 9,200 ha from 23,000 ha of the large Setiu-Chalok-Bari-Merang basin wetland. Furthermore, there are so many species of mangroves that can be found which is important and related in this study. The study area that had been chosen was Kg. Pengkalan Gelap (05° 40.647’ N, 102° 42.602’ E). This study area consists of vegetation type such as Nypa, Bruguiera and mixed mangrove. The average temperature in Setiu was 30.6 °C where the highest was 32.5 °C and the lowest was 29.5 °C.

A circular plot for an adult tree was set up with a radius of 5.64 m. The total area for the plot was 100 m². A circular plot was used usually as an inventory besides reducing-edge error while sampling. The coordinate of the trees will be recorded by using the Global Positioning System (GPS). DBH of each species was measured at 1.3 m above the soil sediment surface. For the tree that have buttresses that extended up to stem above 1.3 m such as Rhizophora apiculata, the stem was measured just above the buttresses. The height of the trees was measured by using a clinometer. All the data that had been recorded from the sampling period should be analyzed. Data that had been obtained were a group of species, diameter breast height (DBH), and height of the tree. The data of salinity and pH recorded were used as a physical parameter.

Aboveground biomass will be analyzed by using the data of DBH and the height of the trees recorded. The allometric equation that will be used to calculate the aboveground biomass is 116.6 \[(DBH)^2 H\] [19].

3. Results and Discussion
A total of 330 individuals that belong to three species of Rhizophoraceae and eight species from non-Rhizophoraceae were recorded in Setiu Wetland. 22 plots were established in this study area. The species were Bruguiera cylindrica, B. gymnorrhiza, Rhizophora apiculata, Heritiera littoralis, Avicennia alba, Dolichandrone spathacea, Excoecaria agallocha, Xylocarpus granatum, Hibiscus tiliaceus, Avicennia lanata and Lumnitzera littorea (Table 1).

Figure 1 show obvious differences between the number of individual for each species. The highest number of trees that had been recorded for Rhizophoraceae was 189 individuals that belong to B. cylindrica while B. gymnorrhiza recorded the lowest number of trees with five individuals. H. littoralis was the species from non-Rhizophoraceae with highest number of trees sampled with 36 individual while the lowest was L. littorea with two individuals.

| Family | Species                | No. of tree (N) | Tree per hectare | Percentage (%) |
|--------|------------------------|-----------------|------------------|----------------|
| R      | Bruguiera cylindrica   | 189             | 859              | 57.27          |
|        | Rhizophora apiculata   | 13              | 59               | 3.93           |
|        | Bruguiera gymnorrhiza  | 5               | 23               | 1.52           |
| NR     | Heritiera littoralis    | 36              | 164              | 10.91          |
|        | Avicennia alba          | 24              | 109              | 7.27           |
|        | Dolichandrone spathacea | 5              | 23               | 1.52           |
|        | Excoecaria agallocha    | 29              | 132              | 8.78           |
|        | Xylocarpus granatum     | 7               | 32               | 2.12           |
|        | Hibiscus tiliaceus      | 5               | 23               | 1.52           |
|        | Avicennia lanata        | 15              | 68               | 4.55           |
|        | Lumnitzera littorea     | 2               | 9                | 0.61           |
| TOTAL  |                        | 330             | 1501             | 100            |

Notes: R = Rhizophoraceae, NR = Non-Rhizophoraceae
Figure 1. Number of individuals of mangrove species sampled in Setiu Wetland, Terengganu

Although this study area is mixed mangrove forest type, it also consists of Bruguiera vegetations. This thing might affect the number of individuals of mangrove species due to the dispersion of seed from the nearer place. *H. littoralis* also recorded the highest number of trees after *B. cylindrica*. Furthermore, most of *H. littoralis* can be found in the same area as *B. cylindrica*. Most of these two species can be found in the middle and back zone of the mangrove area that usually cover by stiff sand.

The Table 2 below shows the size range of each species. The smallest values for both DBH and height recorded were 5 cm and 3.5 m. The highest value of DBH was 36 cm while 17.1 m for height.

| Family | Species          | DBH (cm) | Height (m) |
|--------|------------------|----------|------------|
| R      | *B. cylindrica*  | 5.0      | 16.0       |
|        | *R. apiculata*   | 7.2      | 20.4       |
|        | *B. gymnorrhiza* | 6.6      | 10.8       |
| NR     | *H. littoralis*  | 5.0      | 15.0       |
|        | *A. alba*        | 5.6      | 22.1       |
|        | *D. spathacea*   | 5.4      | 8.0        |
|        | *E. agallocha*   | 5.0      | 16.0       |
|        | *X. granatum*    | 7.2      | 19.3       |
|        | *H. tiliaeus*    | 5.5      | 9.5        |
|        | *A. lanata*      | 5.0      | 36.0       |
|        | *L. littorea*    | 5.3      | 7.6        |

Notes: R = Rhizophoraceae, NR = Non-Rhizophoraceae

Linear regression between DBH and height was conducted to compare the stem allometry between different species recorded in Setiu Wetland. According to Medeiros and Sampaio [20], AGB can be estimated better when tree height is included in the equation while AGB significantly linked to the DBH. A good fit was shown by *A. lanata* with $r^2 = 0.90$ and *X. granatum* with $r^2 = 0.70$ show strong regression between these two variables (Table 3). This is because their height becomes higher as the DBH become greater. Furthermore, tree size had an important influence on the allocation of biomass between tree parts [20].
Table 3. Linear regression for DBH and height between mangrove species recorded in Setiu Wetland, Terengganu

| Family | Species                | N   | $r^2$ |
|--------|------------------------|-----|-------|
| R      | B. cylindrica          | 189 | 0.058 |
| R      | R. apiculata           | 13  | 0.308 |
| R      | B. a gymnorhiza        | 5   | 0.468 |
| NR     | H. littoralis          | 36  | 0.302 |
| NR     | A. alba                | 24  | 0.119 |
| NR     | D. spathacea           | 5   | 0.118 |
| NR     | E. a agallocha         | 29  | 0.495 |
| NR     | X. granatum            | 7   | 0.704 |
| NR     | H. tiliaceus           | 5   | 0.046 |
| NR     | A. lanata              | 15  | 0.906 |

Notes: R = Rhizophoraceae, NR = Non-Rhizophoraceae

Good fit = 0.80 - 1.00, Average fit = 0.40 - 0.79, Poor fit = 0.00 - 0.39

The other species (B. gymnorrhiza, R. apiculata, A. alba, H. littoralis, E. agallocha, and D. spathacea) showed a low fit ranging 0.11 - 0.49. The linear regression for L. littorea cannot be done because of lack of data recorded that was only two individuals. Meanwhile, the linear regression between DBH and height were very poor for B. cylindrica and H. tiliaceus when both recorded $r^2 = 0.05$ and $r^2 = 0.04$. This is because B. cylindrica grew tall and thin while the DBH of H. tiliaceus was not compatible with its height due to many branches. Thus, biomass estimation can be enhanced by taking into consideration both vertical and lateral growth.

The estimated total aboveground biomass for all species was 5,202.23 kg ha$^{-1}$. The highest aboveground biomass was recorded by A. lanata with 983.78 kg ha$^{-1}$. D. spathacea was recorded in having the lowest aboveground biomass with 154.36 kg ha$^{-1}$. Table 4 shows the overall results for aboveground biomass for eight species sampled while Table 5 shows the differences between the average aboveground biomass of Rhizophoraceae and non-Rhizophoraceae. Non-Rhizophoraceae had higher aboveground biomass.

Table 4. Aboveground biomass for each mangrove species recorded in Setiu Wetland, Terengganu

| Family      | Species                | Aboveground Biomass (kg ha$^{-1}$) |
|-------------|------------------------|-----------------------------------|
| Rhizophoraceae | Bruguiera cylindrica   | 230.50                            |
|             | Rhizophora apiculata   | 886.93                            |
|             | Bruguiera gymnorrhiza  | 411.50                            |
| Non-Rhizophoraceae | Heritiera littoralis    | 378.25                            |
|             | Avicennia alba         | 604.83                            |
|             | Dolichandrone spathacea| 154.36                            |
|             | Excoecaria agallocha   | 315.71                            |
|             | Xylocarpus granatum    | 912.93                            |
|             | Hibiscus tiliaceus     | 323.44                            |
|             | Avicennia lanata       | 983.78                            |

Total                                         5,202.23

Table 5. Comparison of aboveground biomass between Rhizophoraceae and non-Rhizophoraceae in Setiu Wetland, Terengganu

| Family | Aboveground Biomass (kg ha$^{-1}$) |
|--------|-----------------------------------|
Linear regression between aboveground biomass to DBH and height was showed in Table 6 below. From the table, all species from Rhizophoraceae and five species of non-Rhizophoraceae (H. littoralis, A. alba, E. agallocha, X. granatum and A. lanata) show a good fit regression of aboveground biomass to DBH with $r^2 > 0.80$ while H. tiliaceus show average fit with $r^2 = 0.79$. Meanwhile, D. spathacea showed very poor fit with $r^2 = 0.01$.

The linear regressions of aboveground biomass to height of all species were lower than yielded by DBH. The species that showed good fit with $r^2 > 0.80$ were B. gymnorrhiza of Rhizophoraceae, A. lanata and X. granatum of non-Rhizophoraceae. Meanwhile, B. cylindrica (Rhizophoraceae), A. alba and H. tiliaceus of non-Rhizophoraceae showed weak fit with $r^2$ ranging 0.06 – 0.24. The average fit showed by R. apiculata (Rhizophoraceae) and the other non-Rhizophoraceae with $r^2$ ranging 0.45 – 0.78.

**Table 6.** Comparison of regression between aboveground biomass to DBH and height for each mangrove species recorded in Setiu Wetland, Terengganu

| Family          | Species                  | $r^2$ AGB vs DBH | $r^2$ AGB vs H |
|-----------------|--------------------------|------------------|----------------|
| Rhizophoraceae  | *Bruguiera cylindrica*   | 0.864            | 0.263          |
|                 | *Rhizophora apiculata*   | 0.925            | 0.455          |
|                 | *Bruguiera gymnorrhiza*  | 0.871            | 0.806          |
| Non-Rhizophorace| *Heritiera littoralis*   | 0.879            | 0.540          |
|                 | *Avicennia alba*         | 0.929            | 0.246          |
|                 | *Dolichandrone spathacea*| 0.016            | 0.786          |
|                 | *Excoecaria agallocha*   | 0.948            | 0.582          |
|                 | *Xylocarpus granatum*    | 0.909            | 0.839          |
|                 | *Hibiscus tiliaceus*     | 0.797            | 0.060          |
|                 | *Avicennia lanata*       | 0.917            | 0.811          |

Notes: Good fit = 0.80 - 1.00, Average fit = 0.40 - 0.79, Poor fit = 0.00 - 0.39

In this study, A. lanata of non-Rhizophoraceae recorded the highest AGB with 983.78 kg ha$^{-1}$ (refer to Table 4). A. lanata had both the highest DBH and height compared to other species which are 36 cm and 17.14 m. The linear regression between AGB to DBH and height of A. lanata fit the data best which $r^2 = 0.91$ and $r^2 = 0.81$. Furthermore, the DBH and height were highly correlated.

The other species of non-Rhizophoraceae except D. spathacea also showed a best fit linear regression between AGB and DBH with $r^2 > 0.79$. Meanwhile, the Rhizophoraceae species also proved that the DBH was well-matched with their AGB where $r^2 > 0.86$. This is maybe their DBH were fit to the total AGB produced. This shows that DBH is a good estimator of AGB. D. spathacea showed a very weak relationship ($r^2 = 0.01$) may be due to shorter tree while having DBH relatively higher compared to the other trees [21].

The linear regression between AGB and height of each species illustrated that only B. gymnorrhiza (Rhizophoraceae) and X. granatum of non-Rhizophoraceae had a good fit regression besides A. lanata as stated before with $r^2 = 0.80$ and $r^2 = 0.83$. These three species also showed higher value of $r^2$ from the regression between DBH and height compared to the other species. H. tiliaceus showed very weak regression which was $r^2 = 0.06$ due to the higher tree compare to the small DBH. For some species, adding height may can improve the estimation of AGB, but tree height is difficult to be measured in a closed community and it is a painstaking task. Clough and Scott [3] did not use height as the variable in their allometric equation because it may lessen the reasonableness of its use in the allometric relationships. Smith and Whelan [7] also state that stem height is very difficult to measure non-destructively that may give effects to the estimation of AGB compare to DBH that can be measured accurately with ease.
Table 7 below shows the differences of regression of Rhizophoraceae and non-Rhizophoraceae between total aboveground biomass to the DBH and height. The regression of Rhizophoraceae between aboveground biomass to DBH was in good fit where $r^2 = 0.84$ which is higher than non-Rhizophoraceae. However, the regression between aboveground biomass to the height of Rhizophoraceae was 0.40 which is lower than non-Rhizophoraceae.

**Table 7.** Comparison of regression between aboveground biomass to DBH and height for Rhizophoraceae and non-Rhizophoraceae in Setiu Wetland, Terengganu

| Family              | $r^2$ AGB vs DBH | $r^2$ AGB vs H |
|---------------------|------------------|----------------|
| Rhizophoraceae      | 0.84             | 0.40           |
| Non-Rhizophoraceae  | 0.77             | 0.40           |

Notes: Good fit = 0.80 - 1.00, Average fit = 0.40 - 0.79, Poor fit = 0.00 - 0.39

When comparing the AGB of *B. cylindrica* (Rhizophoraceae) and *H. littoralis* (non-Rhizophoraceae), the range of DBH and height for both species is likely the same but the outcome is different. *H. littoralis* recorded more AGB than *B. cylindrica* due to more variation of DBH and height possess by *H. littoralis*. The AGB of *X. granatum* and *R. apiculata* were also have huge differences although both species have approximately same range of DBH and height. When referring to the Table 6 in the result, the AGB of non-Rhizophoraceae was higher than Rhizophoraceae. It is difficult to state which group whether Rhizophoraceae or non-Rhizophoraceae contribute more AGB in this mixed mangrove forest type because Rhizophoraceae have fewer species compare non-Rhizophoraceae although the number of individual trees is larger.

Furthermore, the stem diameter of all individual of Rhizophoraceae was thinner compare to non-Rhizophoraceae. As discussed before, the AGB of the tree may be predicted by using DBH efficiently compare to the height. This is because when comparing the regression between AGB to DBH and AGB to height in Table 7, the regression between AGB to DBH for both groups were higher compared to the regression between AGB to height. This proves that the larger the DBH, the more AGB inside each individual.

The data of pH and salinity were recorded by dividing the study area into three zones; front (near to the sea), middle and back. Table 8 below showed the pH of the water was not having so much different in the three zones. The degree of salinity of the water in this study area was categorized into polyhaline which have higher salinity that ranging between 18 to 30 ppt.

**Table 8.** The water pH and salinity in three different zones in the study area

| Zone    | pH  | Salinity (ppt) |
|---------|-----|----------------|
| Front   | 6.5 | 28.5           |
| Middle  | 6.0 | 28.9           |
| Back    | 6.0 | 25.3           |

Salinity and pH were the physical environments that had been recorded in this study. They were a part of abiotic components in the mangrove ecosystem. Salinity is important because it may show whether the mangrove species can maintain water balance and ion concentration at high salt content in water by spending more energy on it rather than for primary production and growth [22]. Salinity also may affect the type of species that are suitable to inhabit a certain area. Usually, species of *Bruguiera* and *Heritiera littoralis* can be found in the middle and back zones with stiff sand cover while species of *Avicennia* can be found at the front zone with higher salinity and muddy sediment compare to other zones.

The roots of *Avicennia* are pencil-shaped pneumatophores or aerial roots that are important in gas exchange besides exclusion of salt from the vascular system. In the middle zone of this study area, the
species that can be found were *D. spathacea*, *H. tiliaceus*, *E. agallocha* and *X. granatum*. Meanwhile, *L. littorea* can only be found in the back zone because it is non-secretors like Bruguiera which can only absorb certain ions in the solution that is called the ultrafiltration process.

High salinity may reduce the biomass while low salinity may reduce cell turgidity and decreased respiration. In other words, the greater salt tolerance of the species may slow down the growth rate under the most favorable salinity environment. The pH of water recorded in this study area was in range of 6 to 6.5 which is acidic but more neutral due to the aeration of soil sulphates. Low pH also may cause degradation of mangroves.

4. Conclusion

Mangrove ecology is very important and valuable for various studies such as estimation of aboveground biomass for each species. There are 11 species from Rhizophoraceae and non-Rhizophoraceae that had been recorded in Setiu Wetland which is a mixed mangrove forest type. The species are *Bruguiera cylindrica*, *B. gymnorrhiza* and *Rhizophora apiculata* for Rhizophoraceae while *Avicennia alba*, *A. lanata*, *Heritiera littoralis*, *Excoecaria agallocha*, *Xylocarpus granatum*, *Hibiscus tiliaceus*, *Dolichandrone spathacea* and *Lumnitzera littorea* for non-Rhizophoraceae. *B. cylindrica* recorded the highest number of trees recorded with 189 individuals. The tree with larger DBH and higher height will be measured correctly without bias. *A. lanata* recorded the larger DBH and highest tree with an estimated AGB of 983.78 kg ha\(^{-1}\). The total estimated AGB in this study area is 5,202.23 kg ha\(^{-1}\) and the AGB of non-Rhizophoraceae is higher than Rhizophoraceae because of the various size range of the tree. There is lack of research that have not been explored here compared to the other place in Malaysia such as Matang Mangrove Forest Reserve in Perak. More data on the intensity of sampling must be recorded to get more significant results especially in estimating aboveground biomass in non-Rhizophoraceae.

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