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# Development of Allometry Biomass Model Equation of *Aquilaria Malanccencis* Lam. (Agar) by Using Biomass Expansion Factor

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JULY 2018

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## Development of Allometry Model of *Aqualaria Malanccencis* Lam. (Agar) by Using Biomass Expansion Factor

## Course Title: Project Thesis

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*[This thesis paper has been prepared for the partial fulfillment of the requirements of Four Years B.Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh]*


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## Approval

This is to Certify, Md. Farhad Hosen, ID 140537 has prepared this thesis entitled **"Development of Allometry Model of *Aqualaria Malanccencis* Lam. (Agar) by Using Biomass Expansion Factor"** under my direct supervision and guidance. I do here by approve the style and content of the thesis. This thesis has been prepared in partial fulfillment of the requirements for the 4-years professional B.Sc. (Hons.) degree in Forestry.


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# DECLARATION

I, **Md. Farhad Hosen**, declare that this thesis is the result of my own work and it has not been submitted or accepted for any degree to other university or institution.

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**Signature**

Farhad
............25/10/18............

**Md. Farhad Hosen**

DEDICATED

TO

MY BELOVED PARENTS

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## Acknowledgement

All praises are to the Supreme Being, creator and justice of the universe, whose mercy keeps us alive and enables us to pursue my education in Forestry and Wood Technology Discipline and complete the thesis work for the completion of B.Sc. (Hon's) in Forestry.

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**Md. Farhad Hosen**

# ABSTRACT

*Aquilaria malaccencis* Lam. is an important commercial species in our country that is found to grow in Chittagong and Chittagong Hill tracts and the greater Sylhet region. Biomass is the over dried weight of organic matter that can be found in ecosystem at any given time. This include both live and dead vegetation material. Biomass estimation can be done in two ways by allometry equation or by using biomass expansion factor. In this study objective to derive allometry model for crown, stem and total above ground biomass (TAGB) using biomass expansion factor. The best allometric model was selected based on AIC (Akaike information Critrien), RSE (Residual standard error), $R^2$ (Coefficient of determination) and VIF (Variance influential factor. However, the best fit Crown biomass model was crown biomass=exp(-0.60305+0.42793*ln($D^2H$). and the best fit steam biomass model was steam biomass=exp (-3.248321+1.7909698*ln (DBH)+0.9763264*ln(H). While the best fit TAGB model was TAGB=exp (-1.912097+1.593657*ln (DBH) +0.6151991*ln (H). Those mode was selected on the best on AIC (Akaike Information Critrien), RSE (Residual Standard error), $R^2$(Coefficient of determination) and VIF (Variance influential factor). Model Prediction Error (MPE), Model Efficiency (ME), Root Mean Square Error (RMSE) and percentage of error were used to compare among the derive model and pan tropical model. We have also use 1:1 regression analysis for estimating over and underestimation using the derived model. Our best TAGB model showed lowest MPE=1.533, lowest RMSE=1091.671, lowest percentage of error -0.758 and highest ME=0.996 and 1:1 regression line also showed very law underestimation, which indicated best compared to the pan tropical model.

# Chapter 1

# Introduction

## 1.1 Introduction

The *Aquilaria malaccensis* Lam. (Agar) tree is a well-known important agar wood-producing genus, which is native to Bangladesh (Lee and Mohamed, 2016). It is a precious non-timber product of tropical tree origin (Rasool and Mohamed, 2016). In the past, agar tress naturally grows in the forests of greater Sylhet, Chittagong and Chittagong Hill Tracts of Bangladesh (Baksha et al., 2009). Agar is a highly priced product which can be used in fragrance, incense, medicines aromatherapy and religious ceremonies. Agar (*Aquilaria malaccensis)* is one of the most promising non-timber forest products (NTFPs) of Bangladesh, earned Tk. 300 million through exports of *attar* (agar oil) in 2004 (Hayder et al., 2005). About 25,000-30,000 workers were engaged in cultivation, collection, processing and marketing of agar and agar-based products in the country (Baksha et al., 2009).

Despite the huge demand of Agar in local and international markets, no major extension program has so far conducted by Governments or other agencies in Bangladesh. The Forest Department (FD) raised some agar plantations in the denuded and encroached forest areas of Chittagong, Sylhet, Chittagong Hill Tracts (Rangamati, Khagrachari and Bandarban hill districts) and Cox's Bazar districts. There are also some privately-owned agar plantations in the north-east, particularly in Maulvibazar district where many families have been engaged in production and marketing of agar and agar-based secondary products for several decades (Uddin et al., 2008). Bangladesh has favorable weather to produce agar and this is why it can be promoting agar cultivation by developing agar sector. According to Bangladesh Forest Research Institute (BFRI), Bangladesh can earn more than Tk 100 crore annually by developing agar wood sector and exporting agar products abroad (Baksha et al., 2008).

With the increasing demand for agar wood, the population of *Aquilaria* species is declining rapidly in the wild, and all species of Aquilaria have been placed on the Appendix II list of the

Convention on International Trade in Endangered Species. In response to this situation, sustainable planting and management of agar wood with artificial methods are arising, and the agar wood yield is increasing. As a result, agar wood is no longer needs to be obtained from wild natural resources, enabling its wider application and investigation, especially on pharmaceutical study. Based on the phytochemical studies, several new compounds have been isolated and identified from agarwood and Aquilaria plants. However, there is no literature concentrating on the how much amount biomass losses during agar harvesting in every year. We should measure the biomass concentration as reducing emissions from deforestation and forest degradation (REDD+) is becoming an important mechanism for conserving forests and protecting biodiversity (Mukul et al., 2014).

Estimates of tree biomass are useful in assessing forest structure and condition (Chavé et al., 2003); forest productivity, carbon stocks and fluxes based on sequential changes in biomass; sequestration of carbon in biomass components; i.e., wood, leaves, and roots and they can be used as an indicator of site productivity. Several biomass-prediction equations are available for tropical tree species but those are common not suitable for estimation biomass of species specific and regional (Brown et al., 1989). That's why we need species specific biomass equation for estimation of Total biomass of a species

## 1.2 Objective

The objective of this study is to develop biomass expansion factor and allometric biomass model for *Aquilaria malaccensis*.

# Chapter 2

# Literature Review

## 2.1. Species distribution

*Aquilaria malaccensis*is the main species of the commerce and chiefly distributed in 10 countries: Bangladesh, Bhutan, India, Indonesia, Iran, Malaysia, Myanmar, Philippines, Singapore and Thailand (Oldfield et al., 1998). In India it is confined to the north east region of India and mostly distributed in the foot-hills of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and West Bengal (Asian regional workshop, 1997). Recently, natural population of the species has been reported existing in pockets in Assam and Arunachal Pradesh (Tabin et al., 2012). Earlier, this species was mainly reported from the hills and forests of Arunachal Pradesh, Nagaland, Manipur, Mizoram, and Tripura as well as in West Bengal (Palit, 1996). In Arunachal Pradesh, it is found under natural conditions and distributed in the rocky terrain forests of Changlang, Lower Dibang Valley, Lohit and Papum Pare district (Tabin, 2012).

In Bangladesh The Forest Department (FD) raised some agar plantations in the denuded and encroached forest areas of Chittagong, Sylhet, Chittagong Hill Tracts (Rangamati, Khagrachari and Bandarban hill districts) and Cox's Bazar districts. There are also some privately-owned agar plantations in the north-east, particularly in Maulvibazar district where many families have been engaged in production and marketing of agar and agar-based secondary products for several decades (Uddin et al., 2008).

## 2.2 Soil and environmental suitability for agar cultivation in Bangladesh

*Aquilaria* species grows naturally in all ecological zones and on a variety of soils under wide climatic condition (Table 1), including those that are rocky, sandy or calcareous, well-drained slopes and ridges and land near swamps. However, significant mortality rate was reported 3 - 4 years after plantation in Kaiyachara Tea Estate, Fatikchari seemingly due to water logging

(Akter and Neelim, 2008). Planting on sloping land is thus recommended for agar (Jansen, 2003). The precipitation normal in Sylhet division ranges from 2351 mm to 4048 mm (Talucder *et al.*, 2015). In addition, average temperature and soil condition are also well suited for agar cultivation in this region. *Aquilaria*i s first growing trees and in areas with adequate moisture, can achieve 10 cm DBH in 4 to 6 years (Blanchette *et al.*, 2015). They are especially suited for the hill ecosystem of northeastern India. In Assam, as well as in Northern Bangladesh around the Sylhet area, *Aquilaria* have been successfully planted in plantations (Blanchette et al., 2015).

## 2.3. Importance of the species

*A. malaccensis* is known to be one of the most important species of commerce and valued for its production of impregnated resinous heart wood that gives fragrance (Anonymous, 1948). Agar wood is highly demanded for medicine, incense and perfumes across Asia and the Middle East. It is medicinally used as stimulant tonic and diuretic. The plant is being used to treat small pox, rheumatism, illness during and after childbirth; to relieve spasms especially in the digestive and respiratory systems, abdominal pain, asthma, cancer (used as a general tonic), colic, chest congestion, diarrhea, hiccups, nausea, nerves and treatment of regurgitation (Burkill, 1966; Chakrabarty et al., 1994; Kim et al., 1997; Barden et al., 2000; Bhuiyan et al., 2009). The plant is also reported to possess remarkable anti-cancer activity (Gupta et al., 1994, 1995). In Egypt, Arabia and throughout the northeast part of Bangladesh, agarwood is described as a stimulant, cardiac tonic and carminative (Bhuiyan et al., 2009). It is used as a traditional sedative, analgesic and digestive medicine in traditional Chinese and Japanese medicine (Abdullah et al., 2007; Liu et al., 2008). It bears acrid, bitter, warm, aromatic properties and plays an important role in incense and perfume industries too. It has been used for centuries as incense in Buddhist, Hindu and Islamic ceremonies (Naef, 2011).

## 2.4. Agar plantation in Bangladesh

Table 1 presenting about the *Aquilaria malaccensis* plantation in Bangladesh and its management body along with plantation time. Almost 3000 hectares *Aquilaria malaccensis* plantation have been done throughout the Bangladesh, in where, privately own agar plantation in Sylhet clicked the highest area than another plantation which covers roughly 1500 hectares.

Table 1: Total area under *Aquilaria malaccensis* plantation

| Location | Area (ha) | Management Body | Time | Reference |
|---|---|---|---|---|
| Kaiyachara Tea Estate, Fatikchari | 6.9 | The Bangladesh Rural Advanced Committee | July 2007 | Akter and Neelim (2008) |
| Karnafuli tea estate | 0.6 | BRAC | 2004 | Akter and Neelim (2008) |
| Buffer zone of the Kaptai National Park | 283 | Participants of social forestry programe | 2007-2012 | Rahman (2013) |
| Charaljani and Keochia research stations in Chittagong | 2.3 | Bangladesh Forest Research Institution (BFRI) | | Rahman et al. (2015) |
| Government agar garden in Denuded forest areas of Sylhet, Chittagong and CHTs | 1217 | Forest Department (FD) | | |
| 121 Privately owned agar garden in Sylhet Division | >1500.0 | Private owner | 1999-2011 | Novel (2017) |

## 2.5. Biomass

Biomass is the components of the biota in the form of organic matter. The Biomass of a tree might be characterized as "the total amount of woody parts of shrubs, bushes or trees parts like branches, twigs, bark and stem, alive or dead without root, seed and stump" or biomass is the total dry weight of the all components of trees expressed as ton $ha^{-1}$ (FAO, 1997)". The Biomass Expansion Factor (BEF) is "the ratio of total oven dry above ground biomass density of a tree with a specific diameter at breast height (DBH) to the oven dry biomass density of the inventoried volume (FAO, 1997)" The estimation of biomass and carbon stocks of a forest based on inventory data can be figure out by using the allometric equation or by using BEF (Kim et al. 2011). To report carbon stock and change in carbon stock a constant BEF of forest is used but the constant value of BEF is not applicable because the value of BEF varies with forest stand, site age and other biotic and a biotic factor (IPCC, 2003).

## 2.6. Biomass Expansion factor

Biomass expansion factor (BEF) defined as "the ratio of aboveground oven-dry biomass of trees to oven dry biomass of inventoried volume.

BEF was calculated as;

$BEF=W_{aboveground}/W_{bole}$

where, BEF=biomass expansion factor

$W_{crown}$= tree crown dry weight (kg), composed of foliage, thick and thin branches.

$W_{bole}$= tree bole dry weight (kg)

$W_{avobeground}=W_{crown} + W_{bole}$(kg).

## 2.7. Allometric equation

The "Allometric, Biomass and Carbon factors" database was designed to facilitate the estimation of the biomass carbon stocks of forests in order to support the development and the verification of greenhouse gas. Global analyses have recently shown that allometric relationships between height and diameter for tropical trees vary with geographic location (Feld et al., 2011). In addition, location within a specific continent has been found to explain almost 50% of variations in tree allometry (Banin et al., 2012).

Recently, pan tropical allometric equations have been commonly used across the globe to estimate the aboveground biomass of the forests, However, in relation to regional differences in diameter, height and wood density, the lack of data measured, may raise the question on accuracy of pan tropical allometric that's why species specific allometry model are needed. (Alvarez et al., 2012; Nam et al., 2014).

**Figure 1: World distribution of *Aqualaria malaccencis*;** Source: Tharanathan et al. (2007)

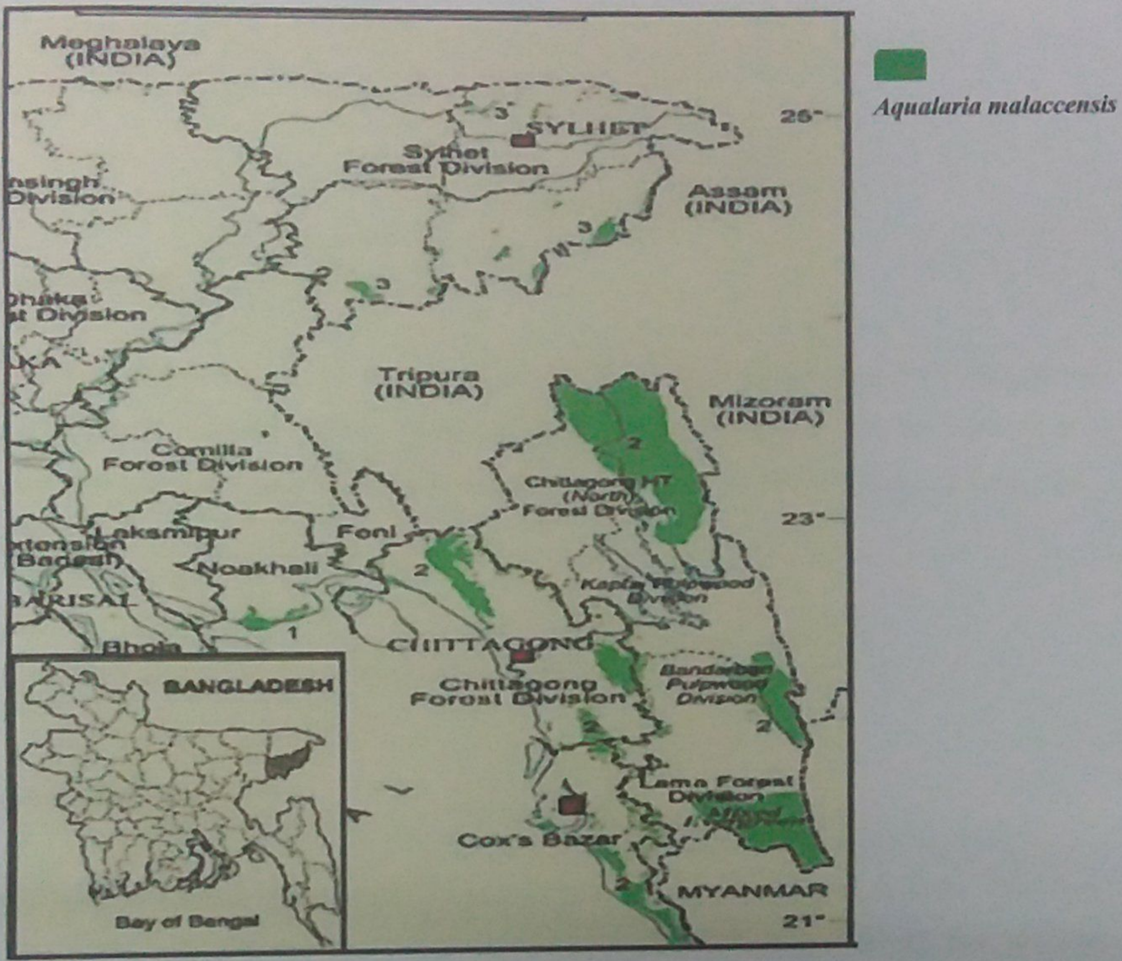


**Figure 2**: Distribution of *Aqualaria malaccensis* in Bangladesh. Source: Uddin et al. (2008)

# Chapter 3

# Materials and methods

## 3.1. Data source

We use 250 individual volume data of Agar tree. This data was collected from Bangladesh Forest Research Institute (BFRI). BFRI has used this data to prepare volume table of this species. The collected data contained sample tree diameter at Breast height (DBH), Total height (H) and steam volume of everyone.

## 3.2. Development of biomass expansion factor

### 3.2.1. Selection of sample tree

I have selected 15 individuals' tree. The plantation of this species at Moulavibajar. The DBH and TH of the selected tree were 14.48 cm to 38.61 cm and 6.50 m to 21 m. The tree was selected properly avoiding disease and not affected by human cutting.

### 3.2.2. Measurement of sample tree

DBH and total height of the selected trees were recorded and felled at the ground level. The felled trees were separated into stem, bigger branches and smaller branches. The fresh weight of each part of the felled tree was measured separately in the field.

### 3.2.3. Development of branch allometry.

Smaller branches of each species were taken immediately for laboratory processing to get fresh to oven-dry (80 °C) weight conversion ratio. This conversion ratio was used to estimate the oven-dry biomass of the sampled trees. Then Ln transportation of oven dry weight of leaf smaller branches other woody parts were taken for get correction factor (Taeroe et al., 2015).

#### 3.2.4. Estimation of tree biomass

We get steam biomass multiplying steam volume and wood density.

Steam biomass = steam volume * wood density.

Branch biomass= Bigger branch volume * wood density.

Total biomass=stem biomass +bigger branch biomass + smaller branch biomass.

#### 3.2.5 Biomass expansion factor

The biomass expansion factor refers to the ratio of the biomass of stem, foliage`s, branches and twigs to main stem/bole volume, i.e. BEF is equal to the aboveground biomass divided by the volume of stem expressed by the following equation.

$$BEF = W / V$$

Where W is the dry weight of all the components of the tree above the ground in kilograms while V refers to the volume of main stem/bole in meter cube (Lehtonen et al., 2004).

### 3.3. Development of allometric model

#### 3.3.1. Model development

Two set data, data set A and data set B was used to model development and evaluation. Data set A contain 200 individual and set B contain 50 individual data. Statistical software R was used for model development. Three different pan-tropical models were used for model development and evaluation (Sprugel, 1983).

#### 3.3.2. Model selection

The best fit model was selected based on the following criteria

Model have lowest AIC (Akaike information Criterion) and RSE (residual standard error) and also have highest $AIC_w$ (Akaike information Criterion Weight) and coefficient of determination $R^2$ value. $AIC_w$ was calculated to saw the very small difference among AIC value. statistical software was used for data analysis and selection. (Silieshe 2014; Picard et al., 2015).

AICw was calculated from the following equation.

$$\text{AICw} = \frac{\exp\left\{-\frac{1}{2}\Delta i(\text{AIC})\right\}}{\sum_{k-1}^{k}\exp\left\{-\frac{1}{2}\Delta k(\text{AIC})\right\}}$$

Where Δi AIC is the difference between model having minimum AIC value and AIC of the individual model.

kullbackleibler discrepancy and evidence ratio were also calculated to determine the best fit model

kullbark-leiblerdisperancy= $\frac{Higest\ AICw\ value}{Second\ higest\ AICw\ value}$.........

Evidence ratio= $\frac{Higest\ AICw\ value}{Higest+Second\ higest\ AICw\ value}$

VIF (variance influential factor) was calculated to saw the multicollinear among more than one independent factor. VIF higher than 10 indicates that it is multicollinearity among the predictor (Shishi, 2014).

$VIF=SD^2(n-1)\ SE^2/MSR$

SD=standard deviation of an individual factor, the SE=standard error of each factor, (n-1) =Total degree of freedom, MSR=Mean square residual.

### 3.3.3. Model evolution

The model of this study was compared and evaluated with existing pantropical and regional model in terms of model prediction error (MPE), Model Efficiency (ME) Root Mean Square Error (RMSE) and percentage error (PE) (Mayer and Butler, 1993.)

$$MPE\ (\%) = \frac{100}{n} X \sum\left(\frac{(Y_p - Y_o)}{Y_o}\right)$$

$$ME = 1 - \left(\frac{\sum(Y_o - Y_p)^2}{\sum(Y_o - Y)^2}\right)$$

$$RMSE = 100\,X \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_p - Y_o)^2}$$

Where, n= of tree, Yp = predicted biomass, Yo =observed biomass, Y=Mean of the observed biomass.

Graphically a regression analysis called 1: 1 ratio was done for a select best model of this study compare with other pan-tropical and regional equation. This help to understand overestimation or underestimation value (Shishi, 2014).

# Chapter 4

## Result

### 4.1. Result

#### 4.1.2. Biomass expansion factor BEF

The best-fit biomass expansion model was BEF = exp (2.1123189-(D*H)) ^0.1066121having lowest AIC value 1.610558, RMSE value 0.1622637 and highest $R^2$ value 0.4330766 (Table 2).

Table 2: Comparison of the derived models of Biomass Expansion Factor (BEF)

| | Formula | a | b | RMSE | AIC | RSE | R2_adj |
|---|---|---|---|---|---|---|---|
| 1 | BEF ~ a * exp (DBH_cm * b) | 1.948596 | -0.0160986 | 0.1726055 | 3.216994 | 0.1796535 | 0.3585084 |
| 2 | BEF ~ a * exp (Total_Height_m * b) | 1.957459 | -0.0292599 | 0.1716542 | 3.07329 | 0.1786633 | 0.3655604 |
| 3 | BEF ~ exp (a - (DBH_cm * Total_Height_m) ^b) | 2.112318 | 0.1066121 | 0.1622637 | 1.610558 | 0.1688894 | 0.4330766 |
| 4 | BEF ~ a - (DBH_cm * Total_Height_m) ^b | 3.366072 | 0.1246449 | 0.1657051 | 2.156217 | 0.1724713 | 0.4087742 |
| 5 | BEF ~ a - (DBH_cm^2 * Total_Height_m) ^b | 3.391871 | 0.0817698 | 0.1661039 | 2.218712 | 0.1728864 | 0.4059252 |
| 6 | BEF ~ a - (DBH_cm * Total_Height_m^2) ^b | 3.333592 | 0.0840809 | 0.1659955 | 2.201743 | 0.1727736 | 0.4067002 |

### 4.1.3. Allometry model for crown biomass:

The best fit model for crown biomass was Crown biomass =-0.60305+0.427934*ln ($D^2H$). This model showed lowest AIC (-176.169) and highest ($R^2$) value of 0.855378 (Table 3). The (RSE) value of model 2 was 0.155281 which is lower among other models (Silence, 2014, Picard et al., 2012) but highest $AIC_w$ value 0.64 and evidence ratio and Kullback –Liber discrepant prefer this model as better than another model saw in the table (Wagenmakers and Farrell, 2004)

Table 3: Comparison among best-fit crown biomass model

| | Formula | a | b | $R^2$ adj | RSE | AIC | AIC w | VIF b | VIF c | Evidence ratio | Kull back |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Crown biomass = a +b log($D^2H$) | -0.60305 | 0.42793 | 0.85538 | 0.15559 | -176.1694 | 0.64331 | | | 1.55447 | 0.64331 |
| 2 | Crown biomass = a + b log (D)+ c log(H) | -0.63532 | 0.91381 | 0.85524 | 0.15528 | -174.9899 | 0.35669 | 3.51117 | 3.51117 | | |
| 3 | Crown biomass = a + b log(D) | -0.72730 | 1.25595 | 0.83131 | 0.16805 | -144.7597 | 9.72499 E-8 | | | | |

#### 4.1.4 Allometry model for stem biomass:

The best fit stem biomass model was Stem biomass = -3.248321+1.79909698*ln (D) +0.78805325*ln (H) having lowest AIC (-286.955) and RSE (0.1180153) and highest $R^2$ (0.976) (Table 4). (Sileshi, 2014, Picard et al., 2012). This model has also highest AIC w value 0.5329024. Evidence ratio and Kullback- liber discrapane was 0.5329 and 1.1409. (Wagenmakers and Farrell, 2004). The VIF (variance influential factor) 3.511174 was also below than 5 Table 4 (Sileshi, 2014).

**Table 4**: Comparison among best-fit stem biomass model

| SL | Formula | a | b | c | R adj | RSE | AIC | AIC w | VIF b | VIF c | Evidence ratio | kullback |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Stem biomass = a +b log(D)+c log(H) | -3.24832 | 1.79097 | 0.78805 | 0.97632 | 0.118015 | -286.955 | 0.532902 | 3.51117 | 3.511174 | 1.1409 | 0.5329 |
| 2 | Stem biomass = a+ b log ($D^2H$) | -3.20752 | 0.858849 | | 0.97618 | 0.118672 | -286.6914 | 0.467098 | | | | |
| 3 | Stem biomass = a + b log(D) | -3.44321 | 2.515864 | | 0.94511 | 0.180148 | -116.3857 | 4.80E-38 | | | | |

### 4.1.5. Allometry model for a total aboveground biomass

The best fit model for total aboveground biomass (TAGB) was TAGB = -1.912079+1.593657*ln (D) +0.615991*ln (H) having lowest AIC (-2.83737) and RSE (0.1189) and highest R2 value 0.967 (Table 5). However, evidence ratio was 8.61 and kullback-Liber discreapne were 0.89 and VIF were 3.511174 also for the best fit model (Table 5).

Table 5. Comparison among best-fit Total aboveground biomass model

| Sl | Formula | a | b | c | R2adj | RSE | AIC | CF | AICw | Evidence | kullback | VIF b | VIF c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | TAGB= a + b log(D) + c log(H) | -1.91208 | 1.59366 | 0.6152 | 0.96747 | 0.11895 | -283.737 | 1.00714 | 1.00 | 8.61 | 0.89595 | 3.51117 | 3.51117 |
| 2 | TAGB= a +b log($D^2H$) | -1.84310 | 0.73489 | | 0.96662 | 0.12080 | -279.431 | 1.00732 | 0.12 | | | | |
| 3 | TAGB= a + b log (D) | -2.06422 | 2.15955 | | 0.94181 | 0.15950 | -166.0628 | 1.01280 | 2.80E-26 | | | | |

#### 4.1.7. Model evaluation

We have compared the best fit model with the various pan-tropical models such as Brown (1997), Brown et al. (1989) and Djomo et al. (2010). Among them our best fit model has lowest (1.532373) MPE%, lowest RMSE (1091.671) and lowest percentage of error (-0.75827) and highest (0.999607) ME The brown 1997 have highest (177.4998) MPE%, highest (1780.54) RMSE, and highest percentage of error (64.082) and highest ME (0.89553). Djomo et al. (2010) have lowest MPE% (109.0532), lowest RMSE (12960.01), lowest percentage of error (55.4373) and Brown et al. (1989) have lowest MPE% (103.2621), lowest RMSE (12105.91), and highest ME (0.944659) lowest percentage of error -0.75827 (Table 6).

Table 6. Comparison among best-fit Total Aboveground biomass model with another various pantropical model.

| Model no | Source | Equation | MPE (%) | ME | RMSE | Error (%) |
|---|---|---|---|---|---|---|
| 1 | Brown (1997) | TAGB=exp (-2.134+2.5430ln (DBH) | 177.4998 | 0.895553 | 17804.54 | 64.82012 |
| 2 | Brown (et al. (1989) | TAGB=exp (-3.1141+0.9719ln (DBH^2*H) | 103.2621 | 0.951713 | 12105.91 | 53.89647 |
| 3 | Djomo et al. (2010) | TAGB=exp (-3.2249+0.9885ln (DBH^2*H) | 109.0532 | 0.944659 | 12960.01 | 55.4373 |
| 4 | Best fit | TAGB=exp (-1.92107+1.593567ln (DBH)+0.6151991ln(H) | 1.532737 | 0.999607 | 1091.671 | -0.75827 |

Figure 3 showing the comparison among the best fit TAGB of *A. malanccesis* and frequently used pan-tropical and regional models by 1:1-line graph. Here, in case of best fit equation, best fit line and reference line are very close where the difference between predicted value and observed value must be little too.

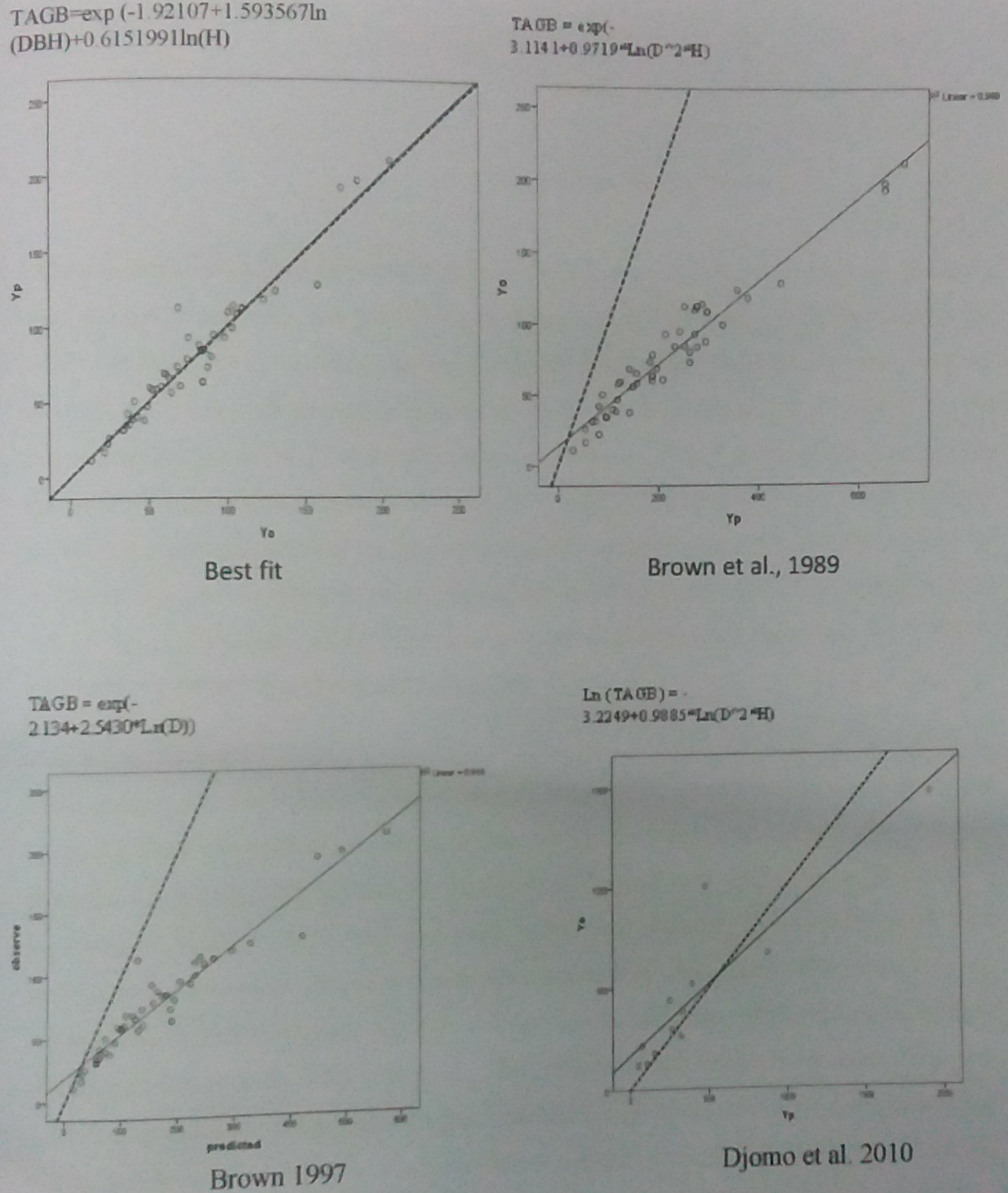


Fig. 3. Comparison among best-fit Total Aboveground biomass model with another various pantropical model.

# Chapter 5

## Discussion

Development of allometric biomass model is a laborious and time-consuming task involving field and laboratory work, and precise statistical analysis (Picard et al., 2015; Mahmood et al., 2017). Selection of best fit allometric biomass model among the set of derived models involves a critical analysis of selection criteria (Sileshi, 2014). The selection of the appropriate model reduces the uncertainty in biomass estimation (Nam et al., 2016). For *Aqualaria malaccencis,* the best fit biomass expansion model was BEF = exp (2.1123189-(D*H)) ^0.1066121 While the best fit model was selected for Crown biomass determination was =-0.60305+0.427934*ln ($D^2$H). Besides, the best fit model was selected for steam biomass= -3.248321+1.79909698*ln (D) +0.78805325*ln(H), and the total aboveground biomass the best fit model was TAGB= -1.912079 + 1.593657*ln (D) +0.615991*ln (H).

Total above-ground biomass of sample trees of Data Set B was estimated using best fit and frequently used pan-tropical allometric models, which was also compared with their observed biomass. All the regional and pan-tropical biomass models have shown lower efficiency in biomass estimation, which indicates poor prediction capacity. Tree species and their architecture, management practices, forest types, site quality, climatic condition are not similar to our studied species and sites, which may influence the efficiency of the compared regional and pan-tropical models (Mugasha et al., 2016). Some recent studies have shown that pan-tropical allometric models produced higher variation in biomass estimation compared to the locally developed models,. However, this variation implies that one should locally check the range of variation or error in using regional and pan-tropical allometric models to estimate biomass of trees and forests (Alvarez et al., 2012; Nam et al., 2014). Unfortunately, such comparison for the regional and pan-tropical allometric model is rare (Nam et al., 2016). In other way, newly developed best fit allometric model also demands validation and comparison with the existing regional and pan-tropical models to assess their suitability at the local scale (Sileshi 2014, Nam et al., 2014).). However, our derived best fit allometric models have very lower underestimation. The context provided by this study and the results presented herein demonstrates that our derived model can accurately estimate the TAGB of the studied species.

# Chapter 6

## Conclusion

From the above discussion, we found that for determination (Total aboveground biomass) TAGB for A*qualaria malaccencis* our derived model is more suitable and accurate rather than other various regional and pantropical model.

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