**Open Journal of Forestry, 2016, 6, 72-81**
Published Online April 2016 in SciRes. http://www.scirp.org/journal/ojf
http://dx.doi.org/10.4236/ojf.2016.62007

# Above-Ground Biomass, Nutrients and Carbon in *Aegiceras corniculatum* of the Sundarbans

**Mahmood Hossain[1*], Md. Al-Amin Shaikh[1], Chameli Saha[1], S. M. Rubaiot Abdullah[1], Sanjoy Saha[2], Mohammad Raqibul Hasan Siddique[1]**

[1]Forestry and Wood Technology Discipline Khulna University, Khulna, Bangladesh
[2]Centre for Integrated Studies on the Sundarbans Khulna University, Khulna, Bangladesh
Email: *mahmoodhossain@hotmail.com, alaminku22@gmail.com, chamelifwt@gmail.com, rubaiot@yahoo.com, sanjoyfwt@yahoo.com, raqibulhasan_fwt@yahoo.com

Received 20 December 2015; accepted 1 February 2016; published 4 February 2016



## Abstract

***Aegiceras corniculatum*** **grows as single-stemmed evergreen shrub or small tree in the Sundarbans mangrove forest of Bangladesh. The objectives of this study were to derive the allometric models for estimating above-ground biomass, nutrients (N, P and K) and carbon stock in** ***A. corniclatum.*** **A total of 8 linear models (y = aX + b, $\sqrt{y} = a\sqrt{X} + b$, y = aLogX + b, Logy = aX + b, Logy = aLogX + b, y = alnX + b, Lny = aX + b and Lny = alnX + b) with 64 regression equations were tested to derive the allometric model for biomass of each plant part; and nutrients and carbon stock in total above-ground biomass. The best fit allometric models were selected by considering the values of $R^2$, CV, $R_{mse}$, $MS_{error}$, $S_a$, $S_b$, F value, AICc and Furnival Index. The selected allometric models were Logbiomass = 0.76LogDBH² − 1.39; Biomass = 0.07DBH² − 0.49; Logbiomass = 1.04LogDBH² − 1.80; Logbiomass = 1.04LogDBH² − 0.99; $\sqrt{\text{Biomass}}$ = 0.48DBH − 0.13 for leaves, branches, bark, stem without bark and total above-ground biomass respectively. The selected allometric models for Nitrogen, Phosphorous, Potassium and Carbon stock in total above-ground biomass were $\sqrt{\text{Nitrogen}}$ = 0.67DBH + 0.11; $\sqrt{\text{Phosphorus}}$ = 0.94DBH + 0.08; $\sqrt{\text{Potassium}}$ = 1.06DBH − 0.18; $\sqrt{\text{Carbon}}$ = 0.33DBH − 0.09 respectively.**

## Keywords

**Allometry, Biomass, Carbon, Nutrient, Sundarbans**

*Corresponding author.

**How to cite this paper:** Hossain, M., Shaikh, M. A., Saha, C., Abdullah, S. M. R., Saha, S., & Siddique, M. R. H. (2016). Above-Ground Biomass, Nutrients and Carbon in *Aegiceras corniculatum* of the Sundarbans. *Open Journal of Forestry, 6,* 72-81. http://dx.doi.org/10.4236/ojf.2016.62007

## 1. Introduction

Mangroves are various trees and shrubs that grow in saline muddy habitats in the tropical and subtropical sheltered coastline (Tomlinson, 1986). About 35% of the total mangrove area of the world was destructed within 20 years from 1980 to 2000 (MA, 2005) through the conversion to agriculture, aquaculture, urbanization, tourism and over exploitation of resources (Alongi, 2002; FAO, 2007). Presently this forest covers about 181,377 $km^2$ and distributed in 124 countries (FAO, 2005). Mangrove ecosystem is one of the most productive ecosystems with a mean production of 2.5 $g \cdot Cm^{-2} \cdot day^{-1}$ which contributes about 11% of global total export of organic carbon to the aquatic ecosystem (Jennerjahn & Ittekkot, 2002). Mangrove ecosystem provides wood and fuel, protection from cyclones and tsunamis, nursery and breeding sites for many aquatic organisms. It also reduces coastal erosion, flooding, and maintains nutrient cycling and water quality (Lugo & Snedekar, 1974; Dinerstein et al., 1995; Mahmood et al., 2005; Ellison, 2008; Mahmood et al., 2008a). Biomass estimation has many applications like timber extraction, estimation of productivity, tracking changes in carbon stocks of the forest and global carbon and nutrient cycle (Komiyama et al., 2008; Mahmood et al., 2008b; Mahmood, 2014). The allometric method estimates the whole or partial weight of a tree using regression equations, which is a useful and non-destructive method for estimating forest biomass from the independent variables (Like diameter and height) (Golley et al., 1975; Ketterings et al., 2001) and has widely been used for estimating biomass of mangroves e.g. Tamai et al. (1986); Komiyama et al. (2002); Clough et al. (1997); Fromard et al. (1998); Mahmood et al. (2012); Siddique et al. (2012); Peters et al. (2014); Mahmood et al. (2015).

*Aegiceras corniculatum* is found to restrict in the indo pacific region and can tolerate comparatively high saline condition (Spalding, 2010). In the Sundarbans, it appears as single-stemmed evergreen shrub or small tree with *Avicennia officinalis*, *Excoecaria agallocha*, *Ceriops decandra*, *Kandelia candel*, *Sonneratia apetala*, *Xylocarpus mekongensis* and *Acanthus ilicifolius* at the moderate to high saline areas. Honey bees produce best quality honey from the nectar of this specie and wood is used for fuel and charcoal production (Siddiqi, 2001). This is a less studied species in the world (Ning et al., 1996; Saintilan, 1997) and there is not a single study on this species in the Sundarbans mangrove forest of Bangladesh. Each mangrove plant species plays a specific role in forest productivity, carbon sequestration and nutrient fluxes (Mahmood, 2004), which helps to understand the contribution of that species in functioning of the mangrove ecosystem (Hutchings & Saenger, 1987). The objectives of the present study were to derive allometric models for estimating above-ground biomass, nutrients (N, P and K) and carbon stock in *A. corniculatum* of the Sundarbans mangrove forest. This outcome will be helpful to estimate the specific role of this species in biomass production and nutrient stock and cycling which can contribute in sustainable management of this species in the Sundarbans.

## 2. Materials and Methods

### 2.1. Study Site

The study was carried out at the Sundarbans mangrove forest of Bangladesh which is located between 21˚30'N and 22˚30'N and 89˚00'E and 89˚55'E (**Figure 1**). This forest is almost flat and the maximum ground elevation is about 3 m above the mean sea level and the tidal height varies from 2 m to 6 m. The Sundarbans is dominated by the freshwater flows with high seasonal variation in their discharge. The salinity found to decrease from west to east of this forest and it has been divided into three salinity zones, less saline (salinity <2 $dSm^{-1}$), moderately saline (2 - 4 $dSm^{-1}$) and strongly saline (>4 $dSm^{-1}$). Rainfall varies around 1800 mm per year and the average temperature varies from 28˚C - 30˚C in summer and 18˚C - 20˚C in winter (Siddiqi, 2001). Soil texture is silty to sandy clay loam and pH is around 7.8. Bulk density, particle density and porosity varied from 1.18 to 1.27 $gcc^{-1}$, 2.31 to 2.52 $gcc^{-1}$ and 46% to 52%, respectively. The major species of the Sundarbans are *Heritiera fomes*, *E. agallocha*, *C. decandra*, *A. officinalis*, *A. corniculatum*, *S. apetala*, *S. caseolaris*, *Nypa fruticans*, *Bruguiera gymnorrhiza*, *B. sexangula*, *Rhizophora apiculate*, *R. mucronata*, *X. granatum* and *X. mekongensis* (Iftekhar & Seanger, 2008).

### 2.2. Sample Collection and Processing

Twenty nine individual of *A. corniculatum* having Diameter at Breast Height (DBH) from 1 to 15 cm were selected subjectively (avoiding mechanically or insect damaged or infested with disease) from the study area (**Table 1**). DBH and total height (TH) of the selected individuals were measured and felled at the ground level.

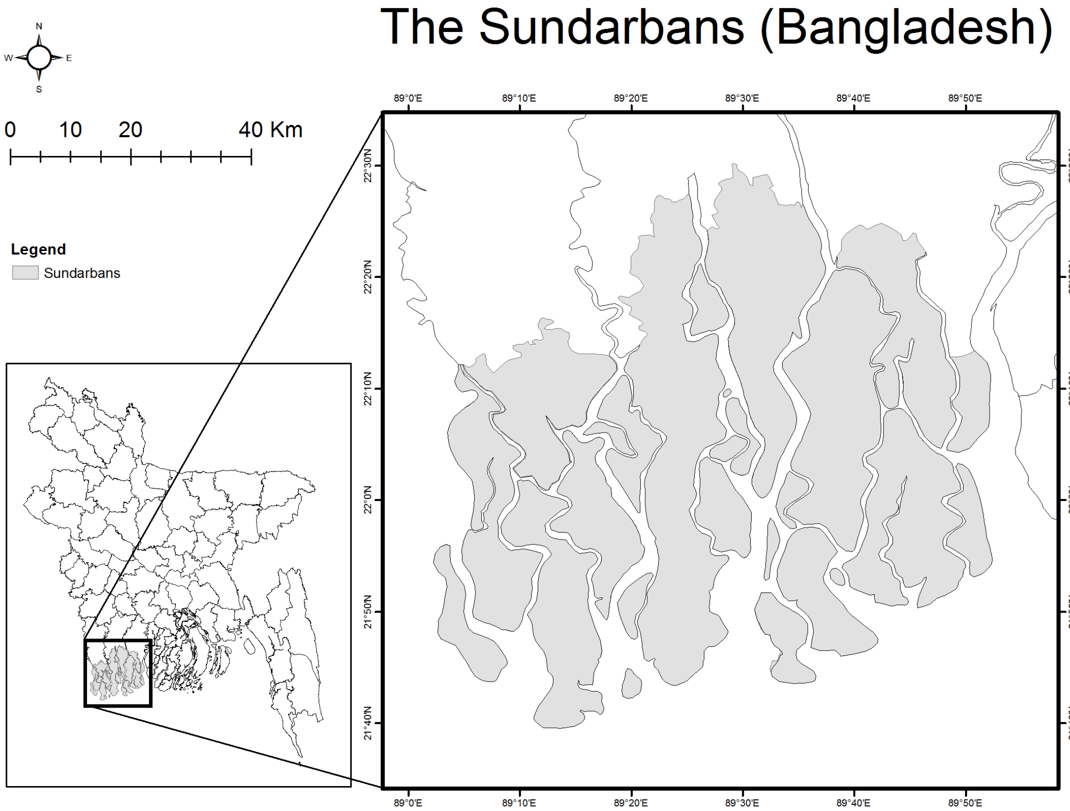


**Figure 1.** Location map of the study area.

The felled individuals were separated into leaves, smaller branches (diameter <2 cm), bigger branches (diameter > 2 cm) and stems; and all these parts of an individual were weighted (fresh mass) separately in the field and recorded. Ten stem sections of 50 cm in length were collected from the base, middle and upper portion of the stem. These stem sections were then debarked in the field to get fresh mass ratio of bark and stem wood. Five disks (2 cm thick) of stems and bigger branches (for trees) and 10 sub-samples (about 100 g) of each part such as leaves, smaller branches and bark were taken randomly from the sampled plant and brought back to the laboratory. These samples were oven-dried at 80˚C for 10 days to get of fresh mass to oven-dry mass conversion ratio. The oven-dried mass of different parts of individual *A. corniculatum* was calculated from the derived conversion ratio and fresh mass of the corresponding plant part (Mahmood et al., 2004, 2012, 2015).

## 2.3. Nutrients and Carbon in Plant Part

Ten sub-samples (about 100 g) of each plant part were collected randomly from the selected individual and oven-dried at 80˚C until constant weight for 10 days, crushed and sieved through 2 mm mesh. Kjeldahl digestion for Nitrogen and tri-acid ($H_2SO_4$, $HClO_4$ and $HNO_3$) digestion for Phosphorus and Potassium were applied to get the sample extract (Allen, 1989). Nitrogen and Phosphorus in the sample extract were measured calorimetrically according to Baethgen and Alley (1989) and Timothy et al. (1984) respectively using UV-visible Recording Spectrophotometer (HITACHI, U-2910, Japan). Potassium concentration in the sample extract was measured by Flame Photometer (PFP7, Jenway LTD, England). Organic carbon concentration in samples was determined by ignition method (Allen, 1989). Nutrients and carbon concentration in plant parts were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test by using SAS (6.12) statistical software. The amount of nutrients and carbon stock in each part of individual tree were estimated from their concentration and the oven-dried biomass of respective plant parts.

## 2.4. Allometric Models

A total of 8 linear models ($y = aX + b$, $\sqrt{y} = a\sqrt{X} + b$, $y = aLogX + b$, $Logy = aX + b$, $Logy = aLogX + b$, $y =$

**Table 1.** Sampled stems along with their Diameter at Breast Height (DBH), Total Height (TH) and oven-dried biomass of plant parts.

| DBH (cm) | Total Height (m) | Oven-dried biomass (Kg) of plant part | | | | Total above-ground Biomass (kg) |
|---|---|---|---|---|---|---|
| | | Leaf | Branch | Bark | Stem without bark | |
| 1.10 | 2.20 | 0.05 | 0.12 | 0.02 | 0.16 | 0.35 |
| 1.70 | 1.87 | 0.06 | 0.07 | 0.04 | 0.28 | 0.45 |
| 1.80 | 2.37 | 0.09 | 0.13 | 0.05 | 0.33 | 0.60 |
| 2.00 | 2.35 | 0.11 | 0.15 | 0.07 | 0.43 | 0.74 |
| 2.10 | 2.24 | 0.12 | 0.24 | 0.08 | 0.50 | 0.93 |
| 2.20 | 2.77 | 0.20 | 0.20 | 0.10 | 0.63 | 1.13 |
| 2.40 | 2.38 | 0.15 | 0.18 | 0.08 | 0.54 | 0.95 |
| 2.50 | 3.00 | 0.20 | 0.21 | 0.13 | 0.85 | 1.38 |
| 3.00 | 2.70 | 0.28 | 0.44 | 0.18 | 1.14 | 2.04 |
| 3.10 | 3.46 | 0.32 | 0.41 | 0.17 | 1.10 | 2.00 |
| 3.30 | 2.08 | 0.42 | 0.63 | 0.16 | 1.01 | 2.22 |
| 3.40 | 3.05 | 0.17 | 0.23 | 0.16 | 1.04 | 1.60 |
| 3.60 | 3.28 | 0.31 | 0.61 | 0.22 | 1.39 | 2.52 |
| 3.80 | 3.10 | 0.20 | 0.38 | 0.21 | 1.37 | 2.16 |
| 4.11 | 3.34 | 0.43 | 0.58 | 0.27 | 1.77 | 3.06 |
| 4.30 | 3.85 | 0.33 | 0.35 | 0.25 | 1.59 | 2.52 |
| 5.30 | 4.27 | 0.72 | 1.53 | 0.46 | 2.99 | 5.70 |
| 6.20 | 4.93 | 0.70 | 1.21 | 0.78 | 5.03 | 7.73 |
| 6.30 | 4.91 | 0.64 | 1.84 | 0.83 | 5.33 | 8.64 |
| 6.50 | 4.70 | 0.47 | 2.59 | 0.91 | 5.86 | 9.83 |
| 7.00 | 4.40 | 0.72 | 1.58 | 0.91 | 5.83 | 9.04 |
| 7.30 | 5.42 | 0.55 | 2.91 | 1.08 | 6.93 | 11.46 |
| 7.50 | 4.80 | 0.93 | 4.13 | 1.17 | 7.56 | 13.79 |
| 8.10 | 6.00 | 0.64 | 2.94 | 1.47 | 9.44 | 14.49 |
| 10.40 | 5.50 | 1.65 | 7.24 | 1.68 | 10.82 | 21.40 |
| 10.70 | 6.22 | 1.87 | 6.90 | 2.57 | 16.55 | 27.89 |
| 10.80 | 6.46 | 2.00 | 8.61 | 2.63 | 16.91 | 30.15 |
| 12.50 | 5.46 | 2.10 | 10.39 | 3.23 | 20.79 | 36.50 |
| 15.00 | 6.65 | 2.03 | 16.43 | 3.74 | 24.06 | 46.25 |

alnX + b, Lny = aX + b and Lny = alnX + b) with 64 regression equations were tested to derive the allometric model for biomass of each plant part; and nutrients and carbon stock in total above ground biomass (Mahmood et al., 2015). Significance test of regression equations were tested by using SAS (6.12) statistical software. The best fit regression equations were selected considering the highest $R^2$ and F-value, with the lowest value of CV, $R_{mse}$, $MS_{error}$, $S_a$, $S_b$, AICc, CF and Furnival Index and readily measureable independent variables (Furnival 1961; Chave et al., 2005; Soares et al., 2005; Siddique et al., 2012; Mahmood et al., 2015) where $R^2$ = Coefficient of determination; CV = Coefficient of variation, $R_{mse}$ = Root mean square error; $MS_{error}$ = Mean square error; $S_a$ = Standard error of intercept "a"; $S_b$ = Standard error of regression coefficient "b", CF = Correction Factor (to solve the deformation during calculation back to the original value from $\log_{10}$ and ln transformed value) and

AICc = Akaike's information criterion corrected.

## 3. Results

The mean biomass proportion of different parts of *A. corniculatum* was varied with DBH classes. Comparatively higher proportion of leaf (13.96%) was observed at the lowest DBH class of 1 to 4 cm while higher proportion of branch biomass (30.22%) was observed for the higher DBH class (10 cm and above). The higher proportion of bark and stem biomass were observed at DBH class of 4 to 7 cm (**Table 2**). Nutrients (N, P and K) and carbon concentration in plant parts varied significantly ($p < 0.05$). Comparatively highest concentration of nitrogen (6.40 mg/g) and phosphorus (1.04 mg/g) were observed in leaf while highest concentration of potassium was observed in both leaf (6.50 mg/g) and bark (6.50 mg/g). Higher concentration (48.59%) of carbon was observed in stem followed by bigger branches (48.22%) (**Table 3**).

Most of the regression equations were significant ($p < 0.05$), but 209 equations were excluded considering the value of co-efficient of determination ($R^2$) less than 0.93 for leaves, 0.98 for branch, 0.99 for bark, stem without bark and total above-ground biomass. The selected allometric models were Log biomass = $0.76\text{LogDBH}^2 - 1.39$; Biomass = $0.07\text{DBH}^2 - 0.49$; Log biomass = $1.04\text{LogDBH}^2 - 1.80$; Log biomass = $1.04\text{LogDBH}^2 - 0.99$; $\sqrt{\text{Biomass}} = 0.48\text{DBH} - 0.13$ for leaves, branches, bark, stem without bark and total above-ground biomass respectively (**Table 4**). Irrespectively, allometric models for nutrients (N, P and K) and carbon stock in the above-ground biomass were also selected by considering the same principle as followed for the biomass equations. The selected allometric models for Nitrogen, Phosphorous, Potassium and Carbon were $\sqrt{\text{Nitrogen}} = 0.67\text{DBH} + 0.11$; $\sqrt{\text{Phosphorus}} = 0.94\text{DBH} + 0.08$; $\sqrt{\text{Potassium}} = 1.06\text{DBH} - 0.18$; $\sqrt{\text{Carbon}} = 0.33\text{DBH} - 0.09$ (**Table 5**).

## 4. Discussion

The architecture, morphological characteristics and adaptation ability of mangrove plants varies with species (Hutchings & Saenger, 1987) and stages (seedlings, saplings and trees) which may affect the pattern of biomass allocation in their parts (Mahmood et al., 2004). Stand structure, regional climate, environmental conditions, geographical location, management intervention, along with other abiotic factors may also influence the biomass allocation in plant parts of an individual species (Saenger & Snedaker, 1993; Steinke et al., 1995; Tam et al., 1995; Clough et al., 1997; Mahmood et al., 2004; Peichl & Arain, 2007). Similar to the present study, higher proportion of leaf biomass was observed at lower DBH classes and higher proportion of branch biomass was

**Table 2.** Biomass proportions in plant parts of *Aegiceras corniculatum* according to DBH classes.

| DBH class (cm) | Biomass proportion (%) | | | |
|---|---|---|---|---|
| | Leaf | Branch | Bark | Stem without bark |
| 1 to 4 | 13.96 ± 0.69 | 21.10 ± 1.52 | 8.73 ± 0.25 | 56.21 ± 1.59 |
| 4 to 7 | 9.83 ± 1.30 | 20.11 ± 1.90 | 9.42 ± 0.26 | 60.64 ± 1.69 |
| 7 to 10 | 5.32 ± 0.72 | 25.20 ± 2.78 | 9.34 ± 0.46 | 60.14 ± 2.99 |
| 10 to above | 6.24 ± 0.56 | 30.22 ± 1.97 | 8.54 ± 0.25 | 55.00 ± 1.62 |

**Table 3.** Nutrients and carbon concentration in different parts of *Aegiceras corniculatum* (Similar alphabet along the column are not significant ($p > 0.05$) different).

| Plant Parts | Nitrogen (mg/g) | Phosphorus (mg/g) | Potassum (mg/g) | Carbon (%) |
|---|---|---|---|---|
| Leaf | $6.40 \pm 0.08^{A}$ | $1.04 \pm 0.01^{A}$ | $6.50 \pm 0.07^{A}$ | $45.97 \pm 0.06^{C}$ |
| Smaller Branch | $3.29 \pm 0.10^{B}$ | $0.82 \pm 0.01^{B}$ | $6.05 \pm 0.07^{A}$ | $47.59 \pm 0.20^{B}$ |
| Bigger Branch | $1.52 \pm 0.08^{C}$ | $0.41 \pm 0.02^{C}$ | $4.69 \pm 0.08^{C}$ | $48.22 \pm 0.03^{A}$ |
| Bark | $1.97 \pm 0.05^{C}$ | $0.31 \pm 0.01^{D}$ | $6.50 \pm 0.14^{B}$ | $43.10 \pm 0.11^{D}$ |
| Stem without bark | $1.60 \pm 0.08^{C}$ | $0.26 \pm 0.01^{D}$ | $4.26 \pm 0.07^{D}$ | $48.59 \pm 0.17^{A}$ |

**Table 4.** Best fit models for plant parts and total above-ground biomass (kg) of *Aegiceras corniculatum*.

| Plant part | Equation | $R^2$ | a | b | Sa | $S_b$ | CV | $R_{mse}$ | $MS_{error}$ | F value | AICc | FI | CF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Leaf | Logbiomass = aLogDBH + b | 0.93 | 1.52 | −1.39 | 0.08 | 0.06 | −29.76 | 0.12 | 0.02 | 366.97 | −116.548 | 0.054 | 1.042 |
| | *Logbiomass = aLogDBH$^2$ + b | 0.93 | 0.76 | −1.39 | 0.04 | 0.06 | −29.76 | 0.12 | 0.02 | 366.97 | −116.548 | 0.054 | 1.042 |
| | lnbiomass = alnDBH + b | 0.93 | 1.52 | −3.21 | 0.08 | 0.13 | −29.76 | 0.29 | 0.08 | 366.97 | −67.8263 | 0.108 | 1.042 |
| | lnbiomass = alnDBH$^2$ + b | 0.93 | 0.76 | −3.21 | 0.04 | 0.13 | −29.76 | 0.29 | 0.08 | 366.97 | −67.8263 | 0.108 | 1.042 |
| Branch | *Biomass = aDBH$^2$ + b | 0.98 | 0.07 | −0.49 | .002 | 0.14 | 23.02 | 0.58 | 0.34 | 1214.88 | −26.588 | 0.583 | |
| | Biomass = aDBH$^2$ × TH + b | 0.98 | 0.01 | −0.03 | 0.0002 | 0.12 | 21.46 | 0.54 | 0.29 | 1402.70 | −27.9736 | 0.539 | |
| Bark | Logbiomass = aLogDBH + b | 0.99 | 2.08 | −1.80 | 0.04 | 0.03 | −14.46 | 0.07 | 0.004 | 2394.68 | −152.179 | 0.022 | 1.012 |
| | *Logbiomass = aLog DBH$^2$ + b | 0.99 | 1.04 | −1.80 | 0.02 | 0.03 | −14.46 | 0.07 | 0.004 | 2394.68 | −152.179 | 0.022 | 1.012 |
| | Logbiomass = aLogDBH × TH+ b | 0.99 | 1.35 | −2.08 | 0.03 | 0.04 | −14.70 | 0.07 | 0.005 | 2316.43 | −149.473 | 0.024 | 1.012 |
| | Logbiomass = aLogDBH$^2$ × TH+ b | 0.99 | 0.82 | −1.98 | 0.01 | 0.03 | −12.18 | 0.06 | 0.003 | 3385.37 | −161.231 | 0.019 | 1.008 |
| | Logbiomass = aLogDBH$^2$ × TH$^2$ + b | 0.99 | 0.67 | −2.08 | 0.01 | 0.04 | −14.70 | 0.07 | 0.005 | 2316.43 | −149.473 | 0.024 | 1.012 |
| | lnbiomass = aln DBH + b | 0.99 | 2.08 | −4.15 | 0.04 | 0.07 | −14.46 | 0.15 | 0.02 | 2394.68 | −104.091 | 0.049 | 1.012 |
| | lnbiomass = aln DBH$^2$ + b | 0.99 | 1.04 | −4.15 | 0.02 | 0.07 | −14.46 | 0.15 | 0.02 | 2394.68 | −104.091 | 0.049 | 1.012 |
| | lnbiomass = alnDBH × TH + b | 0.99 | 1.35 | −4.80 | 0.03 | 0.08 | −14.70 | 0.16 | 0.02 | 2316.43 | −100.035 | 0.049 | 1.012 |
| | lnbiomass = alnDBH$^2$ × TH + b | 0.99 | 0.82 | −4.55 | 0.01 | 0.06 | −12.18 | 0.13 | 0.02 | 3385.37 | −111.142 | 0.049 | 1.008 |
| | lnbiomass = alnDBH$^2$ × TH$^2$ + b | 0.99 | 0.67 | −4.80 | 0.01 | 0.28 | −14.70 | 0.16 | 0.02 | 2316.43 | −100.035 | 0.049 | 1.012 |
| Stem | Logbiomass = aLogDBH + b | 0.99 | 2.08 | −0.99 | 0.04 | 0.03 | 19.09 | 0.07 | 0.004 | 2394.68 | −152.179 | 0.141 | 1.012 |
| | *Logbiomass = aLogDBH$^2$ + b | 0.99 | 1.04 | −0.99 | 0.02 | 0.03 | 19.09 | 0.07 | 0.004 | 2394.68 | −152.179 | 0.141 | 1.012 |
| | Logbiomass = aLogDBH × TH+ b | 0.99 | 1.35 | −1.27 | 0.03 | 0.04 | 19.41 | 0.07 | 0.005 | 2316.43 | −149.473 | 0.157 | 1.012 |
| | Logbiomass = aLogDBH$^2$ × TH+ b | 0.99 | 0.82 | −1.17 | 0.01 | 0.03 | 16.08 | 0.06 | 0.003 | 3385.37 | −161.231 | 0.122 | 1.008 |
| | Logbiomass = aLogDBH$^2$ × TH$^2$ + b | 0.99 | 0.67 | −1.27 | 0.01 | 0.04 | 19.41 | 0.07 | 0.005 | 2316.43 | −149.473 | 0.157 | 1.012 |
| | lnbiomass = alnDBH + b | 0.99 | 2.08 | −2.28 | 0.04 | 0.07 | 19.09 | 0.15 | 0.02 | 2394.68 | −104.091 | 0.314 | 1.012 |
| | lnbiomass = alnDBH$^2$ + b | 0.99 | 1.04 | −2.28 | 0.02 | 0.07 | 19.05 | 0.15 | 0.02 | 2394.68 | −104.091 | 0.314 | 1.012 |
| | lnbiomass = alnDBH × TH + b | 0.99 | 1.35 | −2.93 | 0.03 | 0.08 | 19.41 | 0.16 | 0.02 | 2316.43 | −100.035 | 0.314 | 1.012 |
| | lnbiomass = alnDBH$^2$ × TH + b | 0.99 | 0.82 | −2.69 | 0.01 | 0.06 | 16.08 | 0.13 | 0.02 | 3385.37 | −111.142 | 0.314 | 1.008 |
| | lnbiomass = alnDBH$^2$ × TH$^2$ + b | 0.99 | 0.67 | −2.93 | 0.01 | 0.08 | 19.41 | 0.16 | 0.02 | 2316.43 | −100.035 | 0.314 | 1.012 |
| Total above-ground-biomass | Biomass = aDBH$^2$ + b | 0.99 | 0.22 | −0.20 | 0.01 | 0.35 | 15.99 | 1.48 | 2.18 | 1844.98 | 27.4388 | 1.476 | |
| | * $\sqrt{\text{Biomass}}$ = a DBH + b | 0.99 | 0.48 | −0.13 | 0.01 | 0.06 | 7.27 | 0.18 | 0.03 | 2591.57 | −94.0711 | 0.684 | |
| | $\sqrt{\text{Biomass}}$ = aDBH × $\sqrt{\text{TH}}$ + b | 0.99 | 0.18 | 0.38 | 0.004 | 0.06 | 7.77 | 0.19 | 0.04 | 2266.72 | −87.4106 | 0.790 | |
| | Logbiomass = aLogDBH$^2$ × TH + b | 0.99 | 0.81 | −0.90 | 0.02 | 0.04 | 12.62 | 0.07 | 0.01 | 1855.10 | −143.001 | 0.385 | 1.015 |
| | lnbiomass = alnDBH$^2$ × TH + b | 0.99 | 0.81 | −2.08 | 0.02 | 0.09 | 12.62 | 0.17 | 0.03 | 1855.10 | −94.4561 | 0.666 | 1.015 |

Note: $R^2$ = coefficient of determination; $S_a$ = standard error of intercept "a"; $S_b$ = standard error of regression coefficient "b", CV = Coefficient of variation, $R_{mse}$ = Root mean square error; $MS_{error}$ = Mean square error, AICc = Akaike's information criterion corrected; FI = Furnival index; CF = Correction Factor; *Selected equations.

observed at higher DBH classes of *E. agallocha* in the Sundarbans (Mahmood et al., 2015), *B. parviflora* in Malaysia (Mahmood et al., 2004), *R. apicuata* and *R. stylosa* in north-eastern Australia (Clough, 1992).

The rate of nutrient uptake and its distributional patterns in plant parts (leaf, branch, bark and stem) varies with species, stages of plant growth and productive capacity of the site (Alongi et al., 2005; Mahmood, 2007; Krishtensen et al., 2008; Mahmood et al., 2008a). Structural component of plant cell (Kaakinen et al., 2004) physiological age of the tissue, position of the tissue in plant, available form of nutrients in the substrate, concentration of other nutrients, climatic and soil edaphic factors (Mahmood, 2004) may be responsible for the variation in nutrients and carbon concentration in plant parts. The trend of nitrogen, phosphorus and carbon concentration in plant parts of the studied species was similar to that of *E. agallocha* (Mahmood et al., 2015), *C. decandra* (Mahmood et al., 2012), *B. parviflora* (Mahmood et al., 2006), *Avicennia* spp., *Bruguiera* spp. and *Ceriops* spp. (Aksornkoae & Khemnark, 1984) and *R. apiculata* (Ong et al., 1984).

DBH and TH (Total height) are widely used independent variables for allometric equations to estimate above-ground biomass of mangrove species (Lee, 1990; Saintilan, 1997). But, allometric models with DBH as single independent variable might be more practical and user friendly in the field instead of using other independent variable like total height of a tree (Mahmood et al., 2015). The selection of best regression equation is the major concern in allometric modeling for biomass estimation (Grundy, 1995; Steinke et al., 1995; Tam et al., 1995; Mahmood et al., 2015). Therefore, present study recommended DBH as independent variable for allometric models considering the scope of application and different statistical test. In comparison with the present study, common allometric biomass model of Komiyama et al. (2005) and Chave et al. (2005) showed about 4% to 100% and 2% to 40% of over estimation in above-ground biomass respectively with the studied DBH range (1 to 15 cm) (**Figure 2**). Similarly, higher estimation (16% - 60%) of total above-ground biomass was also observed for *Excoecaria agallocha* of the Sundarbans by comparing that common allometric model of Komiyama et al. (2005)

**Table 5.** Best fit models for nutrients (N, P and K) and carbon stock in total above-ground biomass (kg) of *Aegiceras corniculatum.*

| Equation | $R^2$ | a | b | $S_a$ | $S_b$ | CV | $R_{mse}$ | $MS_{error}$ | F value | AICc | FI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\sqrt{\text{Nitrogen}}$ = a DBH + b | 0.99 | 0.67 | 0.11 | 0.02 | 0.10 | 8.10 | 0.31 | 0.09 | 1782.12 | −63.7732 | 1.849 |
| $\sqrt{\text{Phosphorus}}$ = a DBH + b | 0.98 | 0.94 | 0.08 | 0.02 | 0.15 | 8.34 | 0.43 | 0.19 | 1731.83 | −43.4436 | 3.688 |
| $\sqrt{\text{Potassium}}$ = a DBH + b | 0.99 | 1.06 | −0.18 | 0.02 | 0.14 | 7.37 | 0.41 | 0.17 | 2434.85 | −46.7529 | 3.657 |
| $\sqrt{\text{Carbon}}$ = a DBH + b | 0.99 | 0.33 | −0.09 | 0.01 | 0.04 | 7.28 | 0.13 | 0.02 | 2598.32 | −115.167 | 0.385 |

Note: $R^2$ = coefficient of determination; $S_a$ = standard error of intercept "a"; $S_b$ = standard error of regression coefficient "b", CV= Coefficient of variation, $R_{mse}$ = Root mean square error; $MS_{error}$ =Mean square error, AICc = Akaike's information criterion corrected; FI = Furnival index; CF = Correction Factor; *Selected equations.

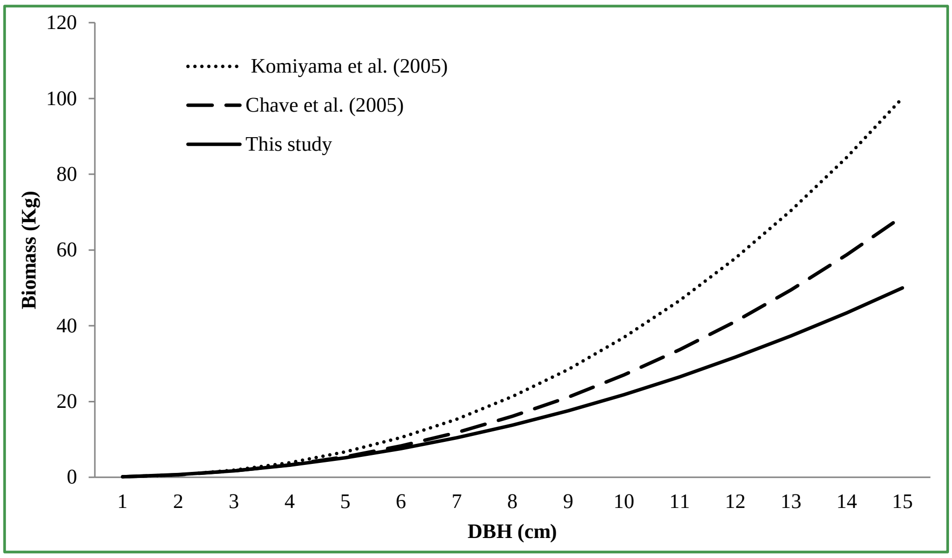


**Figure 2.** Comparison of estimated total above-ground biomass of *Aegiceras corniculatum.*

(Mahmood et al., 2015). So, the applicability of the common allometric models may not be suitable for biomass estimation of different mangrove species of the Sundarbans. This variation in biomass estimation implies that allometric models should be site and species specific (Ketterings et al., 2001; Chave et al., 2005; Soares & Schaeffer-Novelli, 2005; Mahmood et al., 2004; Kairo et al., 2009; Mahmood et al., 2015).

## 5. Conclusion

The derived models are simple, more practical and user-friendly by using DBH as independent variable. These allometric models for *A. corniculatum* of the Sundarbans will be helpful in estimating biomass, nutrient and carbon stock which may contribute in broader study on nutrient cycling, nutrient budgeting and carbon sequestration and finally can contribute in planning for utilization and management of this species in the Sundarbans.

## Acknowledgements

We are thankful to the Ministry of Science and Technology of Bangladesh for this research grant. We are also indebted to Forestry and Wood Technology Discipline and Forest Department for their logistic support and continuous adherences.

## References

Aksornkoae, S., & Khemnark, C. (1984). Nutrient Cycling in Mangrove Forest of Thailand. In E. Soepadmo, A. N. Rao, & D. J. Macintosh (Eds.), *Proceedings of the Asian Symposium on Mangrove Environment Research and Management* (pp. 545-557). Kuala Lumpur: University of Malaya.

Allen, S. E. (1989). *Chemical Analysis of Ecological Materials*. Oxford: Blackwell Scientific Publications.

Alongi, D. M. (2002). Present State and Future of the World's Mangrove Forests. *Environmental Conservation, 29,* 331-349. http://dx.doi.org/10.1017/s0376892902000231

Alongi, D. M., Clough, B. F., & Robertson, A. I. (2005). Nutrient-Use Efficiency in Arid-Zone Forests of the Mangroves *Rhizophora stylosa* and *Avicennia marina*. *Aquatic Botany, 82,* 121-131. http://dx.doi.org/10.1016/j.aquabot.2005.04.005

Beathgen, W. E., & Alley, M. M. (1989). A Manual Colorimetric Procedure for Measuring Ammonium Nitrogen in Soil and Plant Kjeldahl Digests. *Communications in Soil Science and Plant Analysis, 20,* 961-969. http://dx.doi.org/10.1080/00103628909368129

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J. P., Nelson, B. W., Ogawa, H., Puig, H., Riera, B., & Yamakur, T. (2005). Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests. *Oecologia, 145,* 87-99. http://dx.doi.org/10.1007/s00442-005-0100-x

Clough, B. F. (1992). Primary Productivity and Growth of Mangrove Forests. In A. I. Robertson, & D. M. Alongi (Eds.), *Tropical Mangrove Ecosystem, Coastal and Estuarine Studies* (pp. 225-250). Washington, DC: American Geophysical Union. http://dx.doi.org/10.1029/ce041p0225

Clough, B. F., Dixon, P., & Dalhaus, O. (1997). Allometric Relationships for Estimating Biomass in Multi-Stemmed Mangrove Tress. *Australian Journal of Botany, 45,* 1023-1031. http://dx.doi.org/10.1071/BT96075

Dinerstein, E., Oslon, D. M., Graham, D. J., Webster, A. L., Primm, S. A., Bookbinder, M. P., & Ledec, G. (1995). *A Conservation Assessment of the Terrestrial Ecoregions of Latin America and the Carrbbean*. Washington, DC: World Wildlife Fund and World Bank. http://dx.doi.org/10.1596/0-8213-3295-3

Ellison, A. M. (2008). Mangrove Ecology—Applications in Forestry and Coastal Zone Management. *Aquatic Botany, 89,* 77. http://dx.doi.org/10.1016/j.aquabot.2008.01.001

FAO (2005). *Global Forest Resources Assessment 2005*. FAO Forestry Paper 147, Rome.

FAO (2007). *The World's Mangroves 1980-2005*. FAO Forestry Report 153, Rome.

Fromard, F., Puig, H., Mougin, E., Marty, G., Betoulle, J. L., & Cadamuro, L. (1998). Structure, Above-Ground Biomass and Dynamics of Mangrove Ecosystems: New Data from French Guiana. *Oecologia, 115,* 39-53. http://dx.doi.org/10.1007/s004420050489

Furnival, G. M. (1961). An Index for Comparing Equations Used in Constructing Volume Tables. *Forest Science, 7,* 337-341.

Golley, B. F., McGinnis, T. J., Clements, G. R., Child, I. G., & Duever, J. M. (1975). *Mineral Cycling in a Tropical Moist Forest Ecosystem*. Athens: University of Georgia Press.

Grundy, I. M. (1995). Wood Biomass Estimation in Dry Miombo Woodland in Zimbabwe. *Forest Ecology and Management, 72,* 109-117. http://dx.doi.org/10.1016/0378-1127(94)03467-B

Hutchings, P., & Saenger, P. (1987). *The Ecology of Mangroves*. Queensland: University of Queensland Press.

Iftekhar, M. S., & Saenger, P. (2008). Vegetation Dynamics in the Bangladesh Sundarbans Mangroves: A Review of Forest Inventories. *Wetland Ecology and Management, 16,* 291-312. http://dx.doi.org/10.1007/s11273-007-9063-5

Jennerjahn, T. C., & Ittekkot, V. (2002). Relevance of Mangroves for the Production and Deposition of Organic Matter along Tropical Continental Margins. *Naturwissenschaften, 89,* 23-30. http://dx.doi.org/10.1007/s00114-001-0283-x

Kaakinen, S., Jolkkonen, A., Iivonen, S., & Vapaavuori, E. (2004). Growth, Allocation and Tissue Chemistry of *Picea abies* Seedlings Affected by Nutrient Supply during the Second Growing Season. *Tree Physiology, 24,* 707-719. http://dx.doi.org/10.1093/treephys/24.6.707

Kairo, J. G., Bosire, J., Langat, J., Kirui, B., & Koedam, N. (2009). Allometry and Biomass Distribution in Replanted Mangrove Plantations at Gazi Bay, Kenya. *Aquatic Conservation: Marine and Freshwater Ecosystems, 19,* 63-69. http://dx.doi.org/10.1002/aqc.1046

Ketterings, Q. M., Coe, R., Noordwijk, M. V., Amagau, Y., & Palm, C. A. (2001). Reducing Uncertainty in the Use of Allometric Biomass Equations for Predicting Above-Ground Tree Biomass in Mixed Secondary Forest. *Forest Ecology and Management, 146,* 199-209. http://dx.doi.org/10.1016/S0378-1127(00)00460-6

Komiyama, A., Jintana, V., Sangtiean, T., & Kato, S. (2002). A Common Allometric Equation for Predicting Stem Weight of Mangroves Growing in Secondary Forests. *Ecological Research, 17,* 415-418. http://dx.doi.org/10.1046/j.1440-1703.2002.00500.x

Komiyama, A., Ong, J. E., & Poungparn, S. (2008). Allometry, Biomass, and Productivity of Mangrove Forests: A Review. *Aquatic Botany, 89,* 128-137. http://dx.doi.org/10.1016/j.aquabot.2007.12.006

Komiyama, A., Poungparn, S., & Kato, S. (2005). Common Allometric Equations for Estimating the Tree Weight of Mangroves. *Journal of Tropical Ecology, 21,* 471-477. http://dx.doi.org/10.1017/S0266467405002476

Krishtensen, E., Bouillon, S., Dittmar, T., & March, C. (2008). Organic Carbon Dynamics in Mangrove Ecosystems: A Review. *Aquatic Botany, 89,* 201-219. http://dx.doi.org/10.1016/j.aquabot.2007.12.005

Lee, S. Y. (1990). Primary Productivity and Particulate Organic Matter Flow in an Estuarine Mangrove Wetland in Hong Kong. *Marine Biology, 106,* 453-463. http://dx.doi.org/10.1007/BF01344326

Lugo, A. E., & Snedekar, S. C. (1974). The Ecology of Mangrove. *Annual Review of Ecological Systems, 5,* 36-64. http://dx.doi.org/10.1146/annurev.es.05.110174.000351

MA (2005). *Mille Ecosystems and Human Well-Being: Synthesis*. Washington DC: Island Press.

Mahmood, H. (2004). *Biomass, Litter Production and Selected Nutrients in Bruguiera Parviflora (Roxb.) Wight & Arn. Dominated Mangrove Forest Ecosystem at KualaSelangor, Malaysia*. PhD Thesis, Seri Kembangan: University Putra Malaysia.

Mahmood, H. (2007). Biological Cycling of Macro-Nutrients (N, P, K, Ca, Mg and S) in *Bruguiera parviflora* Dominated Mangrove Forest at Kuala Selangor Nature Park, Malaysia. *Khulna University Studies, 8,* 49-56.

Mahmood, H. (2014). Carbon Pools and Fluxes in *Bruguiera parviflora* Dominated Naturally Growing Mangrove Forest of Peninsular Malaysia. *Wetland Ecology and Management, 22,* 15-23. http://dx.doi.org/10.1007/s11273-013-9318-2

Mahmood, H., Saberi, O., JaparSidik, B., & Misri, K. (2005). Litter Flux in Kuala Selangor Nature Park Mangrove Forest, Malaysia. *Indian Journal of Forestry, 28,* 233-238.

Mahmood, H., Saberi, O., JaparSidik, B., & Misri, K. (2008b). Net Primary Productivity of *Bruguiera parviflora* (Wight &Arn.) Dominated Mangrove Forest at Kuala Selangor, Malaysia. *Forest Ecology and Management, 255,* 179-182. http://dx.doi.org/10.1016/j.foreco.2007.09.011

Mahmood, H., Saberi, O., JaparSidik, B., Misri, K., & Rajagopal, S. (2004). Allometric Relationships for Estimating Above- and Below-Ground Biomass of Saplings and Trees of *Bruguiera parviflora* (Wight and Arnold). *Malaysian Applied Biology, 33,* 37-45.

Mahmood, H., Saberi, O., Misri, K., & JaparSidik, B. (2006). Seasonal Variation in Concentrations of N, P and K in Different Components of *Bruguiera parviflora* (Wight and Arnold) at Three Growth Stages in Malaysia. *Indian Journal of Forestry, 29,* 149-155.

Mahmood, H., Saberi, O., Misri, K., & JaparSidik, B. (2008a). Biological Cycling of Micro-Nutrients (Cu, Fe and Zn) in *Bruguiera parviflora* Dominated Mangrove Forest at Kula Selangor Nature Park, Malaysia. *Malaysian Applied Biology, 37,* 63-68.

Mahmood, H., Siddique, M. R. H., Bose, A., Limon, S. H., Saha, S., & Chowdhury, M. R. K. (2012). Allometry, Above-Ground Biomass and Nutrient Distribution in *Ceriops decandra* (Griffith) Ding Hou Dominated Forest Types of the Sundarbans Mangrove Forest, Bangladesh. *Wetland Ecology and Management, 20,* 539-548. http://dx.doi.org/10.1007/s11273-012-9274-2

Mahmood, H., Siddique, M. R. H., Saha, S., & Abdullah, S. M. R. (2015). Allometric Models for Biomass, Nutrients and Carbon Stock in *Excoecaria agallocha* of the Sundarbans, Bangladesh. *Wetland Ecology and Management, 23,* 765-774.

http://dx.doi.org/10.1007/s11273-015-9419-1

Ning, S. J., Yun-Sheng, Deng, Z. L., & Li, X. X. (1996). A Preliminary Study on Biomass of *Aegiceras corniculatum* Natural Forest in Longmen Islets of Guangxi. *Chinese Journal of Plant Ecology, 20,* 57-64.

Ong, J. E., Gong, W. K., & Wong, C. H. (1984). Seven Years of Productivity Studies in a Malaysian Managed Mangrove Forest, Then What? In K. N. Bardsley, J. D. S. Davie, & C. D. Woodroffe (Eds.), *Coastal and Tidal Wetlands of the Australian Monsoon Region* (pp. 213-223). Canberra: Australian National University.

Peichl, M., & Arain, M. A. (2007). Allometry and Partitioning of Above- and Below-Ground Tree Biomass in an Age-Sequence of White Pine Forests. *Forest Ecology and Management, 253,* 68-80. http://dx.doi.org/10.1016/j.foreco.2007.07.003

Peters, R., Alejandra, G., Luna, S., Grüters, U., & Berger, U. (2014). Changes in Allometric Relations of Mangrove Trees Due to Resource Availability—A New Mechanistic Modelling Approach. *Ecological Modeling, 283,* 53-61. http://dx.doi.org/10.1016/j.ecolmodel.2014.04.001

Saenger, P., & Snedaker, S. C. (1993). Pantropical Trends in Mangrove Above-Ground Biomass and Annual Litterfall. *Oecologia, 96,* 293-299. http://dx.doi.org/10.1007/BF00317496

Saintilan, N. (1997). Above- and Below-Ground Biomasses of Two Species of Mangrove on the Hawkesbury River Estuary, New South Wales. *Marine and Freshwater Research, 48,* 147-152. http://dx.doi.org/10.1071/MF96079

Saintilan, N. (1997). Above- and Below-Ground Biomasses of Two Species of Mangrove on the Hawkesbury River Estuary, New South Wales. *Marine and Freshwater Research, 48,* 147-152. http://dx.doi.org/10.1071/MF96079

Siddiqi, N. A. (2001). *Mangrove Forestry in Bangladesh*. Chittagong: Institute of Forestry & Environmental Science, University of Chittagong.

Siddique, M. R. H., Mahmood, H., & Chowdhury, M. R. K. (2012). Allometric Relationship for Estimating Above-Ground Biomass of *Aegialitis rotundifolia* Roxb. of Sundarbans Mangrove Forest, in Bangladesh. *Journal of Forestry Research, 23,* 23-28. http://dx.doi.org/10.1007/s11676-012-0229-5

Soares, M. L. G., & Schaeffer-Novelli, Y. (2005). Above-Ground Biomass of Mangrove Species. I. Analysis of Models. *Estuarine Coastal and Shelf Science, 65,* 1-18. http://dx.doi.org/10.1016/j.ecss.2005.05.001

Spalding, M., Kainuma, M., & Collins, L. (2010). *World Atlas of Mangroves*. London: Earthscan.

Steinke, T. D., Ward, C. J., & Rajh, A. (1995). Forest Structure and Biomass of Mangroves in the Mgeni Estuary, South Africa. *Hydrobiologia, 295,* 159-166. http://dx.doi.org/10.1007/BF00029123

Tam, N. F. Y., Wong, Y. S., Lan, C. Y., & Chen, G. Z. (1995). Community Structure and Standing Crop Biomass of a Mangrove Forest in Futian Nature Reserve, Shenzhen, China. *Hydrobiologia, 295,* 193-201. http://dx.doi.org/10.1007/BF00029126

Tamai, S., Nakasuga, T., Tabuchi, R., & Ogino, K. (1986). Standing Biomass of Mangrove Forests in Southern Thailand. *Journal Japanese Forest Society, 68,* 384-388.

Timothy, R. P., Yoshiaki, M., & Carol, M. L. (1984). *A Manual of Chemical and Biological Methods for Seawater Analysis.* Oxford and New York: Pergamon Press.

Tomlinson, P. B. (1986). *The Botany of Mangroves*. Cambridge: Cambridge University Press.