Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Md Al-Amin Shaikh

Title: Allomeric relationship for estimating above-ground biomass, nutrients and carbon of *Aegiceras corniculatum* of Sundarbans, Bangladesh

Supervisor(s): Dr. Mahmood Hossain, Professor, Forestry and Wood Technology Discipline, Khulna University

Programme: Master of Science in Forestry

Allometric Relationship for Estimating Above-ground Biomass, Nutrients and Carbon of *Aegiceras corniculatum* of the Sundarbans, Bangladesh

MD. AL AMIN
Roll No. MS 1205

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA 9208
BANGLADESH

2015

Allometric relationship for estimating above-ground biomass, nutrients and Carbon of *Aegiceras corniculatum* of the Sundarbans, Bangladesh

MD. AL-AMIN SHAIKH

Roll No: Ms 120517

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE

SCHOOL OF LIFE SCIENCE

KHULNA UNIVERSITY

KHULNA

BANGLADESH

2015

Allometric relationship for estimating above-ground biomass, nutrients and Carbon of *Aegiceras corniculatum* of the Sundarbans, Bangladesh

MD. AL-AMIN SHAIKH

Roll No: Ms 120517

This Project Thesis Submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh, in Partial Fulfillment of the Requirements for the Professional M.Sc. Degree in Forestry.

2015

Dedicated

To

My Beloved Parents

Abstract

Aegiceras corniculatum is an exclusive mangrove species but separately distributed at the high saline areas of the Sundarbans and they often found in association with *Rhizophora apiculata, Rhizophora mucronata, Candelia candle* and *Ceriops decandra.* Allometric equations were used to estimate biomass of leaf, branches, bark, stem without bark and total above-ground biomass of *A. corniculatum.* Ten linear equations with DBH as independent variable were tested for each part of plant. All the regression equations were significant ($p<0.05$), but highest R^2 (0.93- 0.99) and F-values and lowest MS_{error} were observed for Log-Log equition ($Log_{10}y = a\ Log_{10}x + b$). The selected allometric models were Log Leaf biomass = 1.52 Log DBH – 1.39; Log Branch biomass = 2.20 Log DBH – 1.48; Log Bark biomass = 2.08 Log DBH – 1.80; Log stem biomass = 2.08 Log DBH – 0.99; Log Total biomass = 2.06 Log DBH – 0.73. Comparatively higher amount of carbon was observed in stem whereas as the lower content amount was observed in bark. Nutrients (N, P and K) concentration significantly ($p<0.05$) varied among the plant components and comparatively higher concentration of nutrient was observed in leaf whereas as the lower content was observed in stems. The element content in and total above-ground biomass were calculated and allometric equations were developed for total above-ground element content. The selected allometric models were, Log N = 1.91 Log DBH - 0.25; Log P = 1.93 Log DBH + 0.01; Log K = 2.02 Log DBH - 0.01; Log C = 2.06 Log DBH – 1.05.

Acknowledgement

First of all, I express my deep gratitude to the Almighty Allah, for enabling me to complete this project thesis.

I would like to express my indebtedness to my honorable teacher and supervisor, Dr. Mahmood Hossain, Professor, Forestry and Wood Technology Discipline, Khulna University, for his supervision, valuable guidance, regular advice, constructive suggestion and lastly for his friendly behavior from first to last during field works, laboratory works as well as in the time of writing this project thesis paper.

I wish to acknowledge my respected teachers Rubait Abdullah, Lecturer, Forestry and Wood Technology Discipline, Sanjoy Saha, Scentific officer, CISS, Khulna University who were always with me and gave me necessary instructions during this study.

My special thanks to Uzzal Kundu and all the students of 10 batch, FWT discipline for their cordial help during my field work.

I appreciate my parents for their continuous support and loving care during my studies and also during my research works.

At last, my sadness, happiness and emotion always act on all of my well wishers, whose bundles love and affection drive me every moment to do something for life here and life here after.

Declaration

I hereby declare that the project thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Khulna University or other institutions.

Al-Amin

Md. Al-Amin Shaikh

Roll No: MS 120517

Session: 2012-2013

Forestry and Wood Technology Discipline

Khulna University

Khulna-9208

Bangladesh.

Approval

Project thesis submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh, in partial fulfillment of the requirements for the professional M.Sc. degree in Forestry. I have approved the style and format of the project thesis.

Dr. Mahmood Hossain

Professor

Forestry and Wood Technology Discipline

Khulna University

Khulna-9208

Bangladesh

Table of Contents

Title	Page No
Dedication	ii
Abstract	iii
Acknowledgement	iv
Declaration	v
Approval	vi
Table of content	vii
List of tables	ix
List of figures	x
Chapter One: Introduction	1-2
1.1. Introduction	1
1.2. Objectives	2
Chapter Two : Literature review	3-9
2.1. Description of the species	3
2.2. Taxonomical classification	4
2.3. Distribution	4
2.4. Habitat	4
2.5. phenology	5
2.6. Pollination	5
2.7. Reproduction	5
2.8. Adaptations	6
2.8.1. Adaptation to salt	6
2.8.2. Root	6
2.8.3. Anarobic soil	6
2.8.4. Soil and water of high salinity	7
2.8.5. Salt exclusion	7
2.8.6. Salt secretion	7

2.8.6. Xeromorphic Characters 7

2.9. Biomass allometric models 8

2.9.1. Allometry 8

Chapter Three: Materials and method 10-16

3.1. Study site 10

3.2. Selection and collection of samples 10

3.3. Sample processing and allometric relationships 10

3.4. Nutrients in plant components 11

3.5. Phosphorus and Potassium in plant components 14

3.6. Determination of Organic Carbon (C) 16

Chapter Four: Result and Discussion 17-29

4.1. Conversion ratio 17

4.2. Allometric relationship 19

4.3. Nutrients in plant parts 24

References 20-32

List of Tables

Table no	Title	Page No
Table 1	Selected ten models for plant parts and total above-ground biomass of Khalshi (*Aegiceras corniculatum)*	21
Table 2	Parameter of estimates of allometric models	22
Table 3	Nutrients (N, P and K) and carbon concentration in different parts of Khalshi (*Aegiceras corniculatum)*	24
Table 4	Parameter of estimate of allometric models for nutrients (N, P and K) and Carbon in total above-ground biomass of Khalshi (*Aegiceras corniculatum)*	25
Table 5	Comparison of nutrients concentration in different parts of different mangrove species	27

List of Figures

Table no	Title	Page No
Fig.-1	Relationship between fresh mass of stem without bark and fresh mass of bark	17
Fig.-2	Relationship between fresh mass of leaves and their oven-dried mass	18
Fig.-3	Relationship between fresh mass of smaller branches and their oven-dried mass	18
Fig.-4	Relationship between fresh mass of bigger branches and their oven-dried mass	18
Fig.-5	Relationship between fresh mass of bark and their oven-dried mass	19
Fig.-6	Relationship between fresh mass of stem without bark and their oven-dried mass	19
Fig.-7	Allometric relationship between diameter at breast height (DBH) and biomass of leaf	22
Fig-8	Allometric relationship between diameter at breast height (DBH) and biomass of branch	23
Fig.-9	Allometric relationship between diameter at breast height (DBH) and biomass of stem without bark	23
Fig.-10	Allometric relationship between diameter at breast height (DBH) and biomass of bark	23
Fig.-11	Allometric relationship between diameter at breast height (DBH) and total above-ground biomass	24
Fig.-12	Allometric relationship between diameter at breast height (DBH) and amount of Nitrogen, Phosphorus and Potassium in total above-ground biomass	25

Chapter-1

1.1 Introduction

Mangroves are found in sheltered intertidal zones of tropical and subtropical regions and can tolerate varying degrees of salinity (Ong, 1993). They are unique ecosystems prominent in vulnerable coastal strips all over the world. Mangroves got special interest in research after its importance in estuarine detritus food web was proved (Heald, 1969; Odum, 1970; Odumand Heald, 1972). *Aegiceras corniculatum* is a widespread mangrove species and one of major species of mangroves in the Sundarbans. It can withstand a high level of salinity. It is both a salt secretor and salt extruder. *Aegiceras corniculatum* is well known as a tree of high honey production. As mangroves grow on muddy and anaerobic soil, which suffers from tidal inundation, they show a unique pattern of biomass allocation (Komiyama et al., 2005). The biomass of mangrove forests has been studied for several decades (Clough and Scott, 1989; Clough et al., 1997; Komiyama et al., 1998, 2000, 2002; Ong et al., 1995, 2004; Tamai et el., 1986, Mahmood et al., 2008) by using allometric relations. Allometry is a nondestructive powerful tool for estimating the whole or partial weight of a tree from measurable tree dimensions (Komiyama et al., 2005, Mahmood et al., 2008).

In recent decades, research on mangroves has been focused on the diversity of species, resources, flora, physiological ecology, different stages of organic matter cycling in the mangroves (Soares, 1997), examining litter production and decomposition, export of dissolved and/or particulate organic matter, consumption by the mangrove resident fauna, incorporation of organic matter into the substratum, and its export through the assimilation and feeding by organisms that spend part of their life cycle in the mangroves, which, when they leave the ecosystem, become export agents of assimilated matter. However, as far as ecological anatomical research is concerned, little work has been done (Janssonius, 1950; Lin, 1988; Panshin, 1932; Tomlinson, 1986). To better understand the dynamics of organic matter cycling in the mangroves; it is important to know the amount of biomass that is present in the vegetation covering at a given time through the analysis of existing studies on the biomass of mangrove species.

Different mangrove species at different localities shows wide range of biomass values and shows different trend of biomass allocation in their components (Steinke et al., 1995; Tam et al., 1995; Suzuki and Tagawa, 1983; Clough and Attiwill, 1975; Gong and Ong, 1990). Different tree species usually vary in their architecture due to variation in forest types, stand density or canopy closure (Clough and Scout, 1989). As allometric equation of mangrove species does vary greatly among sites for the same species (Komiyama et al., 2008), it is preferable to use species-specific allometric equations for biomass estimation (Ketterings et al., 2001; Mahmood et al., 2008). Nutrient removal by harvest and its potential consequences on future nutrient cycling and productivity of a forest have been well documented (White, 1974; Hansen and Baker, 1979; Morrison and Foster, 1979; Tritton et al., 1987; Federer et al., 1989; Hornbeck et al., 1990). Information on biomass stocking and nutrient distribution in both above and below-ground parts of trees are essential for assessing sustainable production and as well as evaluating the impact of various silvicultural practices (Santa Regina, 2000). The present study is designed to derive allometric models of above-ground biomass, nutrients and carbon stock in *Aegiceras corniculatum* of the Sundarbans.

1.2. Objectives: The objectives of this study were

- To derive allometric models for estimating above-ground biomass of different parts of *Aegiceras corniculatum* in the Sunderbans.
- To calculate the nutrients (N, P and K) and Carbon concentration in different parts (leaves, branches and stems) of *Aegiceras corniculatum.*
- To drive allometric models for estimating nutrients (N, P and K) and carbon stock in above ground biomass of *Aegiceras corniculatum.*

Chapter-2

Literature review

2.1. Description of species

Aegiceras corniculatum, commonly known as Black Mangrove, River Mangrove or Khalsi is a species of shrub or tree mangrove in the Myrsine family (or Primrose family) with a distribution in coastal and estuarine areas ranging from Bangladesh through South East Asia to southern China, New Guinea and Australia. *Aegiceras corniculatum* grows as a shrub or small tree up to 7 m high, though often considerably less. The leaves are alternate, simple, spirally arranged, leathery in texture and hairless. They are elliptic to obovate in shape, 4-8 cm long, 1.8-4 cm wide, with a rounded to slightly notched tip and a wedge-shaped base. Its fragrant, small, white flowers are produced as umbellate clusters of 10–30, with apeduncle up to 10 mm long and with pedicels 10–18 mm long. The calyx is 2–4 mm long and corolla 4-6 mm long. The fruit capsule is horn-shaped, 3.8-8 cm long, has a persisting calyx, light green to pink in color, and is crypto-viviparous, enclosing 1 propagule.

Figure: Khalshi (*Aegiceras corniculatum)*

2.2. Taxonomical classification of *A. corniculatum*

Taxonomical classification of *A. corniculatum* is as follows, (Roome et al, 2011)

Kingdom:	Plantae
Division	Spermatophyta
Sub division	Angiosperms
Class	Eudicots
Sub class	Asterids
Order:	Ericales
Family:	Myrsinaceae (or Primulaceae)
Genus:	*Aegiceras*
Species:	*A. corniculatum*

2.3. Distribution

Aegiceras corniculatum is widely distributed across the Indo-West Pacific from India and Sri Lanka through Asia to Polynesia and Australia. In Australia, the species occurs in most estuaries and embayments from Cossack, Western Australia (20° 40' S, 117° 12' E) in the west, across the Northern Territory and Queensland, to Merimbula, New South Wales (36° 53' S, 149° 55' E) in the east. It is also found on Lord Howe Island. (Duke, 2006)

2.4. Habitat

Aegiceras corniculatum is tolerant of a wide range of growing conditions and as a consequence is found across a range of tidal environments. It can tolerant varying levels of salinity and sunlight and grows in a variety of soil types. It often occurs as a dense sub-canopy bordering on the fringe of tidal creeks and river margins, whereas in coastal

mangrove habitats it is most commonly found along landward margins .Low intertidal, intermediate-upstream estuarine position (Duke, 2006).

2.5. Phenology

In Australia, plants flower from May to October, with fruit maturing from December to March. These events tend to occur later in higher latitude areas, particularly along the east coast into New South Wales. The sweet smell extruded from the flowers suggests they are bee pollinated. *Aegiceras corniculatum* is generally known to be viviparous, although Saegner suggests the embryos do not pierce the pericarp until the fruit has fallen from the parent plant, therefore it is not strictly viviparous. The propagule is suited to water dispersal due to its buoyancy and the tendency for fruit to fall during periods of regular diurnal flooding. *Aegiceras corniculatum* occurring in downstream locations is likely to cohabitate with *Avicennia marina*, *Sonneratia alba* and *Rhizophora stylosa*. In contrast, where it occurs in upriver, brackish waterways in tropical regions it is likely to cohabitate with *Acanthus ilicifolius*, *Sonneratia caseolaris*, *Sonneratia lanceolata* and *Rhizophora mucronata* (Duke, 2006).

2.6. Pollination

Pollination is occured by small insect and night flying insects; moths have been observed visiting the flowers, presumably for the small quantity of nectar secreted by the disc, but bees may be daytime visitors. Pollen release is not an explosive manner (Tomlinson, 1986).

2.7. Reproduction

Aegiceras corniculatum showed viviparous germinationof seeds.. The seed starts germinating and growing its hypocotyl inside the fruit. When it is mature, the embryo, together with the fruit, will detach and stick into the soil and grow its roots and leaves; Black mangrove's seeds do not have the rod-like hypocotyl. They produce two folded, broad oval cotyledons. When the fruit detaches, the cotyledons will spread and float on the water, hence root quickly after landing (Duke, 2006).

2.8. Adaptations

2.8.1. Adaptation to salt

Aegiceras corniculatum is a species of high salt tolerance. Six hundreds of EST were obtained from the leaf SSH library of *A. corniculatum* under salt-stress. *P5CS*(1-pyrroline-5-carboxylate synthetase), which was related to osmotic regulation, and two aquaprin genes, which participate in water transport, were up-regulated in *A. corniculatum* by salt stress. Expression patterns of these 2 aquaprins also indicated that *A. corniculatum* could recover from long-term salt stress and adapt to saline environments. There are several ongoing projects, including transfering *P5CS* and *CPI* (coding for cysteine proteinase inhibitor) genes of *A. corniculatum* into *Arabidopsis*, and microarray analysis of transcript profiling in *A. corniculatum* could further help to depict mechanisms of adaptation and evolution in this species (Tomlinson, 1986).

2.8.2. Root

Aegiceras corniculatum has neither supporting roots nor respiratory roots, but bigger buttress root.

2.8.3. Anaerobic Soil

There are ventilating tissues called aerenchyma. They are hollow cells that decrease the resistance of air diffusion; normal plant cells contain 2-7% of air, but mangrove cells contain 40%.

The root system of *Aegiceras corniculatum* is like thick ropes, and at intervals it develops erect pneumatophores which stick out from the ground for 30 cm. They facilitate air diffusion. Knee joints of the Many-petaled Mangrove are root arcs that stretch out from the soil. Inside them a lot of aerenchyma can be found. There are ventilating surfaces called lenticels in respiratory roots and knee joints.

2.8.4. Soil and water of high salinity

Like all other halophilous plants (plants that grow on saline soil or soil that affected by salt water), mangroves can tolerate higher internal salinity. However, mangroves balance the osmosis through accumulating carbohydrates of small molecular weights inside their bodies instead of proline, an amino acid that most halophilous plants accumulate for the balance.

2.8.5. Salt Exclusion

Aegiceras corniculatum can prevent salt from entering xylem of the roots and stop salt being transported to tissues through ultra filtration. They can also expel extra salt from the roots by an active pump mechanism. These salt exclusion plants can maintain a low salinity, only 30% of that of non-salt exclusion plants.

2.8.6. Salt Excretion

Aegiceras corniculatum can keep excreting salt inside the tissues through salt glands on the leaves.

2.8.7. Xeromorphic Characters

Mangroves are xeromorphic plants, therefore they must preserve a high density of water to minimise absorption of sea water, which has a high salinity. To adapt this unique habitat, mangroves develop some special features:

- Succulence—some species of mangroves contain water storing tissues in the leaves
- Thick cuticle—ceraceous cuticle and periderm
- Sunken stomata—concave breathing pores at the back of the leaves
- Buttress root—thick roots to absorb water on the soil surface

2.9. Biomass allometric models

2.9.1. Allometry

Allometry is all about studying the relative sizes of plant parts. Usually, relationships between dbh (diameter at breast height, or 1.37 m up from ground level), tree height, total biomass, leaf weight, etc., are calculated. For example, what we do here is prepare equations (regressions) to calculate the total above-ground biomass of *Agiceras corniculatum* tree as a function of dbh, we are therefore implicitly assuming that biomass is directly related to tree diameter.

The subject of allometry is variation in morphometric variables or other features of organisms associated with variation in size. Such variation can be produced by several biological phenomena, and three different levels of allometry are therefore distinguished: static allometry reflects individual variation within a population and age class, ontogenetic allometry is due to growth processes, and evolutionary allometry is thc result of phylogenetic variation among taxa. Most multivariate studies of allometry have used principal component analysis. Variation in sizc of organisms usually is associated with variation in shape, and most mctric characters arc highly corrclatcd among one another. These associations are the subject of allometry (Huxley, 1932; Cock, 1966; Gould, 1966, 1975). Although allometry is often used to examine the consequences of size for ecological or physiological variables (Giinther, 1975; LaBarbera, 1989; Reiss, 1989), this review deals only with measurements of traits used to characterize the morphological form of organisms.

Unlike other approaches in morphometrics, which are built on geometric theory, allometry has a largely empirical basis. Huxley (1932) realized that scatter plots of two trait measurements in growing organisms often closely follow a curved line, and that this relationship usually bccomes linear if both measurements are transformed to logarithms. From this, he derived his formula of simple allometry

$$y = bx^a$$

Or in log-transformed notation,

$$\text{Log } y = a \log x + b$$

Where x and y are trait measurements, and a and b are constants. The constant a, the slope in log-log plots of s and y, is often called the allometric coefftcient (terminology is not uniform; some authors call b cocfficicnt). The special case when a = I is called isometry, and indicates direct proportionality between x and *JJ.* If $a > 1$, there is positive allometry, whereas for negative allometry, $a < 1$ (Huxley and Teissier, 1936). In humans, for example, the long bones of the limbs show positive allometric growth relative to overall stature, and the height of the head shows negative allometry.

In most morphometric data sets, measurements are positively correlated, i.e., **.u** and JI increase or decrease simultaneously. Even if there is negative allometry, a still is positive; negative allometry implies only that the relative variation in y is smaller than that in x, e.g., v grows by 10% for every 20% growth increment in x. If a is negative, however, there is an absolute reduction in y associated with an increase in x. This case is called enantiometry (Huxley and Teissier, 1936). Reduction of the absolute size of organs during growth is a real phenomenon, although it is not found commonly in morphometric studies. The most striking example is the shrinking of larval structures during metamorphosis, e.g. the gills and tail of anuran tadpoles; but in a subtler way, enantiometry even occurs in cranial growth of primates (Comer and Richtsmeier, 1991). Huxley's approach is not restricted to pairs of measurements. In many multivariate data sets, log-log plots of all pairwise combinations of morphometric variables show approximately linear relationships. Therefore, Huxley's bivariate allometry can be generalized to multiple dimensions. Moreover, it is not confined to growth data, as straight-line relationships are also found in log-log plots of intra- and interspccific variation within one particular ontogenetic stage (most often adults.

Chapter-3

Materials and method

3.1. Study site

The study area is Shatkhira administrative range of the Sunderbans mangrove forest of Bangladesh. The total area is situated between 22°11.226' N; 89°07.768' E and 22°14.062' N; 89°11.679' E. This range is bordering the Indian Sunderbans at the west, Satkhira Range at the east and Bay of Bengal at the South. Rainfall in the area varies around 1800 mm per year and the average temperature varies from 28-30 ° C in summer and 18-20 °C in winter. The mangrove forest in this range is experienced by higher saline water. The major species of this area is *Avicennia alba, A. officinalis, A. corniculatum. Xylocarpus granatum, X. mekongensis, A. rotundifolia, Lumnitzera racemosa, Execoaeria agallocha,* and *Ceriops decandra* (Siddiqi, 2001).

3.2. Selection and collection of samples

A total of 43 individual of *Aegiceras corniculatum* having Diameter at Breast Height (DBH) from 1 to 15 cm were taken randomly (avoiding mechanically or insect damaged or infested with disease) from the study area.

3.3. Sample processing and allometric relationships

The felled individuals were then separated into leaves, bigger branches (diameter > 2 cm), smaller branches (diameter < 2 cm) and stems. One stem section of 50 cm in length was collected from the base, middle and upper portion of the stem. These stem sections were then debarked in the field to the ratio of stem and bark weight.

Five disks (2 cm thick) of stems and bigger branches (for trees) and sub-samples (about 0.25 kg) of leaves, smaller branches and bark were taken randomly and brought back to the laboratory for calculating fresh mass to oven dry mass conversion ratios of samples at

80 °C to constant mass. Oven-dry mass of different parts was estimated from the conversion ratios and fresh mass of the respective parts of plants. Linear regression equations e.g. $y = ax + b$; $y = a \ln(x) + b$ and $Log_{10}y = a \log_{10}(x) + b$ were tested to derive the allometric relationship between Diameter at Breast Height (DBH) and biomass of plant parts. DBH is the independent variable and readily measurable variable that have been used by most of the Studies on biomass estimation in the mangroves (Whittaker and Marks 1975; Ong *et al* 1984; Putz and Chan 1986; Clough and Scott 1989; Gong and Ong 1990; Ketterings *et al* 2001; Mahmood et al., 2008). Significant test of regression equations were tested by using SAS (6.12) statistical software.

3.4. Nutrients in plant components

Sample collection: Sub-samples (about 100 g) smaller and bigger branches, stems and barks were collected randomly from the selected stem of this study. Leaves were also collected randomly as clump. One random sample of leaves consist of one clump, thus each sample minimizes the age effect of leaves in nutrient concentration. All sub-samples of were then oven-dried at 80 °C until constant weight.

Determination of elements in plant parts: Nitrogen, phosphorus, potassium, and carbon concentration in *A. corniculatum* tissue were measured by following different standard methods. The plant samples were acid digested according to Baethgen and Alley (1989) to measure the total nitrogen.

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.

The total concentration of Nitrogen in the sample extract was measured clorometric (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 Distilled water	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

Diluent 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 diluent	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 diluent	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)	Diluent	-
5	2.5	50
10	5	50
15	7.5	50
20	10	50

*Working range 0-50 ppm

Determination of N in the sample extract:

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
df = Dilution factor (times)
fv = Final volume of the digest (ml)
W = Weight of soil/plant taken in digest (g)

3.5. Phosphorus and Potassium in plant components

The plant samples were acid digested to determine total Phosphorus and Potassium according to Allen (1974).

Steps 1

1. Take 0.1 g of plant sample or 0.5 g of soil 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.

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:

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

Potassium concentration in the digested sample extract was measured by Flame Photometer (PFP7, Jenway LTD, England).

3.5. 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 *A. corniculatum* 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.

Chapter-4

Result and Discussion

4.1. Conversion ratio:

The conversion ratio of fresh mass of stem without bark and fresh mass of bark was 0.13±0.01 and the relationship was significant (Figure 1). Moreover , fresh mass to oven dried mass conversion ratios of leaves, smaller braches, bigger branches, bark and stem without bark were found to vary from 0.47 to 0.52 ; and the relationship among their fresh mass and oven-dried mass was significant ($p<0.05$) (Figure 2-6). Woody parts like stem and bigger branches showed higher ratios compared to leaves and smaller branches. Usually leaves and smaller branches contain higher amount of moisture compared to woody parts. This could the reason to observe higher conversion ratios to the woody parts.

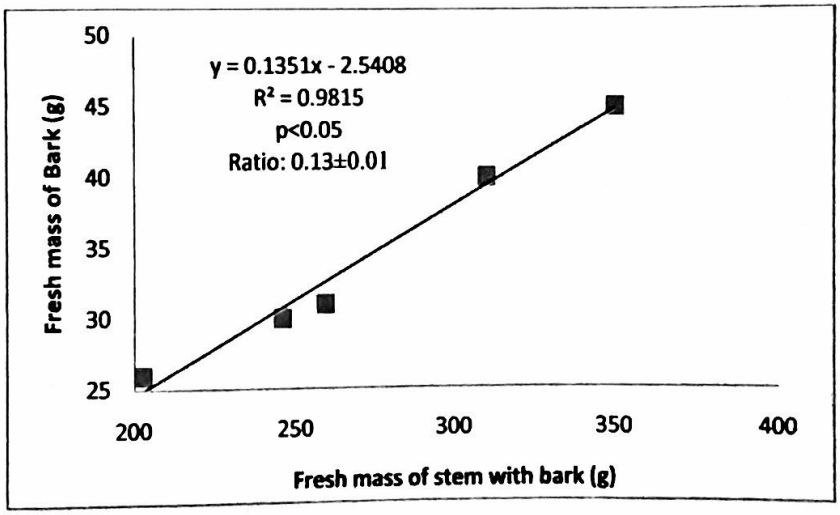


Figure 1: Relationship between fresh mass of stem with bark and fresh mass of bark

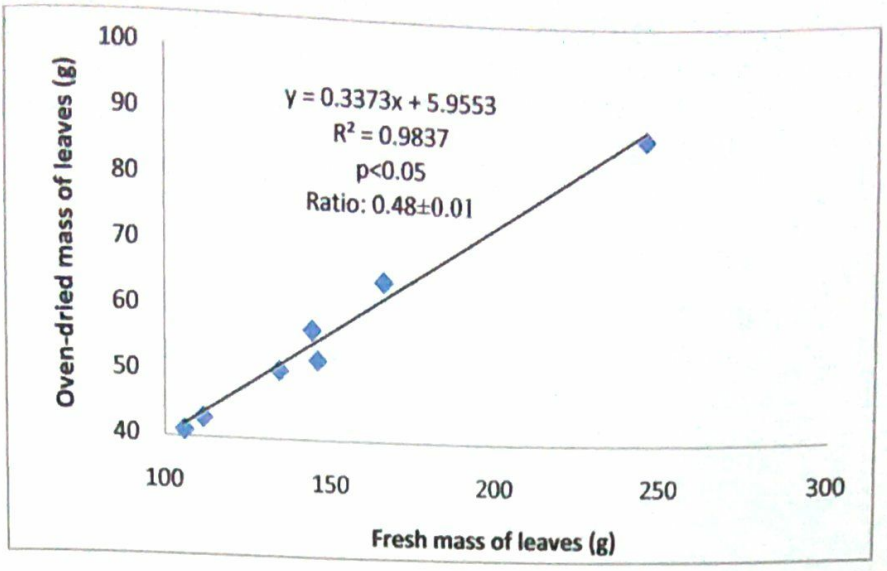


Figure 2: Relationship between fresh mass of leaves and their oven-dried mass

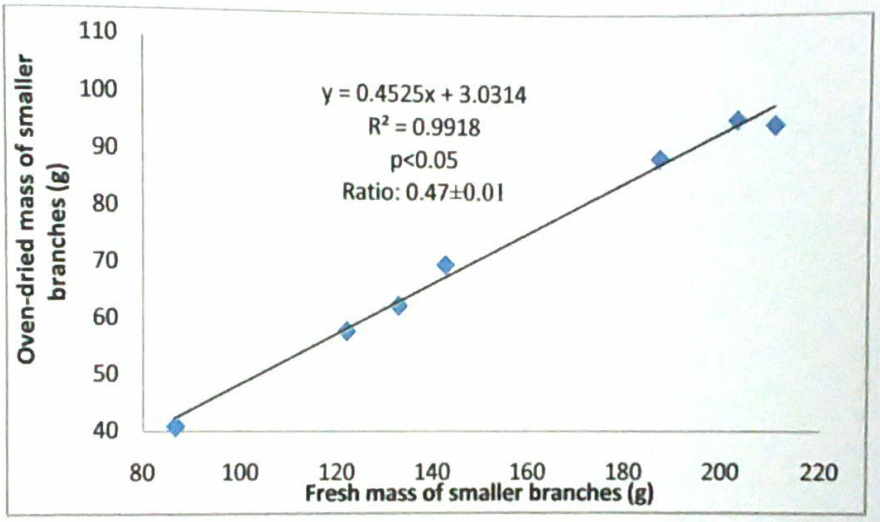


Figure 3: Relationship between fresh mass of smaller branches and their oven-dried mass

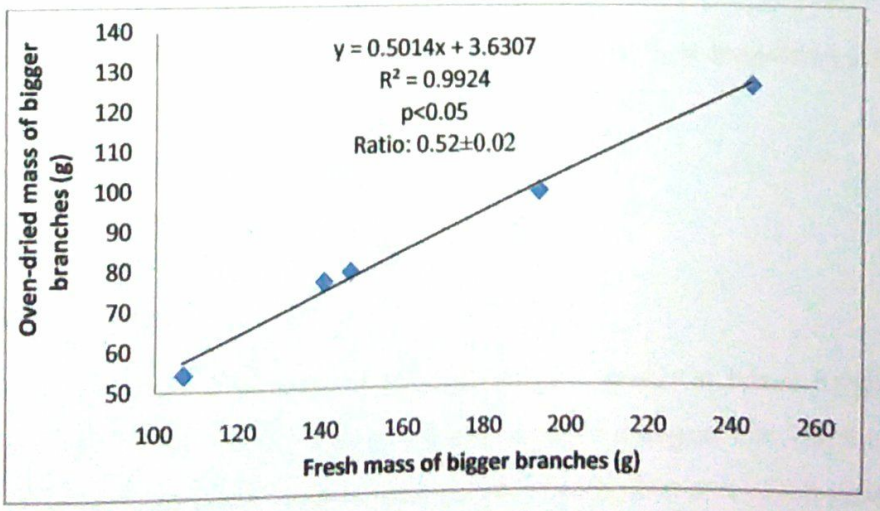


Figure 4: Relationship between fresh mass of bigger branches and their oven-dried mass

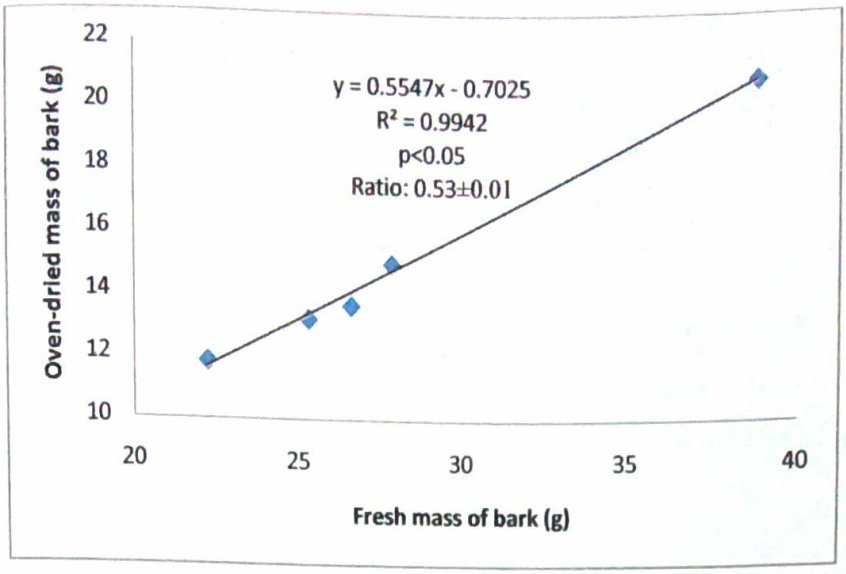


Figure 5: Relationship between fresh mass of bark and their oven-dried mass

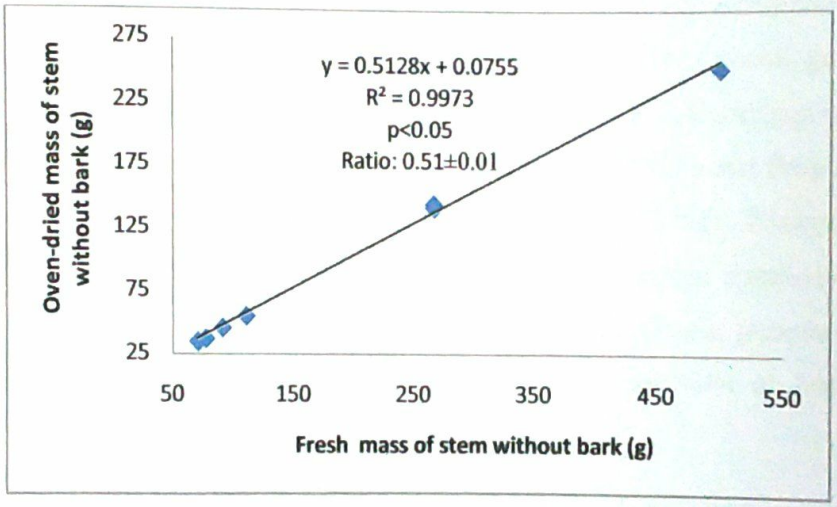


Figure 6: Relationship between fresh mass of stem without bark and their oven-dried mass

4.2. Allometric relationship:

The allometric relation between biomass of plant parts and diameter at breast height (DBH) were tested with $y = ax + b$; $y = a \ln(x) + b$ and $Log_{10}y = a\ Log_{10}x + b$. Ten linear equations with DBH as independent variable were tested for each plant part which yield a total of 50 equations. All the regression equations were significant ($p<0.05$), but highest

R^2 (0.93- 0.99) and F-values and lowest MS_{error} were observed for the equation of $Log_{10}y = a\ Log_{10}x + b$ (Table 2). The best fitted regression equations were obtained by the following equation:

$$Log_{10}\ Biomass = a\ Log_{10}\ DBH + b \qquad (1)$$

Where a and b are the regression constants. However different regression equations were used in biomass estimation of different components of plants. The regression constant a and b with standard error and regression co-efficient R^2 of individual components of plants are presented in table 2.The equation 1 can be written as:

$$Biomass = b_b\ X\ DBH^a \qquad (2)$$

Where a has the same value as in equation (1) and b_b is the antilog of b. The biomass models for different parts of plants were derived from equation (2) and presented at figures 7 to 11. The linear transformation (Equation 1) and the power curve (Equation 2) were found to accept for good description of the relationship between above ground biomass and DBH in different inland forest (Whittaker and Marks 1975; Ketterings et al., 2001) and also in different mangrove species such as *Rhizophora apiculata* and *Bruguiera parviflora* at Matang Mangrove Reserve, Malaysia (Ong et al.,1984), *Rhizophora apiculata* at Pulau Kecil, Malaysia (Putz and Chan, 1986), *Bruguiera gymnorrhiza*, *Bruguiera perviflora*, *Ceriops tagal*, *Rhizophora apiculata* and *Xylocarpus granatum* at Nothern Australia (Clough and Scott, 1989) and *Rhizophora apiculata* at Matang Mangrove Reserve, Malaysia (Gong and Ong, 1990).

Biomass of different parts (stems, branches, leaves, and total biomass) of trees was estimated by using allometric equations. Linear regression method was used to estimate the allometric models (e.g. Snorrason and Einarsson, 2006; Bjarnadottir et al., 2007; Mahmood et al., 2012; Siddiqui et al., 2012). This was done to keep the equation simple. This study tested different linear regression equations with Diameter at Breast Height (DBH) as independent variables (Table 1). Irrespectively, allometric equations for biomass estimation of mangroves commonly use the total height, DBH and Girth at Breast Height (GBH) as independent variables (Cintron and Schaeffer-Novelli, 1985; Clough and Scott, 1989; Ong and Gong, 1990; Mackey, 1993; Soares and Scheffer-Novelli, 2005; Cienciala et al. 2006). However, the allometric equation for stem weight is usually expressed as a function of diameter (Komiyama et al., 2002, Mahmood et al., 2008). Similar findings

were also reported by Soares (1997, 2005). Transformation deforms the variables, potentially introducing bias in the estimation when we go back to the original unit (Baskerville 1972; Beauchamp and Olson 1973). In other words, although they are mathematically equivalent, statistically, they are not so equivalent (Zar, 1968; Payandeh, 1981). To solve the biased-estimate controversy, a correction factor was calculated according to Sprugel (1983). The use of correction factor was supported by Munro (1974), Madgwick and Satoo (1975), Whittaker and Marks (1975). This correction factor is able to reduce approximately 10-20% of the error of estimation (Sprugel, 1983; Baskerville, 1972). The best allometric model 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 and F-value (Table 2). 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; Siddiqui et al., 2012). Conversely, more precise selection of regression equation can be obtained by considering the parameter of estimation values (Ibrahima, 1995; Zar, 1996; Soares and Novelli, 2005). The Best fit regression equations were selected considering the highest R^2 and F-value, with lowest CV, R_{sme}, MS_{error}, S_a, and S_b. The selected allometric models were Log Leaf biomass = 1.52 Log DBH – 1.39; Log Branch biomass = 2.20 Log DBH – 1.48; Log Bark biomass = 2.08 Log DBH – 1.80; Log stem biomass = 2.08 Log DBH – 0.99; Log Total biomass = 2.06 Log DBH – 0.73 (Table 2).

Table 1: Selected ten models for plant parts and total above-ground biomass of Khalshi (*Aegiceras corniculatum)*

1. $y = ax + b$
2. $\sqrt{y} = ax + b$
3. $y = a\sqrt{x} + b$
4. $\sqrt{y} = a\sqrt{x} + b$
5. $y = a\text{Log } x + b$
6. $\text{Log } y = ax + b$
7. $\text{Log } y = a\text{Log } x + b$
8. $y = a\ln x + b$
9. $\text{Ln } y = ax + b$
10. $\text{Ln } y = a\ln x + b$

* x = Diameter at Breast Height

Table 2: *Parameter of estimates of allometric models*

Plant parts	Equation	R^2	a	b	cv	R_{mse}	MS_{error}	S_a	S_b	F value
Leaf	y= ax + b	0.90	0.17	-0.29	32.69	0.21	0.04	0.01	0.07	244.82
	y= a ln(x) + b	0.75	0.82	-0.58	52.13	0.33	0.11	0.09	0.15	79.92
	Log y = a Log_{10} (x) + b	0.93	1.52	-1.39	-29.76	0.12	0.02	0.08	0.06	366.97
Branches	y= ax + b	0.87	0.99	-2.89	56.95	1.44	2.07	0.07	0.49	175.95
	y= a ln(x) + b	0.62	4.48	-4.11	96.43	2.43	5.93	0.68	1.20	43.79
	Log y = a Log_{10} (x) + b	0.94	2.20	-1.48	-263.02	0.17	0.03	0.11	0.08	400.33
Bark	y= ax + b	0.94	0.27	-0.68	31.60	0.26	0.07	0.01	0.09	420.21
	y= a ln(x) + b	0.73	1.30	-1.11	65.94	0.54	0.29	0.15	0.24	75.70
	Log y = a Log_{10} (x) + b	0.99	2.08	-1.80	-14.46	0.07	0.01	0.04	0.03	2394.68
Stem without bark	y= ax + b	0.93	1.77	-4.40	31.60	1.66	2.75	0.09	0.56	420.21
	y= a ln(x) + b	0.74	8.37	-7.15	65.94	3.46	11.98	0.96	1.56	75.70
	Log y = a Log_{10} (x) + b	0.99	2.08	-0.99	19.09	0.07	0.01	0.04	0.03	2394.68
Total above ground	y= ax + b	0.93	3.21	-8.26	34.81	3.21	10.32	0.17	1.09	367.84
	y= a ln(x) + b	0.71	14.97	-12.94	71.43	6.59	43.43	1.83	2.98	66.81
	Log y = a Log_{10} (x) + b	0.98	2.06	-0.73	13.12	0.108	0.01	0.05	0.04	1714.78

* y= Biomass; x = Diameter at Breast Height

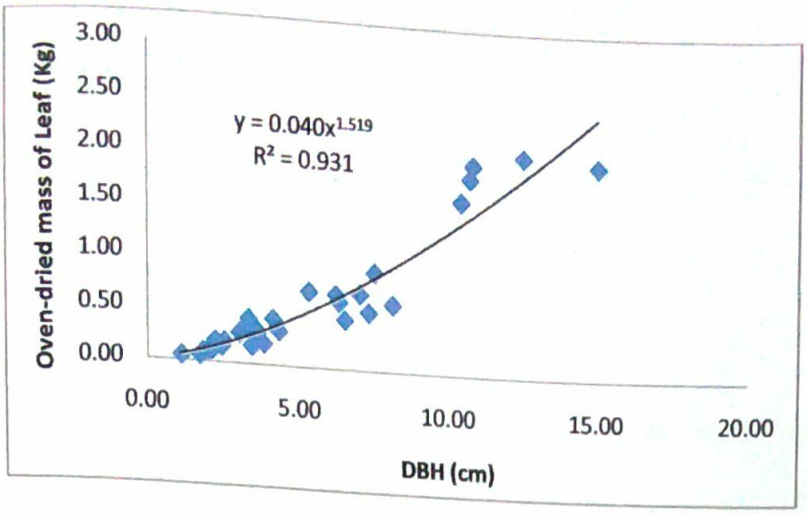


Figure 7: Allometric relationship between diameter at breast height (DBH) and biomass of leaf

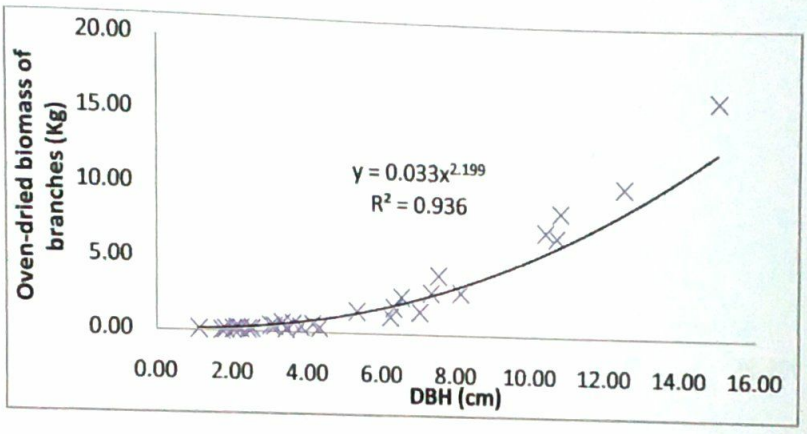


Figure 8: Allometric relationship between diameter at breast height (DBH) and biomass of branch

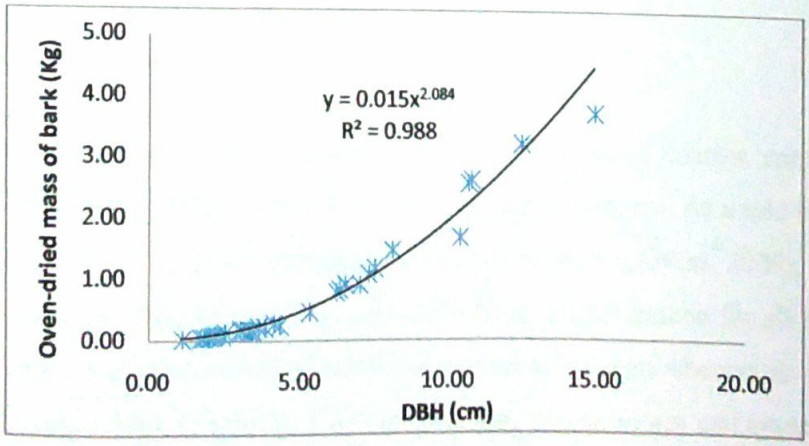


Figure 9: Allometric relationship between diameter at breast height (DBH) and biomass of bark

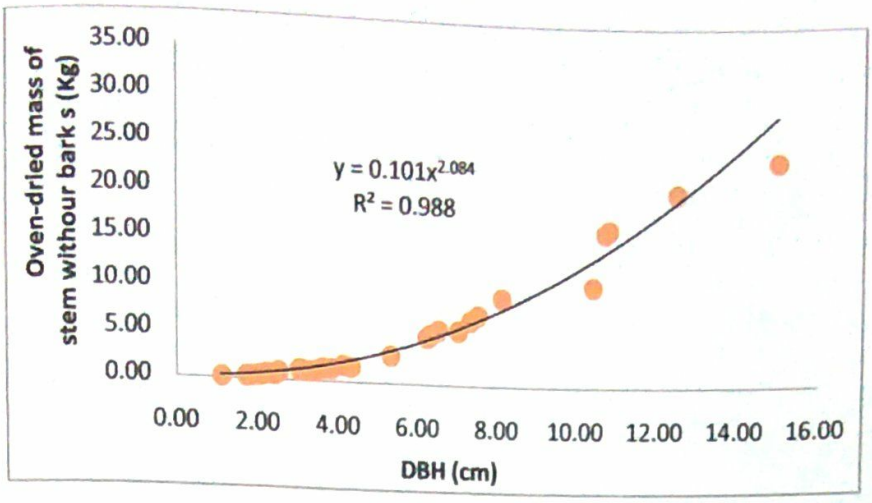


Figure 10: Allometric relationship between diameter at breast height (DBH) and biomass of stem without bark

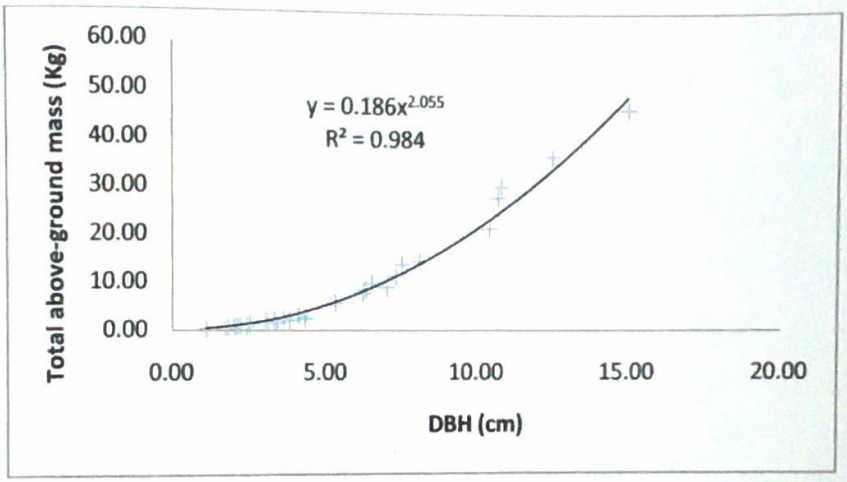


Figure 11: Allometric relationship between diameter at breast height (DBH) and total above-ground biomass

4.3. Nutrients in plant parts:

Based on carbon content analyses, we know that average of carbon content varies (from 43.10% to 48.59%) among different parts of *A. corniculatum* of biomass. As a rule of thumb, it is assumed that 50% of dry wood biomass corresponds to carbon (West, 2009), in IPCC (2006) the values for the tropics range from 46%-49% being most common for all trees dbh >10 cm. Comparatively higher amount of carbon was observed in stem whereas as the lower content was observed in bark (Table 3). This variation may be due to age and types of plant parts.

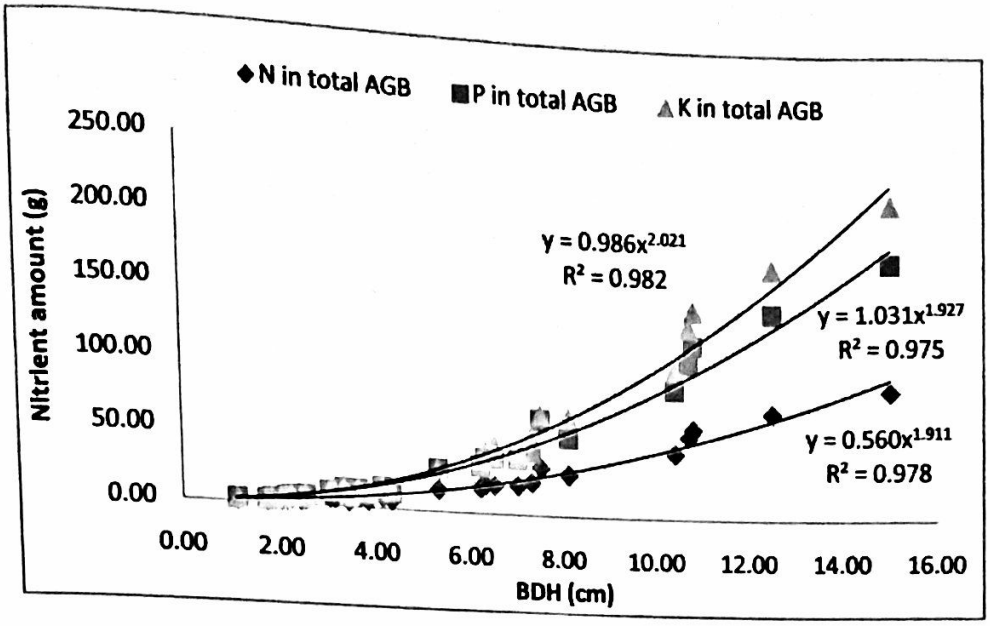
Table 3: Nutrients (N, P and K) and carbon concentration in different parts of Khalshi (*Aegiceras corniculatum)*

Plant Parts	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassum (mg/g)	Carbon (%)
Leaf	6.40±0.08	10.44±0.26	6.50±0.07	45.97±0.06
Smaller Branch	3.29±0.10	8.31±0.06	6.05±0.07	47.59±0.20
Bigger Branch	1.52±0.08	4.10±0.20	4.69±0.08	48.22±0.03
Bark	1.97±0.05	3.09±0.15	6.50±0.14	43.10±0.11
Stem without bark	1.60±0.08	2.64±0.06	4.26±0.07	48.59±0.17

Table 4: *Parameter of estimate of allometric models for nutrients (N, P and K) and Carbon in total above-ground biomass of Khalshi (Aegiceras corniculatum)*

Nutrients	**Equation**	**R^2**	**a**	**b**	**cv**	**R_{mse}**	**MS error**	**S_a**	**S_b**	**F**
Nitrogen	Log y = a Log_{10}(x) + b	0.98	1.91	-0.25	8.70	0.09	0.01	0.05	0.04	1234.52
Phosphorus	Log y = a Log_{10} (x) + b	0.97	1.93	0.01	7.44	0.09	0.01	0,06	0.04	1046.24
Potassium	Log y = a Log_{10} (x) + b	0.98	2.02	-0.01	6.24	0.08	0.01	0.05	0.04	1529.78
Carbon	Log y = a Log_{10} (x) + b	0.98	2.06	-1.05	29.18	0.08	0.01	0.05	0.04	1683.76

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



*AGB = Total Above-ground Biomass

Figure 12: Allometric relationship between diameter at breast height (DBH) and amount of Nitrogen, phosphorus and Potassium in total above-ground biomass

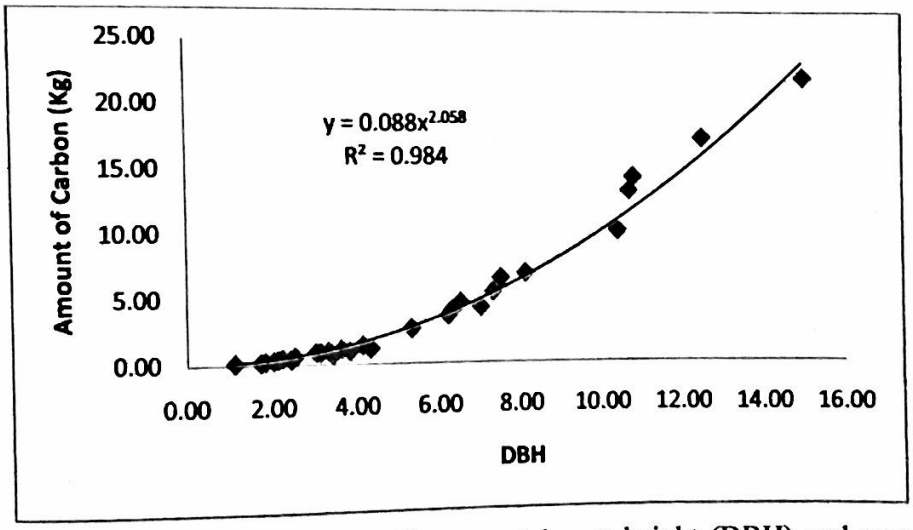


Figure 13: Allometric relationship between diameter at breast height (DBH) and amount of carbon in total above-ground biomass

Nutrients (N, P and K) concentration significantly (ANOVA, $p<0.05$) varied among the plant parts and comparatively higher concentration of nutrient was observed in leaf whereas as the lower content was observed in stems (Table 4). Similar result was observed by Binkley

(1986) in case of nitrogen. The 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 components (Mahmood et al., 2003). In the present study the trend of nitrogen, phosphorus and potassium in *A. corniculatum* was similar to that of *C. decandra* (Mahmood et al. 2012), *Rhizophora apiculata* (Ong et al., 1984), *Avicennia* spp., *Bruguiera* spp. and *Ceriops* spp (Aksornkoae and Khemnark, 1984) and *B. parviflora* (Mahmood et al., 2003) in different mangrove forests (Table 5). From the above comparison, it was revealed that different mangrove species might have different rate of nutrient uptake and distributional pattern in their parts, which may have been also site and species specific.

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	

Species	Plant parts	Nutrients (mg/g)			Sources and Location
		N	P	K	
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	
	Branches	5.4	1.5	8.5	
	Stems	6.8	0.7	2.1	
	Roots	4.4	1.6	12.6	
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	

The element content in the plant parts and total above-ground biomass were calculated and allometric equations were developed for total above-ground element content. All the equations were significant ($p<0.05$) and the value of co-efficient of determination (R^2) varied from0.97 to 0.98 for Nitrogen, Phosphorus, Potassium and Carbon. The selected 5 allometric models were, Log N = 1.91 Log DBH - 0.25; Log P = 1.93 Log DBH + 0.01; Log K = 2.02 Log DBH - 0.01; Log C = 2.06 Log DBH – 1.05 (Table 4).

Refferences

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

Allen, S.E., 1974 Chemical analysis of ecological materials. Blackwell Scientific publication, Oxford.

Allen, S.E., 1989. Chemical analysis of ecological materials. 2nd edn. Blackwell Scientific Publications, Oxford.

Baethgen, W.E., Alley, M.M., 1989. A manual colorimetric procedure for measuring ammonium nitrogen in soil and plant Kjeldahl digests. Commun. Soil Sci. Plant Anal, 20 (9&10): 961-969.

Bjarnadottir, B., Inghammar, A.C., Brinker, M.M., Sigurdsson, B.D., 2007. Single tree biomass and volume functions for young Siberian larch trees (Larix sibirica) in estern Iceland. Icelandic Agricultural Sciences, 20:125-135.

Baskerville, G.L., 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J For. Res, 2: 49-53.

Beauchamp, J.J., Olson, J.S., 1973. Corrections for bias in regression estimates after logarithmic transformation. Ecology, 54(6): 1403-1407.

Binkley, D., 1986. Forest Nutrition Management. John Wiley & Sons, New York.

Cintron, G., Novelli, S.Y., 1984. Methods for studying mangrove structure. In The mangrove ecosystem: research methods, ed. C.S. Snedaker and J.G. Snedaker, pp 91-113. United Kingdom: Unesco.

Corncr, B. D.. and J. T. Richtsmeier, 1991. Morphornetric analysis of craniafacial growth in C'rhus. American Journal of Physical Anthropology, 84:33-342.

Cienciala, E., Černý, M., Tatarinov, F., Apltauer, J., Exnerová, Z., 2006. Biomass functions applicable to Scots pine. Trees, 20: 483–495.

Clough, B.F., Attiwill, P.M., 1975. Nutrient cycling in a community of Avicennia marina in a temperate region of Australia. In: Walsh, G.E., Snedaker, S.C., Teas, H.J. (Eds.), Proceedings of the International Symposium on the Biology and Management of Mangroves, vol. I. Institute of Food and Agricultural Sciences. University of Florida, Gainesville, FL, pp. 137-146.

Clough, B.F., Scott, K., 1989. Allometric relationships for estimating aboveground biomass in six mangrove species. Forest Ecol. Manage, 27: 117– 127.

Clough, B.F., Dixon, P., Dalhaus, O., 1997. Allometric relationships for estimating biomass in multi-stemmed mangrove trees. Aust. J. Bot, 45: 1023–1031.

Cock. A. G., 1966. Genetical aspects of metrical growth and form in animals. Quartcrly Review of Biology, 41:131-190.

Duke, N.C., 2006. Australia's Mangroves. The authoritative guide to Australia's mangrove plants. University of Queensland, Brisbane.

Federer CA, Hornbeck JW, Tritton LM, Martin CW, Pierce RS, Smith CT, 1989. Long-term depletion of calcium and other nutrients in eastern US forests. Environ Manag, 13:593–601.

Gong, W.K., Ong, J.E., 1990. Plant biomass and nutrient flux in a managed mangrove forest in Malaysia. Estuarine, Coastal and Shelf Science, 31: 519-530.

Giinther, B., 1975. Dimensional analysis and theory of biological similarity. Physiological Reviews, 55:659-699.

Gould. S. J. 1966. Allometry and size in ontogeny and phylogeny. Biological Reviews, 41:587440.

Gould, S. J., 1975. Allomctry in primates, with emphasis on scaling and the evolution of the brain. Contributions to Primatology, 5:244-292.

Hansen, E.A., Baker, J.B., 1979. Biomass and nutrient removal in short-rotation intensively cultured plantations. In: Proceedings of the Symposium on Impact of Intensive harvesting on Forest Nutrient Cycling. SUNY-ESF, Syracuse, NY, pp. 130–151

Heald, E., 1969. The production of organic detritus in a south Florida estuary. PhD thesis, University of Miami, Coral Gables, FL, 111 pp.

Hornbeck, J.W., Smith, C.T., Martin, C.W., Tritton, L.M., Pierce, R.S., 1990. Efects of intensive harvesting on nutrient capitals of three forest types inNewEngland. For EcolManag, 30:55–64.

Huxley, J. S., 1932. Problems of relative growth. Lincoln Mac Veagh—The Dial Press, New York.

Huxley, J. S., and G. Teissier, 1936. Terminology of relative growth. Nature, 137:78&781.

Ibrahima, S., 1995. Estimating branchwood biomass of a tropical hillforest stand. Biore. Tech, 52 (1): 53-57.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories. Vol. 4: Agriculture, Forestry and Other Land Use. Eggleston S, Buendia L, Miaw K, Ngara T, Tanabe K (eds). Intergovernmental Panel on Climate Change (IPCC), IPCC/IGES, Hayama, Japan, 83 pp.

Janssonius, H. H., 1950. The vessels in the wood of Javan mangrove trees. Blumea, 6: 465–469.

Komiyama, A., Havanond, S., Srisawatt,W.,Mochida, Y., Fujimoto, K., Ohnishi, T., Ishihara, S., Miyagi, T., 2000. Top/root biomass ratio of a secondary mangrove (Ceriops tagal (Perr.) C. B. Rob.) forest. Forest Ecol.Manage, 139: 127–134.

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.

Komiyama, A., Poungparn, S., Kato, S., 2005. Common allometric equations for estimating the tree weight of mangroves. J. Trop. Ecol, 21: 471–477.

Ketterings, Q.M., Noordwijk, C.M.Y., Ambagau, R., Palm, C.A., 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. For. Ecol. Manage, 146: 199–209.

LaBarbcra, M., 1989. Analyzing body size as a factor in ecology and evolution. Annual Review of Ecology and Systematics, 20:97-117.

Lin, P., 1988. Mangrove vegetation. China Ocean Press, Beijing, pp. 16–27.

Morrison IK, Foster NW (1979) Biomass and element removal by complete-tree harvesting of medium rotation forest stands. In: Proceedings of the Symposium on Impact of Intensive Harvesting on Forest Nutrient Cycling. SUNYESF, Syracuse, NY, pp. 111–119.

Mahmood, H., Saberi, O., Japar Sidik, B., Misri, K., 2003. Macronutrients status of seedlings, saplings and trees of *Bruguiera parviflora* Wight & Arn., at Kuala Selangor Nature Park mangrove forest, Malaysia. Khulna Univ. Stu, 5 (1): 15-20.

Mahmood, H., 2004. Biomass, Litter Production and Selected Nutrients in *Bruguiera Parviflora* (Roxb.) Wight & Arn. Dominated Mangrove Forest Ecosystem at Kuala Selangor, Malaysia. PhD thesis, University Putra Malaysia, Malaysia, unpublished.

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. Wetl. Ecol. Manag, 20: 539-548.

Mahmood, H., 2013. Carbon pools and fluxes in *Bruguiera parviflora* dominated naturally growing mangrove forest of Peninsular Malaysia, Wetl. Ecol. Manag, DOI 10.1007/s11273-013-9318-2.

Odum, W.E., 1970. Pathways of energy flow in a South Florida estuary. PhD thesis, University of Miami, Florida, 162 pp.

Odum, W.E., Heald, E.J., 1972. Trophic analysis of an estuarine mangrove community. Bulletin of Marine Science, 22: 671-738.

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

Ong, J.E., 1993. Mangroves—a carbon source and sink. Chemosphere, 27: 1097–1107.

Ong, J.E., Gong, W.K., Clough, B.F., 1995. Structure and productivity of a 20- year-old stand of Rhizophora apiculata B1 mangrove forests. J. Biogeogr, 22: 417–427.

Ong, J.E., Gong, W.K., Wong, C.H., 2004. Allometry and partitioning of the mangrove, Rhizophora apiculata. Forest Ecol. Manage, 188: 395–408.

Panshin, A. J., 1932. An anatomical study of the woods of the Philippine mangrove swamps. Philipp. J. Sci, 48: 143–205.

Payandeh, B., 1981.Choosing regression models for biomass prediction equations. The For. Chro, 57: 229-232.

Roome, Talat; Dar, Ahsana; Naqvi, Sabira; Choudhary, M. Iqbal, 2011. Evaluation of antinociceptive effect of Aegiceras corniculatum stems extracts and its possible mechanism of action in rodents. *Journal of Ethnopharmacology,* **135** (2): 351–358.

Putz, F. E., Chan, H.T., 1986. Tree growth, dynamics and productivity in a mature mangrove forest in Malaysia. Forest Ecology and Management, 17: 211-230.

Santa, Regina, I., 2000. Biomass estimation and nutrient pools in tour Quercus pyrenaica in Sierra de Gata Mountains, Salamanca, Spain. For Ecol Manag, 132:127–141.

Siddiqi, N.A., 2001. Mangrove Forestry in Bangladesh.Institute of Forestry & Environmental Science, University of Chittagong, Chittagong, 201pp.

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. J. For. Res, 23 (1): 23-28.

Snorrason, A., Einarsson, S.F., 2006. Single-tree biomass and stem volume functions for eleven tree species used in Icelandic forestry. Icelandic Agri. Sci, 19:15-24.

Soares, M.L.G., Schaeffer-Novelli, Y., 2005. Above-ground biomass of mangrove species. I. Analysis of models. Estu. Coast. Shelf Sci, 65: 1-18.

Soares, M.L.G., 1997. Estudo da biomassa ae´rea de manguezais do sudeste do Brasil e ana´ lise de modelos, vol. 2. PhD thesis, Instituto Oceanogra´ fico, Universidade de Sa˜o Paulo, Brazil.

Sprugel, D.G., 1983. Correcting for bias in log-transformed allometric equations. Ecology, 64 (1): 209-210

Steinke, T.D., Ward, C.T., Raijh, A., 1995. Forest structure and biomass of mangrove in the Mgemi estuary, South Africa. Hydrobiologia, 295 (1-3): 159-166.

Suzuki, E., Tagawa, E., 1983. Biomass of a mangrove forest and a sedge marsh on Ishigaki Island, south Japan. Jpn. J. Ecol, 33: 231–234.

Tamai, S., Nakasuga, T., Tabuchi, R., Ogino, K., 1986. Standing biomass of mangrove forests in southern Thailand. J. Jpn. Forest Soc, 68: 384–388.

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.

Timothy, R.P., Yoshiaki, M., Carol, M.L., 1984. A maual of chemical and biological methods for seawater analysis. Pergamon press, Oxford.

Tomlinson, P.B., 1986. The Botany of Mangrove. Cambridge University Press, Cambridge, pp. 419.

Tritton, L.M., Martin, C.W., Hornbeck, J.W., Pierce, R.S., 1987. Biomass and nutrient removals from commercial thinning and whole-tree clear cutting of central hardwoods. Environ Manag, 11:659–666.

West, P.W., Wells, K.F., 1990. Estimation of leaf weight of standing *trees* of *Eucalyptus regnans*. Cana. J. For. Res, 20 (11): 1732-1738.

White, E.H., 1974. Whole-tree harvesting depletes soil nutrients. Can J For Res, 4:530–535.

Whittaker, R.H., Marks, P.L., 1975. Methods of assessing terrestrial productivity, In: Primary Productivity of the Biosphere, H. Lieth and R.H. Whittaker (eds.). Springer Verlag, pp. 55-118.

Zar, J.H., 1968. Calculation and miscalculation of the allometric equation as a model in biological data. Bioscience, 18:1118-1120.

Zar, J.H., 1996. Biostatistical Analysis. Prentice Hall, Upper Saddle River, NJ.