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ATTEMPTS OF MODELLING FOREST TREE VOLUME AND BIOMASS IN SRI LANKA

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ABSTRACT

Modelling forest tree volume has a long history due to its importance in forest management decision making. However, tree biomass prediction become more popular recently because it has a strong relationship with carbon sequestration. Over the years, numerous attempts were made to construct allometric models in predicting tree volume and biomass in Sri Lanka for different forest species. Volume and biomass estimation in forest trees in Sri Lanka can be divided into four main types, i.e., (i) use of specific models built for the target species, (ii) use of models originally built for different tree species from the target once, (iii) use of common/universal conversions and (iv) use of remote sensing related studies. The first three types, however, became more common because mainly remote sensing studies do not facilitate the biomass estimation at the tree level. Details of tree volume and biomass prediction models constructed for *Eucalyptus grandis, E. torelliana, E. microcorys, Tectona grandis, Pinus caribaea, Khaya senegalensis* and *Alstonia macrophylla* are discussed in this paper. Moreover, it discusses the result of a study conducted in a wet zone natural forest to predict species-specific individual tree biomass using diameter as the only explanatory variable. Finally it elaborates the issues faced in developing allometric equations in Sri Lanka.

Key words : Modelling forest, Tree volume, Biomass, Sri Lanka.

Introduction

Forest ecosystems are capable of storing large quantities of carbon as biomass. It is a well known fact that tropical forest trees play a major role in the global carbon cycle by having large stores of carbon in their biomass. Therefore such biomass information can effectively be used to estimate carbon stock and energy content.

If commercial forests are managed sustainably, the proportion of the carbon in the harvested trees that is emitted as carbon dioxide as a result of burning or natural decay of residues is absorbed by other growing trees, making the process effectively greenhouse-neutral. In addition, a significant proportion of the carbon leaves the forest and is stored in harvested logs, extending the greenhouse gas mitigation benefits provided by forests.

The quantity of biomass is a result of the difference between production through photosynthesis and consumption by respiration and harvest processes. Biomass of an area is defined as the dry mass of the woody parts, bark, branches, twigs, stumps and roots, of all trees alive and dead as well as the dry mass of all shrubs and bushes on their forest and other wooded land. The biomass of an individual tree includes stem, branches, bark, leaves, woody roots and fine roots.

Accurate biomass estimations are very important for tropical forests to calculate the sources and sinks of carbon to develop carbon inventories and be a carbon trader in climate change mitigation programs and to measure the impact of forest degradation or deforestation. There are two main methods to estimate above ground biomass of a tree viz. direct using destructive methods or excavation methods and indirect using allometric models. Since above ground biomass is highly demanded by climate change agreements and destructive methods are difficult to implement in forests, many studies were limited to above ground biomass estimations. Above ground biomass is defined as the dry mass of woody part (stem, bark, branches, and twigs) of trees, excluding stumps and roots, foliage, flowers and seeds.

Since tree biomass has a strong correlation with tree volume, both volume and biomass estimations are important in predicting carbon contents and carbon sequestrations of trees and forests because carbon is stored in tree biomass. Carbon estimations of forest trees has become important and essential due to recent trends of carbon trading mechanisms especially after the Kyoto Protocol came into the action in 1997.

Often there are contrasts between the data used for modelling and the data available for using the models, especially when these are included in decision-support systems (Amaro *et al*., 2003). Hence it is very important to define the data characteristics. Often the models are

Tree biomass and volume prediction is essential in forest management and the models developed for this purpose in Sri Lanka are presented in this paper, especially for the commercially important timber species.

good, as are the decision tools, but the decisions may still not be as good as they should be due to lack of specific quality in the data.

Modelling is not only a method to bridge the gap between science and management, it can also help to understand its causes. In any modelling project, several aspects of posed problem need to be recognised, which are mainly conceptual, mathematical, engineering and ecological aspects. Historically, predictions were derived from past experiences rather the solution of well-understood equations describing non-linear atmospheric transport processes. These days such equations can be fed with sufficiently actual data and solved computationally such that the corresponding predictions now out-compete the crude empirical models of the past in most cases (Hauhs *et al.*, 2003).

However, modelling process should clearly be linked with the theoretical knowledge which allows to select the most important candidate variables, explanations of the model structures and estimated procedures. Parameter estimation is a dynamic task: reality is changing and the knowledge of the reality is also changing. All the priority research topics in this area have the same objective: reducing uncertainty in the ultimate model predictions.

Forestry in Sri Lanka

The closed canopy forest cover in Sri Lanka as a percentage to the total land area is approximately about 20%. If the sparse and plantation forests are taken into the account, the figure may increased to about 29%-30%.

The most remaining forest in Sri Lanka is the dry monsoon type, which is most extensive in the north and southeast of the island. Only fragments of tropical rain forests, a few larger than 10,000 ha, remain in the southwest wet zone, where species diversity is the highest. Although the total area of mangrove forest is very small, its importance as an ecosystem is considerable. It stabilises the shoreline of estuaries and lagoons, and provides essential spawning and nursery grounds for many species of fish, as well as habitat for a variety of crustaceans and other marine life (FSMP, 1995).

With the decline of the natural forest cover over the past decades, the main alternatives for meeting the present and future needs for wood were the trees grown on non-forest lands, and forest plantations. Due to the expanding population and economy, the demand for industrial forest products, logs, and fuelwood continued to grow. At present, Sri Lanka is almost self-sufficient in most wood-based forest products, but imports appear to be increasing. Further, some of the wood supplies are being met from illicit fellings. In addition, the gap between demand and sustainable supply of round wood will continue, which means that actions need to be taken to meet future demands. If the supply of wood from homegardens and other non-forest lands will decline in the future, there is an even greater need for intensively managed forest plantations (FSMP, 1995).

Forest plantations were established for the first time in the 1870s in Sri Lanka, although most of the planting has been taken place since the 1950s. Within that period, about 89,000 ha of forest plantations of varying quality have been established. This area comprises some 5,000 ha of mainly fuelwood plantations, which are under the control of tea and rubber estates (Bandaratillake, 1998). These plantations were mainly comprised on *Tectona grandis, Eucalyptus species, Pinus caribaea, P. patula* and *Swietenia macrophylla.* In addition, *Acacia species, Khaya senegalensis, Azadirachta indica, Dipterocarpus zeylanicus,* etc. were used in minor scale for plantation establishment.

In 1998, the amount of plantation forests belonged to Sri Lanka Forest Department was 135,525.67 (Bandaratillake, 1998). However, all those plantations are not managed due to the reasons such as encroachment, elephant problems, fire hazards, etc. Besides, many regional plantation companies in the private sector also manage a large amount of forest plantations for fuelwood and timber. The interest in establishing forest plantations in tea growing areas has increased in recent years as the profits from tea trade has come down due to introduction of many regulations on production by European countries and Japan. High production costs and competition from other tea producing countries have also contributed to this.

Modelling approaches of tree volume and biomass

Yield prediction is an essential activity in forest management for the production of commercially important outputs such as fuelwood and sawn timber. Often, it is necessary to predict the future growth scenarios even before the establishment of plantations or at the very early stages. The results of such estimations will be used for the planning purposes and necessary calculations such as expenses, profits etc (Subasinghe, 2013). Mathematical models play a vital role in predicting those values for effective planning.

Vanclay (1994) defined stand growth models as abstractions of the natural dynamics of a forest stand, which may encompass growth, mortality and other changes in stand composition and structure. Therefore Forest models can be used as very successful research and management tools. The models thus designed for research require many complicated and not readily available data, whereas the models designed for management use simpler and more readily accessible data (Johnsen *et al.*, 2001).

Moreover, forestry models play a crucial role in forest management decision making. Over the years, a larger number of models have been developed. New and improved models are also continuing to emerge. The core essence of mimicking or representing the reality in an increasingly accurate and precise manner through the scientific modelling process fits particularly well with a decision maker's needs for facilitating the decision process and enhancing its quality. It appears that no decision maker could make the right forest management decision without access to some kind of forest models, although the emphasis and responsibility of a model builder and a decision maker can be quite different. A sagacious balance between them can sometimes be hard to strike and needs to be continuously pursued (Johnsen *et al.*, 2001).

The estimation of biomass is an essential aspect of studies of carbon storage and carbon balance (Xiao and Ceulemans, 2004). Although weighing the actual tree biomass in the field is undoubtedly the most accurate method to determine tree biomass, it is an extremely time consuming and destructive method that is generally restricted to small areas and small tree sample sizes (Ketterings *et al.*, 2001). 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 (St. Clair, 1993).

Simulation of forest growth and yield can be based on empirical or process-based models. Empirical models are widely used to support decision-making in forestry, especially when site-specific predictions on growth and timber yield based on existing inventory data are required. However, empirical models are based on the assumption that future environmental conditions will be similar to those of the past. Therefore, these calculations exclude the impacts of any environmental changes on tree growth. This is opposite to process-based models, which are based on physiological processes controlled by climatic and edaphic factors. But until now, the use of process-based models for assessment of regional or management unit level impact has been limited. Typically, the structure of process-based models is complex; and to initiate calculations a detailed description of the properties of sites and trees is needed (Garcia-Gonzalo *et al.*, 2007).

Miksys *et al.* (2007) stated that, tree biomass has strong correlations with the morphometrical characteristics of trees. Stem diameter and height are often used for further calculations. Sometimes an index built using diameter and height as a combined variable is also often used for stem wood biomass functions. However, this index is treated as a stem volume parameter and has no direct relationship to the stem form factor. On the other hand, the influence of the form factor could be indirectly reflected in the quantity parameters of the biomass equations. Many researchers have used this index in stem biomass functions and it has been evaluated as being informative and good enough for use (Miksys *et al.*, 2007).

It is relatively easy to predict stand stem wood biomass in relation with the stand age. This relationship is quite similar to that between stem wood biomass and stand volume, which is widely described in growth tables and mathematical models. The relationship between the stand level crown or foliage biomass and stand age is more complicated (Miksys *et al.*, 2007).

Sri Lanka scenario

The requirement of the models depends on the objectives of the management aspects of the forests. If the management objective is to supply fuelwood or pulp, prediction of weight becomes more important since the sales are based on wood weight. However, if a particular forest is managed for sawn timber, volume becomes the most important variable. The reason is that all the calculations are based on the volume to be attained in that particular forest. Other than volume, growth in dbh and height over a given period is also important. Since most of the forest plantations are managed for obtaining timber, prediction of dbh, height and volume (over bark or under bark) is the most common objective among the modellers in commercially important forests. In addition to that, modelling biomass and volume became recently intensive due to the high interest among the scientists and policy makers.

Carbon accounting methods are needed to underpin national carbon inventories as well as investment and trade in forest carbon. Direct measurement of storage of carbon in forests, particularly the amounts of carbon below-ground and the changes in these pools, is difficult, time consuming and costly. Given this, and the fact that there is a need for predictive capability of future rates of sequestration of carbon, a modelling approach is required for carbon accounting. Such a model needs to be accurate, include a measure of uncertainty, be easy to apply, and verifiable (Paul *et al.*, 2006).

Many allometric models were developed in Sri Lanka in the past for predicting volume and biomass of different forest tree species. In addition to that, yield tables were also constructed for a few species. Yield table is the foundation of plantation forest management since it gives information from initial planting density to the final harvest with all the treatments such as thinning. Moreover, it provides information on growth rates at regular intervals. At present, Sri Lanka Forest Department has published yield tables for *Tectona grandis, Eucalyptus, Pinus* and *Cypresus macrocarpa*. Other than the yield tables constructed for *Tectona grandis*, the growth variations due to different site qualities were not taken into account for other species. Only *T. grandis* has three different yield tables for three site classes in Sri Lanka. Moreover, growth differences between different species were considered as even for certain yield tables. For example, a single yield table has been constructed for both *Eucalyptus grandis* and *E. robusta* for saw log production.

Finally, it can be concluded that, in Sri Lanka, tree volume and biomass predictions have been done mainly using three different ways; (i) using models specifically built for target species, (ii) using models built for some other species which are different from the target species or target locations, and (iii) using common or universal conversions of tree parameters to biomass. In addition, some studies were conducted using remote sensing for forest level biomass estimations. However, such studies are not common and also not found for tree level parameter estimations, especially the volume. The following sections describe the first three types mentioned above.

Use of models specifically built for target species

Allometric models have been built for most of the common forest plantation species growing in Sri Lanka for this purpose. Due to the lack of precisely re-measured growth data, the common method applied for data collection is the selection of even-aged plantations growing in a range of age classes. If there were significant differences of growth parameters due to geographical variations between the selected plantation sites, it was common to include the site quality parameters into those models to mimic the effect of the site variations.

Eucalyptus grandis

E. grandis is grown in Sri Lanka as plantations by both state and private sectors in the hilly, colder areas of the country. Many successful attempts were made in the past in Sri Lanka to construct allometric models for volume and biomass predictions for *E. grandis* growing in different geographical regions.

Equation 1 was built by Subasinghe in 2008 for predicting stem volume of *E. grandis* growing in varying site types. A site representation factor has been included into the model by using stand basal area and top height. Equation 2 predicts the volume as a function of age for the same species (Subasinghe, 2013).

$$\sqrt{v} = 0.5946\sqrt{(g \times h)} + 0.0356(G/h_{top}) \qquad \text{equation 1}$$

where, g = tree basal area, m^2
G = stand basal area, m^2ha^{-1}
h = total tree height, m
h_{top} = top height, m
v = stem volume, m^3

$$v = 0.2640 \times 1.006^{age} \qquad \text{equation 2}$$

The models given in equations 3 and 4 have been constructed for both *E. grandis* and *E. robusta* to measure the stem volume up to 5 cm over-bark diameter and 20 cm over-bark diameter respectively (Forest inventory manual for Sri Lanka, 1996).

$$v_5 = [0.337 - (0.151/dbh)] \times [(\pi dbh^2 h/40000)] \qquad \text{equation 3}$$

$$v_{20} = v_5[1 - (6.307\exp(-0.0955\pi dbh))] \qquad \text{equation 4}$$

where,
v_5 = stem volume up to 5 cm over-bark diameter
v_{20} = stem volume up to 20 cm over-bark diameter

Subasinghe (2013) constructed four different biomass prediction models (equations 5 to 8) for above ground, stem, branch and crown of *E. grandis.* All models bear the same basic structure and predictions of biomass on different tree components are made using different statistical parameters.

$$BM_{above\ ground} = 132.7 \times 1.059^{age} \qquad \text{equation 5}$$

$$BM_{stem} = 108.3 \times 1.059^{age} \qquad \text{equation 6}$$

$$BM_{branch} = 19.4 \times 1.056^{age} \qquad \text{equation 7}$$

$$BM_{crown} = 5.2 \times 1.056^{age} \qquad \text{equation 8}$$

where,
BM = biomass, kg

Eucalyptus microcorys

A stem volume prediction model (equation 9) was built for *E. microcorys* in 2014 by Kumara. This model was built by using the common logarithmic stem volume prediction model for forest trees by estimating specific statistical parameters for *E. microcorys* growing in the hill country of Sri Lanka.

$\log v = -4.35 + 2.16 \log dbh + 0.873 \log h$ equation 9

Eucalyptus torelliana

In the attempt of construction of a yield table, Thirunadarajah (2006) built a volume prediction model for *E. torelliana* using dbh and height (equation 10). She built this model for *E. torelliana* growing in the lower elevations in the country, where the elevation is below 1,000 m from mean sea level. Although this species has a faster growth rate in the mid and uplands of Sri Lanka, her study was confined to the lower elevations due to the limitation of data.

$\sqrt{v_{stem}} = -0.107 + 0.0349\sqrt{dbh} + 0.0158h$ equation 10

Tectona grandis

T. grandis which grows in dry and intermediate zones is the most valuable plantation forest species in Sri Lanka due to the high quality timber. The model (equation 11) developed by Subasinghe (2006) predicts stem volume of *T. grandis* irrespective of the site variations because a site representative function has been incorporated into the model using top height and age.

$\sqrt{v} = 0.5730\sqrt{g \times h} + 0.0253[1/(h_{top}/age)]$ equation 11

Stem biomass (equation 12) and stem carbon (equation 13) prediction models were also built in 2005 for *T. grandis* by Rathnasekara using dbh and height. In addition, Rathnasekara (2005) has built another model (equation 14) to predict the variation of stem carbon with the tree age.

$\sqrt{BM_{stem}} = 0.6980\sqrt{dbh} + 0.0470h^2$ equation 12

$\sqrt{C_{stem}} = 0.6050\sqrt{dbh} + 0.0330h^2$ equation 13

$C_{stem} = 22.202exp^{\,0.0545 \times age}$ equation 14

where,

C_{stem} = carbon content of the stem, kg

Pinus caribaea

P. caribaea was introduced to the lower elevations of the wet zone of Sri Lanka to rehabilitate the degraded sites due to previous forest harvesting. Both stem biomass and stem carbon prediction models were built in two separate studies for *P. caribaea*. Subasinghe and Haripriya (2014) built a stem biomass prediction model (equation 15) of this species using dbh and height.

$\sqrt{BM_{stem}} = 0.736dbh - 44.9(1/h)$ equation 15

Subasinghe and Munasinghe (2011) also built two models (equations 16 and 17) to predict stem carbon and above ground carbon of *P. caribaea* using dbh and height as explanatory variables.

$\sqrt{C_{stem}} = -188.0(1/dbh) + 4.30\sqrt{h}$ equation 16

$\sqrt{C_{above\ ground}} = 0.271dbh^2$ equation 17

Alstonia macrophylla

A. macrophylla is not a common plantation species in Sri Lanka. However, the Department of Forest Conservation and the private sector have established *A. macrophylla* plantations in the low elevations of the wet zone in minor scales mainly due to its faster growth rate and high adoptability in growing in low nutrient areas. Using the logarithmic stem volume prediction model, two separate models (equations 18 and 19) were built for this species by Subasinghe in 2010. The author also developed GIS maps depicting the site variations for this species in Sri Lanka to cater to easy identification of the two site types for the model users.

Site Class I: $\log v = -4.30 + 1.69 \log dbh + 1.18 \log h$ equation 18

Site Class II: $\log v = -4.18 + 1.89 \log dbh + 0.897 \log h$ equation 19

Species in natural forests

The study conducted by Welivita and Subasinghe (2006) used a common model (equation 20) to predict above ground biomass of 45 different species belonging to 29 families in a natural forest of low country wet zone. Although the basic model structure is common (equation 20), the statistical parameters were significantly different for most of the species.

$\log BM_{above\ ground} = a + bdbh$ equation 20

Use of models developed for other species

This method is common if species-specific models are not present for the target species and also, if accurate estimations are not required. However, the selection of such models should be based on the similarity of the target species with the species originally used for model construction to minimise the prediction errors. The similarity is based on the structure of the trees and geographical areas or both (e.g., Ottorini *et al*., 1996; Knowe *et al*., 1997).

Use of common/universal conversions

Sustainable management of forest resources requires a large amount of supporting information. For instance, when managing a forest for production of commercially valuable materials, estimation of present growth of variables which are not possible to measure easily (such as timber volume) and to estimate the growth values in future are essential. If such information is not available for the target species, the decisions have to be taken based on universally accepted norms. For example, Carbon Fix Standards (http://www.carbonfix.info/)

provides comprehensive details in calculating tree biomass and carbon contents. Their basic model structure is given in equation 21.

$$BM_{above\ ground} = v + BEF + \rho + C\ fraction + C\ to\ CO_2\ ratio$$

equation 21

where,

BEF = biomass expansion factor

ρ = wood density

C fraction = ratio of carbon to dry mass

The stem volume has to be estimated using existing growth models or using yield tables. If the density values are not available for the target species, CarbonFix Standards instructs the users to assume wood density as 0.3 kgm^{-3}. It further assumes the ratio of carbon to dry mass as 0.5 and carbon to carbon dioxide ratio as 3.667.

Discussion

The accuracy of the models constructed for the timber species growing in Sri Lanka were tested using both qualitative and quantitative methods. Under the qualitative methods, scatter graphs of all combinations of the variables were separately observed to identify the strength of relationships, its direction and the presence of outliers in datasets. In addition to that, the standard residual distributions were also observed. Correlations, coefficients of determinations, modelling efficiencies, average bias etc, were used to test the model performances in quantitative manner. According to the results of those tests, the models given in the above sections were proven to be high in accuracy and therefore suitable for the filed use. However, through validation studies have not been conducted until present for those models.

According to Burkhart (2003), the typical approach taken in past growth and yield studies was to define a population of interest, obtain a sample from the defined population (the sample could consist of temporary plots, permanent plots or both), and estimate coefficients (usually with least squares) in specified equation forms. This approach produces satisfactory prediction tools for many purposes, but it may not be adequate in circumstances where forest management practices and objectives are changing rapidly. Given that growth and yield models are used to project the present forest resource and to evaluate treatment effects, data both of the inventory type (which describe operational stands of interest) and of the experimental or research type (which describe response to treatment) are needed. The amount of effort that should be devoted to each type of data collection is not immediately obvious.

The need of re-measured data from the permanent sample plots is emphasised in modelling. The recording and storing such data in accurate manner is a costly and difficult process and therefore it influences the growth modelling approaches in Sri Lanka. As an option, plantations of different ages have been commonly used to eliminate the problem of lack of proper data collected over a long time period and regular intervals. However, when the models are constructed using such data, the variability of site differences on growth become critical and therefore as a solution, site representative factors have to be incorporated in to the models.

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