Khulna University
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Title: Allometic relationship for estimating above-ground biomass and nutrient stock in *Kandelia candel* of the Sundarbans, Bangladesh

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Programme: Bachelor of Science in Forestry

ALLOMETRIC RELATIONSHIP FOR ESTIMATING ABOVE-GROUND BIOMASS AND NUTRIENT STOCK IN *Kandelia candel* OF THE SUNDARBANS, BANGLADESH

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2014

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Allometric relationship for estimating above-ground biomass and nutrient stock in *Kandelia candel* of the Sundarbans, Bangladesh

Title of the Course: Project Thesis

Course No: FWT-4114

[This thesis has been prepared and submitted to Forestry and Wood Technology Discipline, Khulna University, Khulna-9208 for a partial fulfillment of the four years professional B.Sc. (Hon's) degree in forestry]

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DECLARATION

I hereby declare that the project thesis is based on my own work except for quotations and citations and that it has not been submitted or accepted for a degree in any other University.

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DEDICATED

TO

MY BELOVED PARENTS

ACKNOWLEDGEMENT

First of all I would like to express my thanks and honor to the almighty God for the successful accomplishment of this B.Sc. (Hon's.) thesis work.

I would like to express my heartful gratitude and profound appreciation to my honorable supervisor, Dr. Mahmood Hossain, Professor, Forestry and Wood Technology Discipline, Khulna University, Khulna, whose sympathetic co-operation, guidance, suggestions, advice help me to complete and submit this paper.

I am grateful to Sonjoy Saha and S. M. Rubaiot Abdullah for their inspiration, profound suggestions, encouragement and continuous guidance that help me for conducting this study.

Special thanks to Biplab Kundu, Fatima Najnin Ritu, MD. Najmus Sayadat Pitol and Uzzal Kundu for helping me during this study.

Finally, I would like to divulge my gratefulness to my family members who always inspired me and sacrificed their happiness for my education at Khulna University.

APPROVAL

This project thesis submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh, in partial fulfillment of the requirements for the *B.Sc. (Hon's)* degree in Forestry. I have approved the style and format of the project thesis.

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ABSTRACT

The Sundarbans mangrove forest is the single largest tract mangrove forest of the world and also a world heritage site. *Kandelia candel* is a shrub species in the Sundarbans. The objective of the study was to derive the allometric relationship for estimating above-ground biomass and nutrient stock in *Kandelia candel*. We have selected linear regression model to estimate the above ground biomass of *Kandelia candel*. The best allometric models for plant parts were selected by considering the values of parameter of estimation such as, R^2, CV, R_{sme}, MS_{error}, S_a, S_b, AICc and F-value. The selected allometric models were The selected allometric models were Biomass = 0.014 DBH^2 + 0.03; $\sqrt{}$Biomass = 0.29 DBH -0.21; $\sqrt{}$Biomass = 0.66 $\sqrt{}$DBH – 0.57; $\sqrt{}$Biomass = 1.19 $\sqrt{}$DBH -1.02; Biomass = 0.21DBH^2 + 0.12 for leaves, branches, bark, stem without bark and total above-ground biomass, respectively. Comparatively highest concentration of nitrogen (8.42 mg/g), phosphorus (4.74 mg/g) and potassium (11.09 mg/g) was observed in leaf. Higher concentration (45.25-45.53%) of carbon was observed in woody parts (stem and branches) of *K. candle*. The selected allometric models for Nitrogen, Phosphorous, Potassium and Carbon were N = 0.39DBH^2 + 0.49, P = 0.77DBH^2 + 0.14, K = 0.87DBH^2 + 0.07 and C = 0.09DBH^2 + 0.05.

Keywords: Allometry; biomass; *Kandelia candel*; mangroves; sundarbans

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CHAPTER I
INTRODUCTION

1.1. Introduction

Mangroves are forests of salt-tolerant trees and shrubs that grow in the shallow tidal waters of estuaries and coastal areas in tropical and sub-tropical regions (Ong, 1993; Kristensen et al., 2008). Mangroves have many uses, providing large quantities of food and fuel, building materials, medicines and offer protection against coastal erosion, cyclones and tsunami (Mazda et al., 1997; Alongi, 2002; Mahmood et al., 2008; Mahmood, 2013). Sundarbans is the largest single tract of mangrove forest in the world, lie within the delta of the Ganges, Brahmaputra and Meghna rivers in the Bay of Bengal (Islam and Gnauck, 2008). The main tree species of Sundarbans are *Heritiera fomes, Excoecaria agallocha, Xylocarpus granatum, Xylocarpus mekongensis, Ceriops decandra, Bruguiera spp., Avicennia spp., Sonneratia spp* etc. *Kandelia candel* is a shrub or small tree, up to 7 m tall, with a thickened stem base, from the family of Rhizophoraceae, a viviparous mangrove species, occurs sporadically on banks of tidal rivers among other mangroves, occupying a narrow niche (Robertson and Alongi 1992).

Tree biomass plays an important role in sustainable management and in estimating forest carbon stocks. Through the analysis of existing studies on the biomass of mangrove species, the biomass data of the mangrove species is important for the estimation of primary productivity, determination of storage and cycling of elements, measurement of the conditions of the ecosystem, evaluation of commercial-valued biomass for companies involved in wood exploitation and silvicultural practices (Komiyama et al., 2008).

In our country, there are limited works on mangrove species of the Sundarbans, such as *C. decandra* (Mahmood et al., 2012) and *Aegialitis rotundifolia* (Siddique et al., 2012). The objective of this study is to develop allometric models for above-ground biomass, nutrients (N, P and K) and carbon stock in *Kandelia candel*. The study would generate first-hand information for forest managers and conservation workers for sustainable management of the species *Kandelia candel* in the Sundarbans.

1.2. Objective of the study

- To derive allometric equations for estimating above-ground biomass of *Kandelia candel* in the Sundarbans.
- To estimate the nitrogen, phosphorus, potassium, and carbon concentration in the above-ground parts of *Kandelia candel* in the Sundarbans.
- To derive allometric equations for estimating nutrient (N, P, K) and carbon stock in *Kandelia candel* in the Sundarbans.

CHAPTER II
LLITERATURE REVIEW

2.1. Biomass

The biomass or phytomass of plants comprises the oven dry weight of leaves, buds, flowers, fruits, branches, stems, above and below-ground roots in a certain time. Quantity and distribution of vegetal biomass provide important information on ecosystem such as forest structure and condition (Westman et al., 1977), forest site productivity and carbon fluxes (Chambers et al., 2001; Specht et al., 2003; Mahmood, 2012). Mangrove species at different places showed wide range of standing biomass from 460 t/ha in tall *Rhizophora* spp. dominated forest in Matang, Malaysia (Putz and Chan, 1986) to 6.80 t/ha in low *Avicennia marina* communities in Tuff Crater, New Zealand (Woodroffe, 1985). In general, tropical mangroves have higher standing biomass and more complicated structure than sub-tropical mangroves (Chapman, 1976; Saenger and Snedaker, 1993; Tam et al., 1995b). Moreover, standing biomass and their proportion in the above and below-ground components of mangrove plants are not only affected by the geographical location and microclimates but also vary with the species, stand structure and age of stand (Lugo and Snedakar, 1974; Woodroffe, 1985; Steinke et al., 1995; Tam et al., 1995b).

2.2. Allometric models in mangrove species

Mangrove species are being degraded all over the world for the anthropogenic activities and unsustainable exploitation. Many studies have been conducted on biomass measurements of the mangrove species. Forest ecologists have developed various methods for estimating the biomass of the forests. Among those, three methods are main- the harvest method, the mean-tree method and the allometric method. In a mature mangrove forest, the total weight of an individual tree often reaches several tons (Komiyama et al., 2005). So, the harvest method cannot be used easily in the mature forests and it is not reproducible because all trees must be destructively harvested. The mean-tree method is utilized only such forests those are appeared with a homogeneous tree size distribution, such as plantations. Allometric method is a nondestructive method and it estimates the whole or partial weight of a tree from measurable tree dimensions, including trunk diameter and height using allometric equations. Allometric relationships often show site or species-dependency (e.g., Clough et al., 1997; Smith and Whelan, 2006). So, the site and species-specific dependencies of allometric equations pose a problem to researchers because tree weight measurement in mangrove

forests is labor-intensive. There are various methods to estimate biomass based on allometric relationships. In most studies, D (DBH) was taken as the only independent variable in the allometric equation (Putz and Chan 1986; Day et al., 1987; Clough and Scott 1989; Amarasinghe and Balasubrananiam 1992; Mackey 1993; Clough et al., 1997; Ong et al., 2004; Mahmood et al., 2004). However, incorporation of the variable H (tree height) (i.e., the use of D^2H) may ensure higher accuracy of biomass estimation (Suzuki and Tagawa 1983; Tamai et al., 1986; Kusmana et al., 1992; Komiyama et al., 2000).

Allometric equations for mangroves have been developed for several decades to estimate biomass and subsequent growth. Most studies have used allometric equations for single-stemmed trees, but mangroves sometimes have multi-stemmed tree forms, as often seen in *Rhizophora, Avicennia Excoecaria* species (Clough et al., 1997; Dahdouh Guebas and Koedam, 2006). Clough et al., 1997 and Mahmood et al., 2012 showed that the allometric relationship can be used for trunks in a multi-stemmed tree. Moreover, for dwarf mangrove trees, allometric relationships have been used to estimate the biomass (Ross et al., 2001).

CHAPTER III
MATERIALS AND METHODS

3.1. Study area

This study was carried out in between 21 ° 54′ 2859.9″- 22 ° 11′ 32.2″ N and in 89 ° 35′ 55.3″ - 89 ° 15′ 8.2″ E. The climate is humid subtropical and mean temperature for winter of 18 - 23 °C and 27 - 31 °C for the summer. Mean annual rainfall is 1980 mm; summer (May to September) contributes about 81% of the annual rainfall while winter season contributes about 19% of rainfall. Soil is clayey and pH is around 7.9. Consistent monthly temperature and rainfall data was collected from a nearby meteorological station (MET Station, Data Loggers, Khulna). In the research location the dominant tree species are *Heritiera fomes, Excoecaria agallocha, Xylocarpus mekongensis, X. granatum, Amoora cucullata, Ceriops decandra, Avicennia alba, Kandelia candel.* This area is frequently inundated by tides.

3.2. Sample collection and processing

25 individuals of *Kandelia candel* were selected subjectively (avoiding mechanically or insect damaged or infested with disease). DBH (Diameter at Breast Height), TH (Total Height) of the selected individuals were measured and felled at ground level. The above-ground parts of the individual were then separated into leaves, branches and stems. One stem section of 50 cm in length was collected from the base, middle and upper portion of 5 stem. These stem sections were then debarked in the field to get fresh weight ratio of bark and stem wood. All parts of an individual were weighted (fresh mass) separately in the field and recorded. Ten subsamples from each part were brought back to the laboratory and oven-dried at 80 °C for 10 days to get conversion ratio of fresh weight to oven-dry mass. The oven-dry mass of different parts was calculated from the derived conversion factor and fresh weight of the corresponding plant part. The oven-dried mass of each part (leaf, branch, bark and stem without bark) of individual *Kandelia candel* was estimated.

3.3. Allometric Equation

Allometric relationships between independent variable (Diameter at Breast Height (DBH) and total height (TH)) and dependent variable (oven-dried mass of plant parts) were developed. Linear regression equations were used in allometric relationship for biomass

estimation (Table-1). The significant of those regression equations were tested by using SAS (6.12) statistical software.

Table 1: Regression equations for allometric relationship

Models	Independent variables
$y= aX +b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2
$\sqrt{y}= a\sqrt{X} + b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2
$y= a \text{ Log } X + b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2
$\text{Log } y = a X + b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2
$\text{Log } y = a \text{ Log } X + b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2
$y= a \ln X + b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2
$\text{Ln } y= a X + b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2
$\text{Ln } y= a \ln X + b$	DBH; DBH^2; DBH x TH; DBH^2 x TH; DBH x TH^2; DBH^2 x TH^2

*DBH=Diameter at Breast Height; TH= Total Height

3.4. Determination of elements in plant parts:

Nitrogen, phosphorus, potassium and carbon concentration in leaf, branch, bark and stem of *Kandelia candel* were measured by following different standard methods (Allen, 1974).

3.4.1. Digestion of samples and determination of nutrients

3.4.1.1. Sample Preparation and Digestion for the Determination of Total N According to the Baethgen and Alley (1989).

Steps 1

1. At first take 0.1 g of plant sample in the digestion tube.
2. Add 1.1gm catalyst mixture (Potassium sulphate (K_2SO_4), Cupper sulphate ($CuSO_4$) and Selenium powder (Se) in the proportion of 100:10: 1
3. Add 3 ml of Sulphuric acid (H_2SO_4) and heat continuously to oxidize the organic matter at 200 ^{0}C for 15 minutes.
4. Raise temperature at 400 ^{0}C and heat continuously for 30 minutes.
5. Filter the digested samples through filter paper Whiteman No 1 or 2 and diluted to 100 ml.

Details of Step 2

Preparation of Catalyst Mixture: Potassium sulphate (K_2SO_4): Cupper sulphate ($CuSO_4$): Selenium (Se) = 100:10: 1

Take the following chemical with the given amount (for 20 samples)

K_2SO_4	21.62 gm
$CuSO_4$	2.16 gm
Se	0.22 gm

Details of Step 3

For the digestion of 20 samples take 65 ml of Sulphuric acid (H_2SO_4) into a beaker and then give 3 ml acid to each digestion tube through 10 ml micro-pipette.

Determination of "N"

The concentration of Nitrogen in the sample was measured by clorometric method according to Baethgen and Alley (1989).

Solution Preparation

Solution 1: Working Buffer Solution (for 180 samples, 5.5 ml for each sample)

$Na_2HPO_4.12H_2O$	35.8 g	Dilute to 1 litter with DW	Store in a cold place
N-K tartrate	50 g		
NaOH	54 g		

Solution 2: Na salicylate-Na Nitroprusside solution(for 250 samples, 4 ml for each sample)

Na Salicylate	150 g	Dilute to 1 litter with DW	Store in a light resistant bottle
Na Nitroprusside	0.30 g		

Solution 3: Na Hypochlorite Solution (for 250 samples, 2 ml for each sample)

5.25% Na hypochlorite (clorax)	30 ml	Dilute to 500 ml with DW	Prepare fresh daily

Nitrogen Standard solution preparation

Diluents preparation

K_2SO_4	19.82 g	Dilute to 1 litter with 1.1M H_2SO_4 (60 ml 98% H_2SO_4 in 1L DW)	Store it to prepare standard solution
$CuSO_4$	1.982 g		
Se	0.198 g		

Stock solution preparation (1000 ppm)

Dry NH_4Cl (Dry NH_4Cl at 105°C)	1.9095 g	Dilute to 500 ml with diluents	Nitrogen (N) stock 1000 ppm or mg N/L

Dilute the stock 10 times to prepare 100 ppm standard Nitrogen solution

1000 ppm stock	10 ml	Dilute to 100 ml with diluents	Nitrogen (N) stock 100 ppm or mg N/L

Graduated standard solution preparation for standard curve

Standard N (ppm)	Amount of 100 ppm N Stock required (ml)	Final Volume (ml)
0 (Blank)	Diluents	-
5	2.5	50
10	5	50
15	7.5	50
20	10	50

*Working range 0-50 ppm

Colorimetric determination of "N"

1. Dilute the digest as required (Generally plant sample is diluted 50 times and 5 times for soil if 0.1g plant sample and 0.5g soil sample is taken for Kjeldahl digestion)
2. Take 1 ml aliquot/diluted aliquot of digest in a test-tube
3. Add 5.5 ml of solution-1 and stir with a vortex mixer
4. Add 4 ml of solution-2 and mix again
5. Add 2 ml of solution-3 and mix thoroughly
6. Let stand for 45 minutes at 25 °C (or 15 minutes at 37 °C)

7. Do same thing as describe from 2-6 with the graduated standard solution including blank
8. After immediate stirring with vortex, read absorbance in a spectrophotometer using a wavelength of 650 nm
9. Prepare standard curve from the absorbance with the standard in the spectrophotometer
10. Note the concentration from the spectrophotometer reading

The total Nitrogen content was calculated from the following equation:

$$\textbf{TKN (mg/g)} = (C \times df \times fv) \div (W \times 1000)$$

Where,

C = Concentration obtained from spectrophotometer in ppm or mg N/L
df = Dilution factor (times)
fv = Final volume of the digest (ml)
W = Weight of soil/plant taken in digest (g)

3.4.1.2. Sample Preparation and Digestion for the Determination of Total P and K According to the Allen (1974).

Steps 1

1. Take 0.1 g of plant sample in the digestion tube
2. Add 3 ml concentrated Nitric acid and heat continuously to oxidize the organic matter at 100 °C for 50 to 60 minutes
3. Add 6.4 ml of mixed acid (Nitric acid, Perchloric acid 60% and Sulphuric acid mixed at the proportion of 10:2:1) to the predigested samples and digest at 200 °C for 20 minutes
4. Filter the digested samples through Whiteman filter paper No 42 and diluted to 100 ml

Details of step 2

For the digestion of 20 samples take 65 ml of Nitric acid into a beaker and then give 3 ml acid to each digestion tube through 10 ml micro-pipette.

Details of step 3

Preparation of mixed acid

Take the following acids with the given amount (for 20 samples)

Nitric acid	100 ml
Perchloric acid	20 ml
Sulphuric acid	10 ml

Then mix the acids carefully and give 6.4 ml of mix acid to each digestion tube through 10 ml micro-pipette.

Determination of "P"

The concentration of Phosphate in the sample was measured by clorometric method according to Timothy et al. (1984). Adding 20 ml Ammonium molybdate (3 g in 100 ml deionized water), 50 ml H_2SO_4 (35ml to 250 ml deionized water), 20 ml Ascorbic acid (5.4 g in 100 ml deionized water) and 10 ml Antimony potassium tartrate (0.34 g in 250 ml deionized water) in the solution mixture. After that the mixture was diluted 1.433 g KH_2PO_4 in 1000 ml deionized water. Stock solution was diluted to prepare standard solution of different concentration for standard curve and 1 ml of mixed solution was added with 10 ml of standard solution and sample. Absorbance was measured at 885 nm by UV-visible Recording Spectrophotometer (HITACHI, U-2910, Japan).

The total Phosphorus content was calculated from the following equation:

$$\text{Phosphorus content (mg/g)} = \frac{\text{Phosphate content in sample x Atomic weight of Phosphorus}}{\text{Atomic weight of Phosphate}}$$

Determination of "K"

Potassium concentrations of the samples were measured by Flame Photometer (PFP7, Jenway LTD, England).

3.4.1.3. Determination of Organic Carbon (C)

Organic carbon in plant sample was determined by ignition method (Allen, 1974). Oven-dried plant samples (1 g) were placed in the muffle furnace (Digital Muffle Furnace, FH-05,

DAIHAN Scientific Co Ltd., Korea) for four hours at 450 ° C. After ignition, the samples were then placed in a deccicator to allow it to room temperature and the weight of the ignited sample was taken. Percentage of loss on ignition was calculated from the following calculation.

$$\text{Loss on ignition (\%)} = \frac{\text{Loss of weight (g)}}{\text{Oven dry weight (g)}} \times 100$$

The organic carbon in the plant samples were estimated from the 50% of ash free dry weight (Allen, 1989).

Statistical analysis:

Nutrients and carbon concentration in different parts of *K. candle* of were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p<0.05$) by using SAS (6.12) statistical software.

3.4.2. Allometric equations for nutrients:

Nutrients (N, P and K) and carbon stock in plant parts were estimated from their concentration and biomass of the respective parts. Similar to the biomass allometry, the allometric models for the said nutrients and carbon were derived. The detailed models and equations were mentioned in section 3.3.

3.4.3. Statistical analysis:

Nutrients and carbon in different parts of *K. candel* of were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p<0.05$) by using SAS (6.12) statistical software. Moreover, ANOVA of regression models were performed by using SAS statistical software.

CHAPTER IV
RESULT AND DISCUSSION

4.1 Conversion ratio:

The conversion ratio of fresh mass of stem with bark and fresh mass of bark was 0.27±0.01 and the relationship was significant (Figure 1). Moreover, fresh mass to oven-dried mass conversion ratios of leaves, branches, bark and stem with bark were found to vary from 0.26 to 0.44; and their relationship was significant ($p<0.05$) (Figures 2-5). Woody parts like stem and branches showed higher ratios compared to leaves and bark. Usually leaves contain higher amount of moisture compared to woody parts. This could be the reason to observe higher conversion ratios to the woody parts.

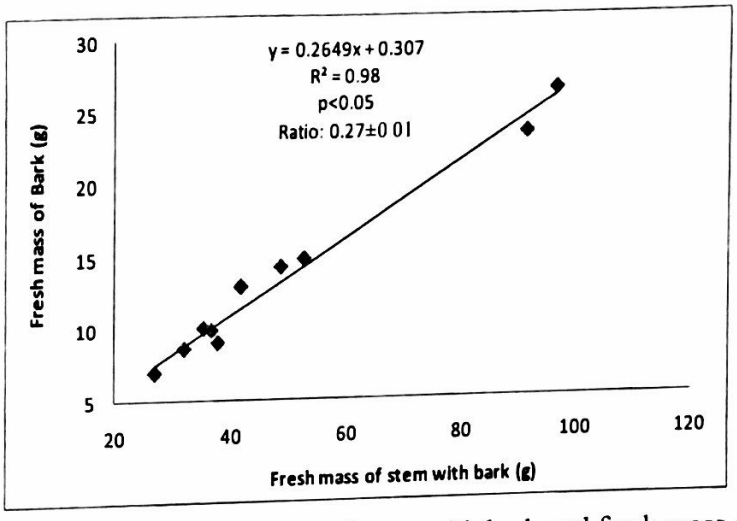

Figure 1: Relationship between fresh mass of stem with bark and fresh mass of bark

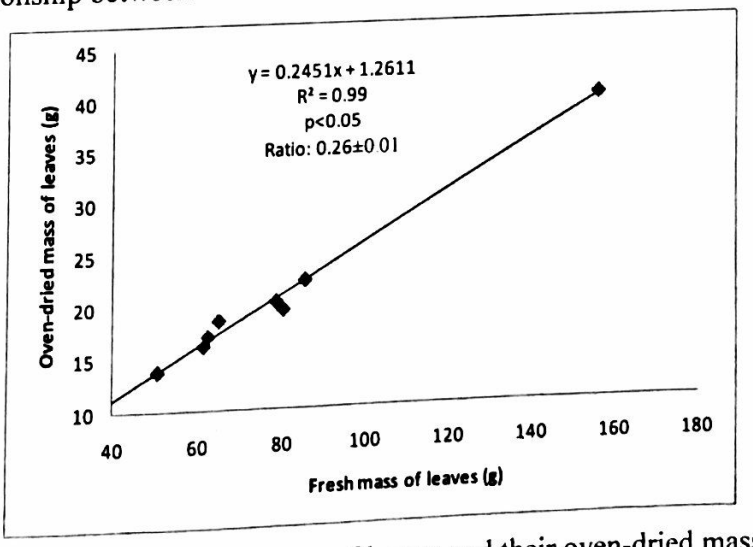

Figure 2: Relationship between fresh mass of leaves and their oven-dried mass

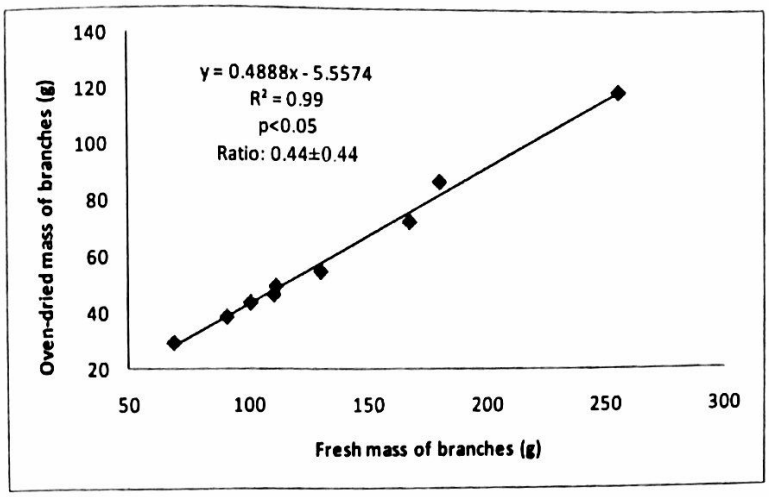

Figure 3: Relationship between fresh mass of branches and their oven-dried mass

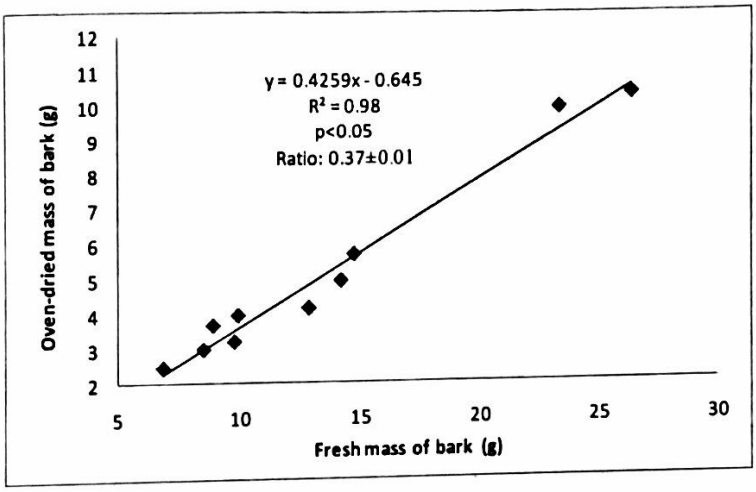

Figure 4: Relationship between fresh mass of bark and their oven-dried mass

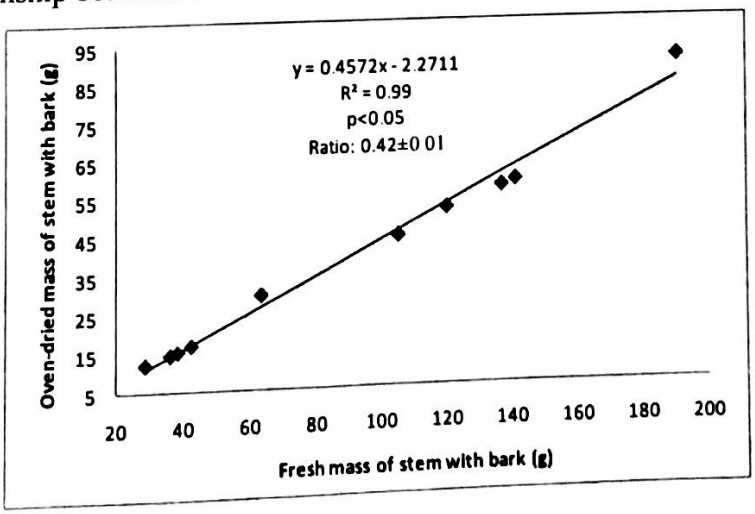

Figure 5: Relationship between fresh mass of stem with bark and their oven-dried mass

4.2 Allometric relationship

Allometic regression equations were tested to estimate the biomass of different parts (leaves, branches, bark and stem without bark) and total above-ground biomass of *Kandelia candle*. Here, biomass used as dependent variable and diameter at breast height (DBH) and total height (TH) considered as independent variables of the regression equations as followed by different researchers (Cintron et al., 1985; Lee, 1990; Saintilan, 1997; Xiao et al., 2004; Cienciala et al., 2006; Mahmood et al., 2012; Siddiqui et al., 2012). This study tested a total of 8 linear models along with 48 regression equations in combination with DBH and TH as independent variables, which yield a total of 240 equations (Table 1). Most of the equations were significant ($p<0.05$) (Appendix-1) but 217 nos were excluded considering the value of co-efficient of determination (R^2) less than 0.80 for leaves, 0.85 for branches, bark, and stem without bark; R^2 value less than 0.90 were also excluded for total above ground biomass. The preliminary selected equations were compared to get best fit equations or models considering the parameter of estimation such as CV, R_{sme}, MS_{error}, S_a, S_b and F-value (Table 3). The use of R^2 as the parameter is erroneous and it gives a general idea for fitting the model (Payandeh, 1981; West and Wells, 1990; Zar, 1996; Siddiqui et al., 2012). The Best fit regression equations were selected to consider the highest R^2 and F-value, with the lowest CV, R_{mse}, MS_{error}, S_a, AICc and S_b. The selected allometric models were Biomass = $0.014\ DBH^2 + 0.03$; $\sqrt{}$Biomass = $0.29\ DBH - 0.21$; $\sqrt{}$Biomass = $0.66\ \sqrt{}DBH - 0.57$; $\sqrt{}$Biomass = $1.19\ \sqrt{}DBH - 1.02$; Biomass = $0.21DBH^2 + 0.12$ for leaves, branches, bark, stem without bark and total above-ground biomass, respectively (Table-3). Allometric relationships were usually derived from commonly used linear regression models (e.g. Mahmood et al., 2004; Snorrason and Einarsson 2006; Bjarnadottir et al., 2007; Mahmood et al., 2012). Using R^2 as the parameter for this choice is erroneous as it simply offers a general idea for fitting the model (Payandeh 1981; West and Wells 1990; Zar, 1996; Mahmood et al., 2004, 2012). More precise selection of regression equation can be obtained by considering the parameter of estimation values as followed by this study (Ibrahima 1995; Zar, 1996; Soares and Novelli, 2005; Siddique et al., 2012). The equations, having large R^2 value than selected equations are excluded for the negative value of regression coefficient, b, because the biomass of any plant part cannot be negative.

Present study showed higher R^2 values for leaf and stem compared to the study of Khan et al (2005), while lower R^2 values for branch and total above-ground biomass (Table-2). The variation may be site specific.

Table 2: Comparison of equations

Plant Parts	Present study (Sundarbans, Bangladesh)		Khan et al, 2005 (Okinawa Island, Japan)	
	Equation	R^2 value	Equation	R^2 value
Leaf	$\sqrt{Y} = a\sqrt{x} + b$	0.82	Ln y = ln g + h ln x	0.758
Branch	$\sqrt{Y} = a\sqrt{x} + b$	0.87	Ln y = ln g + h ln x	0.969
Bark	$\sqrt{Y} = a\sqrt{x} + b$	0.86	Ln y = ln g + h ln x	-
stem	$\sqrt{Y} = a\sqrt{x} + b$	0.86	Ln y = ln g + h ln x	0.759
Total above-ground biomass	Y = ax + b	0.94	Ln y = ln g + h ln x	0.958

* Y = Biomass; x = independent variables; g = coefficient; h = allometric constant

Table 3: *Best fit models for plant parts and total above-ground biomass (kg) of Kandelia candel*

Plant part	Equation	R^2	a	b	Sa	Sb_a	CV	R_{mse}	MS_{error}	F	AICc
Leaf	Biomass = a DBH + b	0.89	0.014	0.03	0.001	0.02	28.46	0.06	0.004	180.98	-132.125
	Biomass =a DBH^2 x TH + b	0.87	0.004	0.05	0.0003	0.02	30.97	0.66	0.004	149.18	-130.894
	√ Biomass = a DBH + b	0.82	0.11	0.08	0.01	0.04	16.51	0.07	0.01	102.47	-128.933
Branch	Biomass = a DBH^2 + b	0.91	0.08	-0.28	0.005	0.09	41.24	0.31	0.10	220.10	-55.3221
	Biomass =a DBH^2 x TH + b	0.88	0.02	-0.18	0.002	0.10	46.22	0.35	0.12	170.53	-47.0585
	√ Biomass = a DBH + b	0.87	0.29	-0.21	0.02	0.09	20.84	0.16	0.03	153.46	-89.5446
	√ Biomass = a √ DBH^2 x TH + b	0.86	0.14	-0.09	0.01	0.08	21.92	0.17	0.03	136.54	-84.0986
Bark	Biomass = a DBH + b	0.87	0.24	-0.37	0.02	0.07	30.07	0.13	0.02	150.84	-99.9855
	√ Biomass = a √ DBH + b	0.86	0.66	-0.57	0.05	0.10	16.30	0.10	0.01	138.19	-115.04
	√ Biomass = a DBH + b	0.85	0.17	0.30	0.01	0.05	16.65	0.10	0.01	131.45	-111.604
	√ Biomass = a √ DBH^2 x TH + b	0.86	0.09	0.10	0.01	0.05	16.10	0.10	0.010	142.19	-110.071
	√ Biomass = a √ DBH^2 x TH^2 + b	0.86	0.04	0.16	0.004	0.04	16.24	0.10	0.01	139.45	-107.214
Stem	Biomass = a DBH + b	0.87	0.79	-0.20	0.06	0.23	30.11	0.44	0.19	150.44	-41.6011
	√ Biomass = a √ DBH + b	0.86	1.19	-1.02	0.10	0.18	16.42	0.18	0.33	136.50	-85.49
	√ Biomass = a √ DBH^2 x TH + b	0.86	0.16	0.18	0.01	0.09	16.22	0.18	0.03	140.43	-80.5211
	√ Biomass = a √ DBH^2 x TH^2 + b	0.86	0.08	0.28	0.01	0.08	16.36	0.18	0.03	137.70	-77.6639
Total above-ground-biomass	Biomass = a DBH + b	0.91	1.78	-3.10	0.12	0.42	27.59	0.79	0.63	231.31	-11.5999
	Biomass = a DBH^2 + b	0.94	0.21	0.12	0.01	0.19	21.60	0.62	0.38	393.72	-21.4726
	Biomass = a DBH^2 x TH+ b	0.94	0.06	0.36	0.003	0.18	21.76	0.62	0.39	387.59	-18.5098
	Biomass = a DBH^2 x TH^2 + b	0.93	0.02	0.56	0.001	0.19	24.20	0.69	0.48	308.92	-10.3434
	√ Biomass = a DBH + b	0.92	0.47	0.03	0.03	0.11	12.79	0.20	0.04	258.71	-78.2842
	√ Biomass = a √ DBH^2 x TH + b	0.92	0.23	0.17	0.01	0.10	12.78	0.20	0.04	259.06	-75.6868
	√ Biomass = a √ DBH^2 x TH^2 + b	0.91	0.11	0.32	0.01	0.09	13.60	0.21	0.04	225.87	-69.7329

Note: R^2 = coefficient of determination; S_a = standard error of intercept ''a''; S_b = standard error of regression coefficient ''b'', CV= Co-variance, R_{mse} =Root mean square error; MS_{error} =Mean square error, AICc = Akaike's information criterion corrected

4.3 Nutrients in plant parts and allomertic relationship for nutrient and carbon stock:

Nutrients (N, P and K) and carbon concentration significantly ($p<0.05$) varied among the plant parts. Comparatively highest concentration of nitrogen (8.42 mg/g), phosphorus (4.74 mg/g) and potassium (11.09 mg/g) was observed in leaf. Higher concentration (45.25-45.53%) of carbon was observed in woody parts (stem and branches) of *K. candle* (Table 4). The trend of nitrogen, phosphorus and potassium in different parts of *K. candle* of this study was similar to that of *C. decandra* (Mahmood et al., 2012), *R. apiculata* (Ong et al., 1984), *Avicennia spp.*, *Bruguiera spp.* and *Ceriops spp.* (Aksornkoae and Khemnark, 1984) and *B. parviflora* (Mahmood et al., 2003) (Table 5). Comparatively higher concentration of nutrients was observed in leaves and highest concentration of carbon was detected in woody parts of *K. candle*. Physiologically more active tissue (leaf, flower) usually contain higher concentration of nutrients (Binkley, 1986) and woody parts (stem and bigger branches) contain higher concentration of carbon (Mahmood, 2013). The variation in nutrients and carbon concentration in different plant parts also related to the structural component of plant cell (Kaakinen et al., 2004). Moreover, plant species, 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 may be the reason for this extent of nutrients variation in plant parts (Mahmood, 2004).

Nutrients (N, P and K) and carbon content in total above-ground biomass were estimated and allometric equations were tested for their stock in total above-ground biomass that has been selected for biomass models (Tables 3-4). The selected allometric models for Nitrogen, Phosphorous, Potassium and Carbon were $N = 0.39DBH^2 + 0.49$, $P = 0.77DBH^2 + 0.14$, $K = 0.87DBH^2 + 0.07$ and $C = 0.09DBH^2 + 0.05$ (Table 6).

Table 4: Nutrients (N, P and K) and carbon concentration in different parts of *Kandelia candel*

Plant components	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Carbon (%)
Leaf	8.42±0.75	4.74±0.02	11.09±0.19	43.27±0.20
Branch	1.21±0.13	4.23±0.39	4.80±0.08	45.25±1.60
Bark	2.91±0.08	4.53±0.40	3.80±0.35	41.72±0.13
stem	1.08±0.12	2.74±0.14	2.59±0.04	45.53±0.23

Table 5: Comparison of nutrients concentration in different parts of different mangrove species

Species	Plant parts	Nutrients (mg/g)			Sources and Location
		N	P	K	
Rhizophora apiculata	Leaves	10.2	1.1	9.8	Ong et al (1984) Matang, Malaysia
	Branches	2.9	0.9	3.6	
	Stem	2	0.2	3.3	
Ceriops decandra	Leaf	16.1	0.17	4.91	Mahmood et al (2012) Sundarbans, Bangladesh
	Branch	10.83	0.11	3.13	
	Stem	8.66	0.07	1.82	
	Bark	9.46	0.05	2.43	
Avicennia spp.	Leaves	19.6	1.4	11	Aksornkoae and Khemnark (1984) Amphoe Khung mangrove, Thailand
	Branch	8.9	1.4	7.5	
	Stem	8.6	0.9	0.51	
Bruguiera spp.	Leaves	11.7	0.7	3.7	
	Branch	9	0.6	3.1	
	Stem	4	0.3	0.8	
Ceriops spp.	Leaves	10.8	0.6	7.8	
	Branch	6.7	0.4	5.5	
	Stem	4.4	0.3	3.1	
Rhizophora apiculata	Leaves	16.4	0.2	5.2	Gong and Ong (1990) Matang mangrove, Malaysia
	Branch	5.5	0.3	1.6	
	Stem	4	0.3	0.6	
	Root	4.5	0.3	1.7	
Aegiceras corniculatum	Leaves	13.7	1.2	5	Li (1997) Futian mangrove, South China
	Branches	7.5	1.9	10.3	
	Stems	5.8	0.7	2.6	
	Roots	4.8	1.7	14.8	
Kandelia candel	Leaves	13.9	1.3	6.4	Li (1997) Futian mangrove, South China
	Branches	5.4	1.5	8.5	
	Stems	6.8	0.7	2.1	
	Roots	4.4	1.6	12.6	

Table 5 (cont.)

Species	Plant parts	Nutrients (mg/g)			Sources and Location
		N	P	K	
B. parviflora (Saplings)	Leaves	12.49	1.23	12.68	Mahmood et al, (2003) Kuala Selangor, Malaysia
	Branches	6.43	0.10	5.46	
	Stems	1.62	0.81	0.98	
	Roots	3.91	1.59	5.21	
B. parviflora (Tree)	Leaves	13.69	1.32	11.89	
	Branches	5.71	1.18	2.60	
	Stems	1.63	0.74	1.06	
	Roots	4.47	1.00	6.08	
Kandelia candel	Leaf	8.42	4.74	11.09	Present study
	Branch	1. 21	4. 23	4.80	
	Bark	2.91	4.53	3.80	
	Stem	1.08	2.74	2.59	

Table 6: Nutrients (N, P and K) and carbon

Nutrient and equation	R^2	a	b	S_a	S_b	CV	R_{mse}	MS_{error}	F
$N = a\ DBH^2 + b$	0.95	0.39	0.49	0.02	0.34	20.07	1.12	1.26	415.23
$P = a\ DBH^2 + b$	0.95	0.77	0.14	0.04	0. 62	20.38	2.08	4.34	469.58
$K = a\ DBH^2 + b$	0.96	0.87	0.07	0.04	0. 68	19.89	2.28	5.21	500.41
$C = a\ DBH^2 + b$	0.95	0.09	0.05	0.01	0.08	21.57	0.28	0.08	396.28

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Appendix

Appendix-1

R^2 values for leaf dry biomass of *Kandelia candel*

Model	D	D^2	D×T	D^2×T	D×T^2	D^2×T^2
Y= a + bx	0.807	0.887	0.742	0.866	0.678	0.836
√Y= a+ b√x	0.772	0.816	0.720	0.799	0.674	0.777
Log Y= a + bLogx	0.680	0.680	0.630	0.655	0.590	0.630
Ln Y= a + b lnx	0.680	0.680	0.630	0.655	0.590	0.630
Y= a + bLogx	0.598	0.598	0.509	0.549	0.453	0.509
Log Y= a+ bx	0.716	0.610	0.701	0.610	0.665	0.599
Y= a + b lnx	0.598	0.598	0.509	0.549	0.453	0.509
Ln Y= a + bx	0.716	0.610	0.701	0.610	0.665	0.599

R^2 values for branch dry biomass of *Kandelia candel*

Model	D	D^2	D×T	D^2×T	D×T^2	D^2×T^2
Y= a + bx	0.767	0.905	0.699	0.881	0.635	0.847
√Y= a+ b√x	0.814	0.869	0.768	0.855	0.724	0.834
Log Y= a + bLogx	0.783	0.783	0.754	0.771	0.722	0.754
Ln Y= a + b lnx	0.783	0.783	0.754	0.771	0.722	0.754
Y= a + bLogx	0.525	0.525	0.439	0.477	0.386	0.439
Log Y= a+ bx	0.784	0.639	0.786	0.643	0.753	0.635
Y= a + b lnx	0.525	0.525	0.439	0.477	0.386	0.439
Ln Y= a + bx	0.784	0.639	0.786	0.643	0.753	0.635

R^2 values for bark dry biomass of *Kandelia candel*

Model	D	D^2	D×T	D^2×T	D×T^2	D^2×T^2
Y= a + bx	0.867	0.823	0.863	0.840	0.838	0.844
√Y= a+ b√x	0.857	0.851	0.844	0.860	0.819	0.858
Log Y= a + bLogx	0.682	0.682	0.642	0.663	0.607	0.6422
Ln Y= a + b lnx	0.682	0.682	0.642	0.663	0.607	0.642
Y= a + bLogx	0.731	0.731	0.667	0.698	0.619	0.667
Log Y= a+ bx	0.615	0.446	0.616	0.453	0.595	0.453
Y= a + b lnx	0.731	0.731	0.667	0.698	0.619	0.667
Ln Y= a + bx	0.615	0.446	0.616	0.453	0.595	0.453

R^2 values for stem dry biomass of *Kandelia candel*

Model	D	D^2	D×T	D^2×T	D×T^2	D^2×T^2
Y= a + bx	0.867	0.823	0.863	0.840	0.838	0.844
√Y= a+ b√x	0.857	0.851	0.844	0.860	0.819	0.858
Log Y= a + bLogx	0.682	0.682	0.642	0.663	0.607	0.6422
Ln Y= a + b lnx	0.682	0.682	0.642	0.663	0.607	0.642
Y= a + bLogx	0.731	0.731	0.667	0.698	0.619	0.667
Log Y= a+ bx	0.615	0.446	0.616	0.453	0.595	0.453
Y= a + b lnx	0.731	0.731	0.667	0.698	0.619	0.667
Ln Y= a + bx	0.615	0.446	0.616	0.453	0.595	0.453

R^2 values for total above ground dry biomass of *Kandelia candel*

Model	D	D^2	D×T	D^2×T	D×T^2	D^2×T^2
Y= a + bx	0.909	0.944	0.873	0.944	0.825	0.930
√Y= a+ b√x	0.897	0.918	0.868	0.918	0.832	0.907
Log Y= a + bLogx	0.817	0.817	0.777	0.798	0.738	0.777
Ln Y= a + b lnx	0.817	0.817	0.777	0.798	0.738	0.777
Y= a + bLogx	0.707	0.707	0.625	0.663	0.569	0.625
Log Y= a+ bx	0.783	0.783	0.786	0.616	0.758	0.613
Y= a + b lnx	0.707	0.707	0.625	0.663	0.569	0.625
Ln Y= a + bx	0.783	0.783	0.786	0.616	0.758	0.613