Model for Tree Volume Estimation, Determination of Root- Shoot Relationship and Biomass Production of *Annona glabra*

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***Abstract*: *Annona glabra* is a widely spreading invasive species which reduces biodiversity in ecosystems. The volume prediction of the tree is imortant for better preventive measures. The objectives of the study were to construct a volume prediction model, determination of the root and shoot ratio and field measures of *A. glabra.* Random sampling was used in Thalangama tank to collect the data from two age classes of 7 years and 12 years. Total biomass was estimated using fresh weight and dry weight of destructive tree samples. Mean total tree biomass estimated for 7 years and 12 years are 6.98 kg per tree (±0.42) and 7.59 kg per tree (±0.40) respectively. Root: shoot ratio for 7 years and 12 years are 1: 2.6 and 1: 2.4 respectively. Model for predicting tree age and tree volume estimated by regression analysis and the best fit models were selected based on R^2value. The models were construted of Age = (-2.527) + (1.525 Ht) for prediction of age of tree and V = (-0.014) + 5.494 BA + 0.002 Ht for prediction of individual height of tree of *A. glabra.* The introduced models of *A. glabra* would provide better calculation of volume stock and helps in better management practises of wetland ecosystems.**

***Keywords*: *Annona glabra*, invasive species, tree modelling, biomass, DBH**

I. INTRODUCTION

Wetlands are the most diversified, dynamic, productive, and environmentally delicate regions on Earth. These wetlands play a significant role in maintaining ecosystem services including preserving the hydrological cycle, agricultural production, fisheries, water filtration, biodiversity and habitat for many flora and fauna species, and regulation of the climate and socio-economic support systems for the city inhabitants [8], [34]. Though, Stakeholders, the government, and the general public continue to disregard or undervalue the value of wetland ecosystems since the majority of the services they provide are not been traded in the economic market [34].

Colombo can be considered as a city built on and around wetlands. Wetlands within the Colombo metropolitan region (CMR) have been progressively degraded with time, infilled and lost. Human activities are progressively degrading the wetlands within the CMR which alter the hydrological dynamics represents a significant threat to native biodiversity across the wetlands. According to Amarasinghe, 2019 [3] unplanned and poorly regulated developments, failure to manage solid waste disposal, a range of point and diffuse sources of waste water and spread of exotic and alien invasive species course damage is considered irreversible. The rates and extent of wetland loss across the CMR are vary. As much as 60% of paddy lands across the wetlands of CMR may have been converted to non-wetlands [24]. The proliferation of invasive plants poses a serious danger to natural ecosystems everywhere and results in high management costs on a social and financial level [21]. Eleven species of alien invasive plants have been recorded across the various wetland types. *Annona glabra,Eichhornia crassipes and Salvinia molesta* are considered widely spreading invasive plant species in wetlands which potentially have implications of harmful threats for the ecological functioning of the wetlands [24].

Sustainable management of forest resources requires a large amount of supporting information. Models provide an efficient way to prepare resource predictions, but the more important role is their ability to investigate management options and silvicultural alternatives [30], [25]. Forestry models play a crucial role in forest management decision makingand makes a bridge between science and management. The requirement of the models depends on the objectives of the management aspects of the forests. Tree volume is one of the most important variables in an ecosystem since all the management decisions are taken on the volume production of trees. Also, volume is the most difficult variable to measure and therefore it has to be predicted using a reliable method [2], [22]. Large scale forest operations require planning of machinery and labour costs. Therefore, it is essential to determine the magnitude of forest operations before leasing or purchasing high cost equipment because it should be capable of completing the task within a certain time. Volume prediction model can be applied to predict time, man power, machine hours and the cost range will use to removing of *A. glabra* in an ecosystem. It may help to enhance the accuracy and efficiency of the work. Also, by volume prediction model able to justify the required area of dumping yard during the removal processof *A. glabra* from an ecosystem and it helps to prepare a suitable management mechanism for the removal process.

Biomass estimation methods are very important for quantifying the energy potential or carbonstock in forests in order to meet the Kyoto Protocol objectives as well as for other environmental and nutritional stability studies. Biomass is the total amount of organic matter present in trees including leaves, twings, branches, bark, woody roots and fine roots [18]. Total biomass of a tree is divided into two as aboveground and belowground biomass. Aboveground biomass consists of all living biomass above the soil including stem, stump, branches, bark, seeds and foliage. Below ground biomass consists of all living roots excluding fine roots (less tan 2mm in diameter) [6], [14], [26]. Biomass is an important indicator in carbon sequestration [4]. About 80% of all above ground and 40% of all below groundterrestrial organic carbon are stored by forest eco system [27]. During productive season, CO2 from the atmosphere is taken up by vegetation and stored as plant biomass. Therefore, tree biomass prediction becomes more popular recently because it has a strong relationship with carbon sequestration [4]. In forest biomass studies, two biomass units are used; fresh weight and dry weight [18], [14], [15].

The use of allometric relationships yields a non-destructive and indirect measurement of biomass compartments and is often the preferred approach since it is less time consuming and less expensive than direct measurements [4], [14]. The non-destructive method does not require the trees to be felled. Measurement can be done by climbing the tree and measuring itsvarious parts and computing the total volume. Tree density which can be found from literature is used to convert the measured volume into biomass estimate [1]. This approach takes even more time and cost to perform.

A diverse variety ofnatural and heavily modified wetlands still remain within the CMR, Sri Lanka comprising densely urban, peri-urban and rural environments. It is estimated that wetlands currently cover approximately 20 km^{2,} or 15.4% of the area. Freshwater wetlands dominate, accounting for almost 85% of all the wetlands. Almost two fifths of the wetlands aredominated by herb species, including the extensive active and abandoned paddy lands [24]. Three main habitat types are present across the CMR – open water, herb- dominated and woodland. The habitats observed within the wetlands reflect primarily natural successional processes, direct human management and the spread of alien invasive species [13]. *Annona glabra* (*Wel atha* in Sinhala and Pond apple in English is a widely spread invasive species which can significantly impact native communities and ecosystems. This plant species is belonging to Family Annonaceae and origin from Florida, the Bahamas, Caribbean, Central and South America, West Africa [28]. It is regarded as one of the worst invasive plant speciesin Sri Lanka because of its invasiveness, potential for spread, and economic and environmental impacts [5]. *A. glabra* is an aggressive invader of native wetlands, reducing biodiversity and threatening some rare species of flora and fauna. It is difficult to manage because it grows in sensitive areas and control methods must avoid adverse impacts on non-target plants or the surrounding environment [23], [32]. It also grows in areas that are hard, and sometimes dangerous, to access [32]. Most of wetlands in Sri Lanka encroached by *A. glabra* and Thalangama tank is one of wetland that affected.

Thalangama tank is one of the wetland get highly threatened by encroachment of invasive plant species of *Annona glabra*.

The Thalangama tank and surrounding area is truly a unique and valuable natural asset within an urban context. It belongs to the Madiwela east division scheme which situated towards the eastern part of Greater Colombo catchment area supported most diverse fauna and flora. This could be an attribute to the presence of many microhabitats such as open water, *Annona* woodlands, marshlands with short grass and highland vegetation associated with the tank [24].

The original full capacity of the Thalangama tank was dropped due to spread of invasive plant species *A. glabra* which covered approximately 8 acres of the tank bed. As a result, the original capacity of the tank 60 Ac. ft. has decreased to 30 Ac. ft where a water deficit could be occurring in the farmer fields, especially during the dry season and increase the flood risk to the Colombo Metropolitan region [24].

The present study was conducted with the objectives of constructing a volume predication model, determining the root-shoot relationship and biomass of *A. glabra* and root: shoot variation with DBH, tree height and tree volume of *A. glabra* for suitable management decisions.

II. METHODOLOGY

A. *Research Site and plant selection*

The study was conducted on 4.5 acres' area of *Annona glabra* patch on Thalangama tank, which belongs to the Madiwela east division scheme which is situated towards the eastern part of the GreaterColombo catchment area. Thalangama tank is situated between Pothuarawa GND and Wickramasinghapura GND. The study site is located at latitude 6° 53' N-6° 56' N: longitude 79° 55' E- 79° 60' E. The mean annual precipitation is about 2573 mm. The mean annual temperature is about 27.0 ˚C. The main landscape of the entire region shows elevations below 100m above MSL and with flat or gentle slopes. The soils are predominantly clay and silt. Stream bed and bank are consisting of alluvium.

Random sampling was used in 0.01 ha sample plots to collect the data of 60 individual trees stratified by age into two age classes of 7 years (2009-2016) and 12 years (2004–2016) using satellite images from Google Earth and field observations. Thirty trees were selected for each age class. (Figure 01; Source: Google earth, 2016)

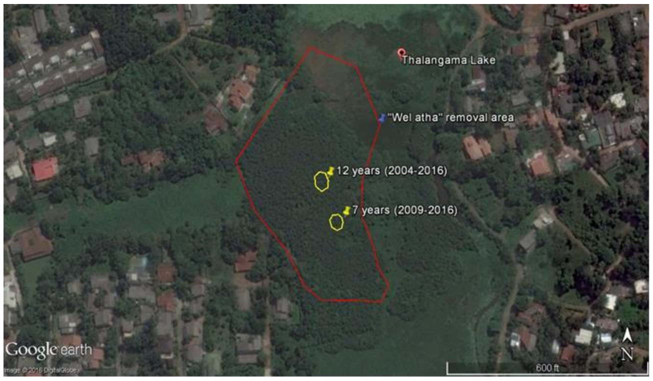

Fig. 1: Locations of *A. glabra* age classes (Source: Google earth, 2016)

B. Data collection

Tree height, DBH, crown height, crown diameter, root length and root width of each tree were measured using standard methods. Measured trees were divided into two main parts; aboveground and belowground using a chainsaw. Aboveground was separated into stem, branch and leaves. The belowground of the tree was separated into root crown, tap root and lateral roots. The fresh weight of each component is determined on-site by weighing on a spring balance. Three sub-samples were collected from each destructive tree component. Sub-samples were collected from the stem at DBH, below and above DBH; from branch bottom, middle and top; three leaves samples; from root crown top, middle and bottom; from tap root top, middle and bottom; lateral roots top, middle and bottom. Each sub-sample was seal and labeled in polythene bags separately and transported tothe laboratory. The fresh weight of each sub-sample was measured in the laboratory to the nearest 0.01 g. Sub-samples were oven dried at 105 °C for 24 hr. as no further weight loss occurred beyond that point. The dry weight of each sub-sample was measured to the nearest 0.01 g.

C. Data analysis

The total log volume was calculated using Newton's formula and the volume of the final section wascalculated by assuming a cone [29], [25]. The tree volume was then calculated by adding all the section volumes together. A theoretical model structure was developed to predict tree volume using total height and DBH and, to predict tree age using tree height [9]. Regression analysis was used to fit the data into the model [10]. Transformed combinations of the model structures were tested in order to select the best models using SPSS. The best models were selected based on R^2 value and distribution ofstandardized residual for *A. glabra* in Thalangama tank. This model had high modelling efficiencies and negligible bias.

III. RESULTS

A. The variation of the measured variables with the age of A. glabra

The summary of the variation of the measured variables with the age of *A. glabra* is given in Table 1 and Figures 2 and 3.

Table I. Summary Of Important Variables Measured

	7 years	12 years
Height/ m	6.36	12.13
DBH/ cm	6.23	7.58
Crown height/ m	2.28	3.23
Crown diameter/ m	1.38	2.42
Root length/ m	1.34	1.52
Tree volume/ m^3	0.01712	0.03223
Basal area/ m^2	0.003050	0.004599

Tree height, DBH, crown height, crown diameter, root length, total stem volume and basal areawere increased with age of the tree.

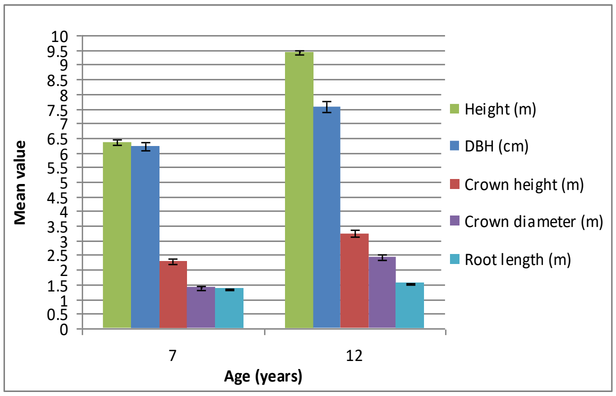

Fig. 2: Variation of mean height, DBH, crown height, crown diameter and root length with (±SE)

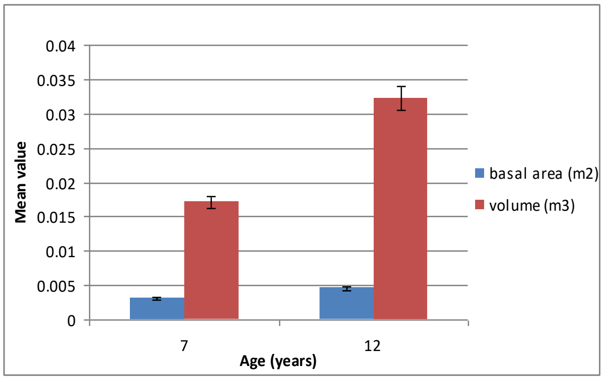

Fig. 3: Variation of mean basal area and volume with (±SE)

B. The correlation and regression analysis

The correlation between tree height and the tree volume was moderate but significant ($R^2 = 0.752$; $p = 0.00$). Diameter at breast height ($R^2 = 0.914$; $p = 0.00$) and basal area ($R^2 = 0.916$; $p = 0.00$) was significantly correlated with tree volume.

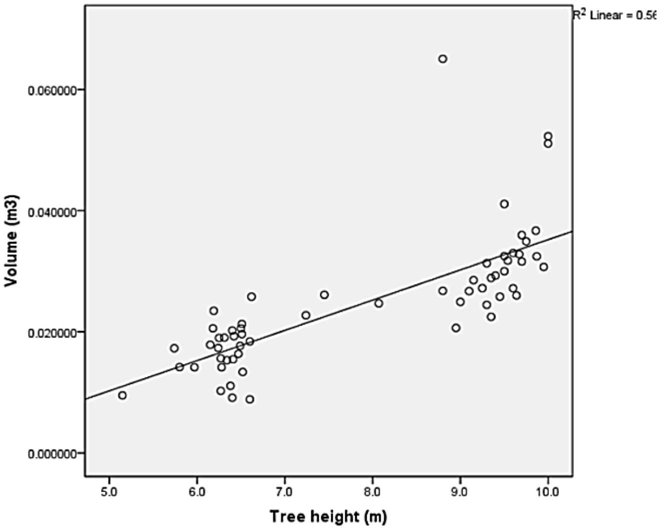

Fig. 4: Scatter plot of tree volume vs.tree height in *A. glabra*

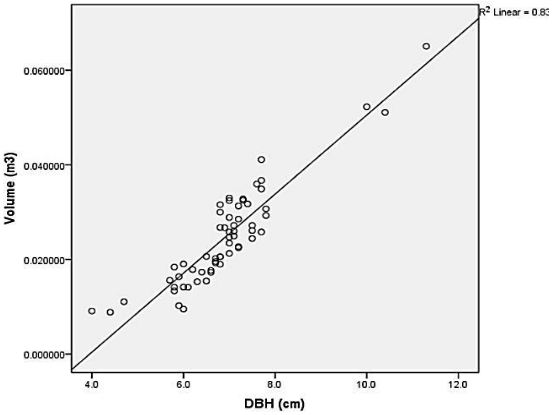

Fig. 5: Scatter plot of tree volume vs.DBH in *A. glabra*

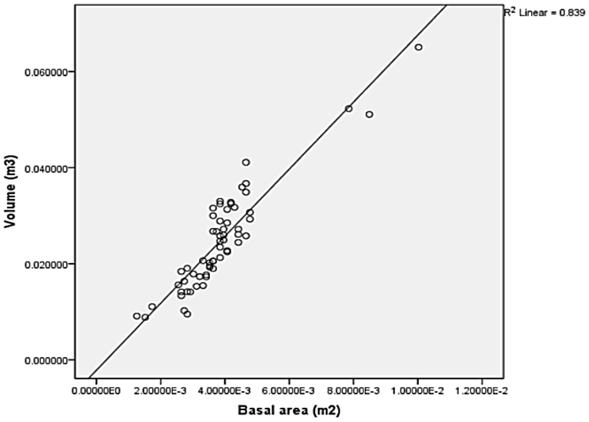

Fig. 6: Scatter plot of tree volume vs. basal area in *A. glabra*

Age has become one of the essential explanatory variables for tree growth prediction in forestry [27], [19], [14]. A model was built to predict the tree height of *A. glabra* using age as the explanatory variable in equation 1. The estimated R^2 value is 93.5%.

The linear model was resultant for the prediction of tree age with height is given in equation 1.The estimated R^2 value is 93.5%. Figure 7 shows the fitted line plot of this model.

Age = (-2.527) + (1.525 Ht) Equation 1

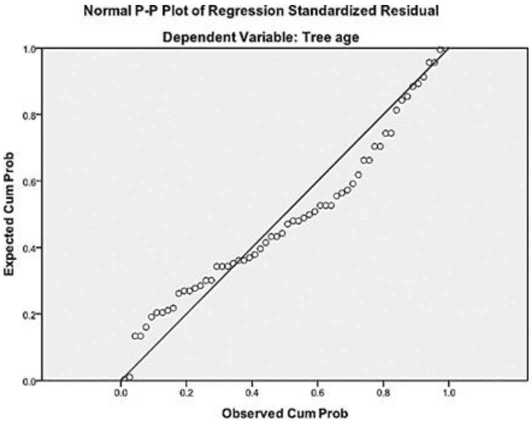

Fig. 7: Normal probability plot of the residuals for the selected model

C. *The best volume prediction model*

All the possible combinations of height and DBH as explanatory variables were tested to identify the best volume prediction model using multiple linear regression and nine models were selected for further analysis. The linear model was fitted to identify the relationship between tree volume with height and basal area. The model resulted in 91.9% proving a strong relationship between tree volume with height and basal area. The fitted line plot of this model is given in Figure 8.

V = (-0.014) + 5.494 BA + 0.002 Ht Equation 2

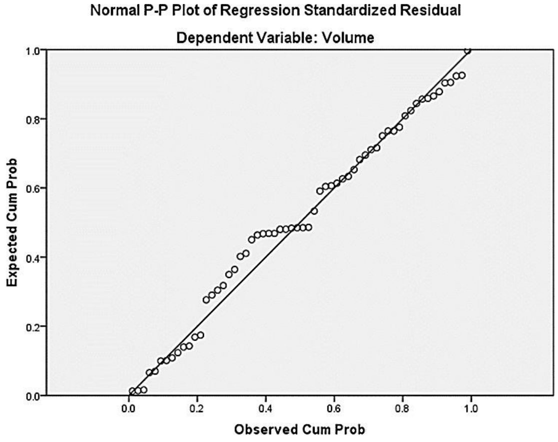

Fig.8: Normal probability plot of the residuals for selected model

D. *The biomass distribution of A. glabra with age*

The summary of the biomass distribution of *A. glabra* with age is given in Table 2.

Table II. Biomass distribution of *A. glabra* with age

	Age	
	7 years	12 years
Mean aboveground biomass (kg per tree)	5.0618	5.3615
Mean belowground biomass (kg per tree)	1.9145	2.2269
Mean total biomass (kg per tree)	6.9762 (±0.4188)	7.5883 (±0.3957)

Biomass partitioning relates to the proportion of biomass appointed to the different components ofa tree. Distribution of total biomass among different plant components for 7 years and 12 yearsold *A. glabra* are given in the below table.

Table III. Distribution of total biomass among different plant components for 7 years and 12 years old A. glabra

		Tree age	
		7 years	12 years
Biomass (%)	Leaves	4.909	4.63
	Branches	26.14	21.39
	Stem	40.48	43.27
	Root crown	22.47	22.88
	Roots	6.00	7.82

The stem has the highest percentage of biomass compared to the percentage of biomass of leaves, branches, root crowns and roots in 7 years and 12 years old trees. The biomass percentage of every plant component increased with the age of the tree.

E. Biomass distribution between root and shoot of A. glabra

Biomass distribution between root and shoot of *A. glabra* at different ages was represented by root: shoot ratio. The root shoot ratio of *A. glabra* is varied with the age significantly given in Table 3. With the age, the root: shoot ratio is decreased.

Table IV**.** Biomass distribution between root and shoot of *A. glabra* at different ages

Age (years)	7	12
Root: shoot	1: 2.6	1: 2.4

Tree height and diameter at breast height were weak positively and significantly correlated with total tree biomass (R^2 = 0.165; p = 0.208 and R^2 = 0.173; p = 0.187). The correlation between total tree biomass and tree volume was weakly positive and not significant (R^2 = 0.186;p = 0.155).

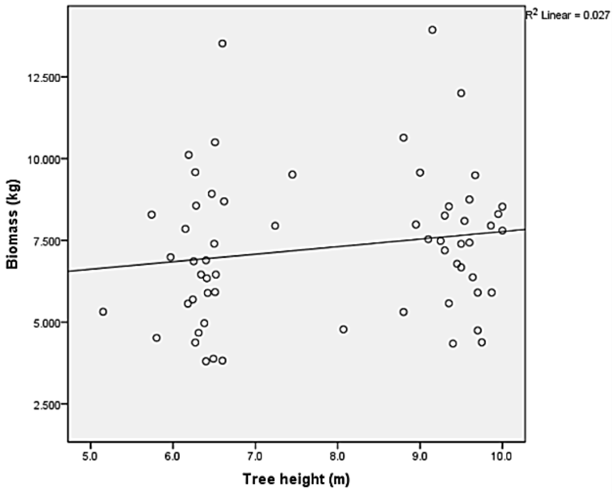

Fig. 9: Scatter plot of total biomass vs tree height in *A. glabra*

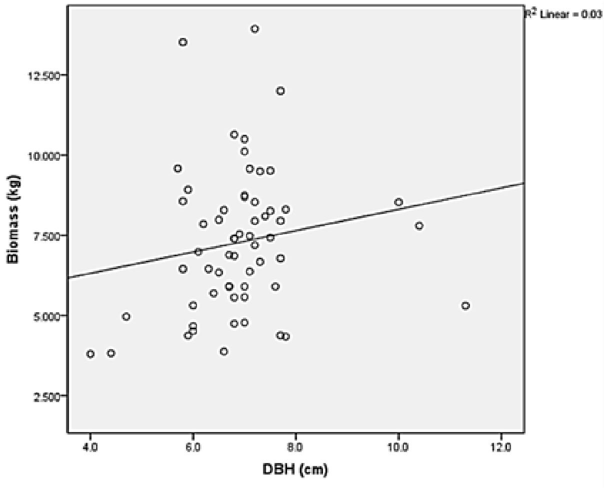

Fig. 10: Scatter plot of total biomass vs DBH in *A. glabra*

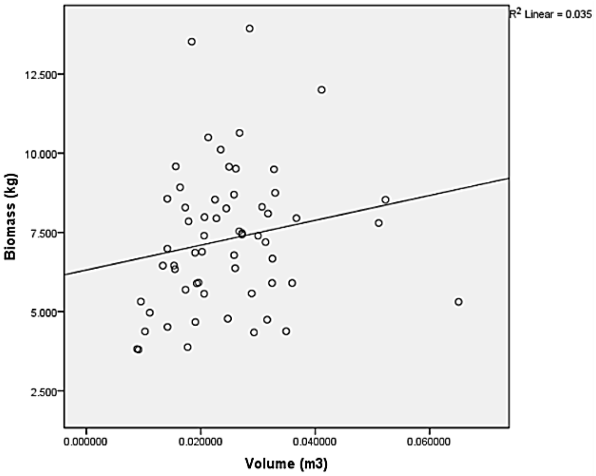

Fig. 11**:** Scatter plot of total biomass vs tree volume in *A. glabra*

IV. DISCUSSION

The growth models for predicting tree parameters on an individual tree basis for forest species in Sri Lanka are hard to find. Most of the studies have been done for forest plantations [11], 12], [25], [33]. Also, growthmodeling studies still haven't been done for *A. glabra* in Sri Lanka or any other country. Most of the growth modeling studies has done for the tree species with economic timber value for theireconomic benefits. Apart from that, *A. glabra* haven't any economic value but growth modeling will help to get proper management decisions in their removal process.

According to the previous studies for calculating the stem volume of standing or fallen trees Newton's formula was used since it is accepted as the most accurate equation for all types of stem shapes [10], [12], [27], [29]. In order to find the best models with the least error, the data were transformed into biologically acceptable forms such as square root, logarithm, square and reciprocal is common to obtain high accuracy in the predictions [10], [25], [27], [29], [30]. Linear and non-linear regression analysis were employed for the construction of models. Linear regression analysis was used in order to build the model to predict the tree volume using DBH, basal area and height as the explanatory variables [9], [10], [27]. For the purpose of testing the constructed models, standard residual distribution and coefficient of determination were used which have been identified as a reasonably good indicator in model evaluation [10], [27], [29], [30].

According to Dhyani, (2021) [10] and Vanclay, (1994) [[30] the most widely used criteria to make a meaningful comparison between alternative functions is probably the coefficient of determination (R^2) and variants such as the correlation coefficient (R) and the ratio of residual mean squares. However, the R^2does not discriminate between "pure error" or normal variation and lack of fit by the model. An R^2 close to one does not mean that it is the best possible model, or that it will provide good predictions. Despite the similar R^2's the quality of the fits varies greatly between data sets due to "pure error", some outliers, the use of wrong model and a case where the estimate of regressionparameter relies entirely on a single point with high leverage without further information.

Therefore, to improve the accuracy of model evaluation standard residuals were also used to select the best models in this study [29], [30]. The reason for usingseveral tests is because the accuracy and bias can be tested in several ways and therefore the quality of the model could be well identified.

The methods used to estimate tree volume and biomass are constantly evolving as the search is always on for estimations that are as close as possible to reality. Volume and biomass estimation models have undergone different changes with the characteristic of the area. *A. glabra*in Thalangama tank used to grow in shallow water areas. Therefore, the constructed models are able to use for the same species grown in a similar environment.

Estimation of total biomass in woody ecosystems is important because of its relevance to nutrient turnover and the potential to store carbon. Most studies on tree biomass have concentrated on aboveground biomass comparatively little is known about ground biomassbecause of its difficulties in doing practically. Both aboveground biomass and below-ground biomass were considered in the present study. According to Yuan *et al.*, (1916) [35], root biomass values vary from one study to another depending on the method used. Belowground biomass varies between stands of different ages, with values increasing with age. Most of the studies that calculate the belowground biomass focus on the upper layers, due to the natural difficulties of measuring root systems in most the forest ecosystems [6], [18]. In order to Xiang *et al*., (2021) [32] sampling protocols differ among studies, with the root excavation methods employed often dictated by site conditions, for example, the type of soil, the presence of hardpans, the rock content, and the type of equipment available.

The percentage of stem biomass obtained for 7 years and 12 years old *A. glabra* from the present study was 40.48% and 43.27% respectively. The stem biomass of *A. glabra* was comparatively higher than the other plant components. As a result of the present study plant components biomass was increased with age except for leaves biomass and branches biomass. Blujdea *et al*., (2012) [6] and Xiang *et al*., (2020) [32] developed an exponential model for biomass prediction as a function of DBH. In the present study, biomass was shown very low correlation with DBH, height and volume. Therefore, the attempt has taken to construct a model to predict biomass as a functionof volume was not successful. The exponential model was the resultant of the prediction of stem biomass with age by Subasinghe (2015) [27]. The present study was given a low correlation with the age.

The root: shoot biomass ratio which is standard to judge the biomass allocation pattern to the underground part of the plant, was 1: 2.6 and 1: 2.4 for 7 years and 12 years old *A. glabra* in Thalangama tank. The root biomass of *A. glabra* was smaller than the shoot biomass. The root:shoot ratio is decreased with the age of the tree. According to Mokany *et al*., (2006) [18] for the forest and woodland shoot: root ratios were affected by a range of factors associated with stand development. They decreased significantly with age, height and mean DBH.

For proper management for forest resources requires a large amount of supporting information. Requirement of specific information for managers and planners is one of the reasons to increase the demand of the forest modelling.

The introduced new tree volume prediction equation will act as a baseline model for the studied species and assist in calculating increasing stock. Since this model gives more accurate predictions of the increasing stock stem volume, using them can assist forest managers in managing forests sustainably.

V. CONCLUSION

The age prediction model for A. glabra; Age = (-2.527) + (1.525 Ht) for prediction of age of the tree at any height. The newly constructed volumeprediction model; V = (-0.014) + 5.494 BA + 0.002 Ht could be utilized in individual tree volume of the *A. glabra*. Mean total biomass of 7 years and 12 years old *A. glabra* is 6.9762 kg per tree (±0.4188) and 7.5883 kg per tree (±0.3957) respectively. The percentage of biomass in leaves, branches, stem, root crown and roots of 7 years old *A. glabra* are 4.909%, 26.14%, 40.48%, 22.47% and 6.00% respectively. The percentage of biomass in leaves, branches, stem, root crown and roots are 4.63%, 21.39%, 43.27%, 22.88% and 7.82% respectively. Root: shoot ratio of 7 years and 12 years old *A. glabra* in Thalangama tank are decreased with the age and the values are 1:2.6 and 1: 2.4 respectively.

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