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BIOMASS ESTIMATION IN FOREST ECOSYSTEMS - A REVIEW

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ABSTRACT

Forest ecosystems plays an important role in global warming serving as both sink and source of one of the prominent green house gases, carbon dioxide (CO_2). Biomass estimation in forest ecosystems is an important aspect of forest management processes aimed at ensuring sustainability. The choice of appropriate method is crucial to achieve the desire objectives. This paper is a review of the works of several authors highlighting the methods, process, pros and cons involved in biomass estimation with the view of providing ample information towards making appropriate choice of biomass estimation methods in forest ecosystems for sustainable forest and environmental management. Findings from this review indicate that, while some method of above and below ground biomass estimation can be said to give accurate or near estimate, the choice of a method over another is not a clear cut issue. This is because the choice of a method over another is likely to be influenced by equipments/technology, finance, experience and manpower or the combination of more than one of these. The choice of a particular method should therefore be guided by the researcher's objectives as well as available resources at the researcher's disposal.

Keywords: Biomass estimation, above and belowground biomass, Forest ecosystems

INTRODUCTION

The carbon dioxide (CO_2) level of the atmosphere has been altered as a result of human activities leading to the rise in global temperature and its attended consequences (Sandberg, 2013). Forest ecosystems as with vegetation in general are excellence sink of CO_2, they mop up CO_2 that would otherwise be present in the atmosphere through the process of photosynthesis (Wani, *et al*., 2012). Large quantities of biomass are stored in stable (undisturbed) forest ecosystem compared to agriculture and other system (Devagiri *et al.*, 2013) thereby generating a considerable interest in forest ecosystems. Biomass can be defined as the organic material that has been generated and accumulated above and belowground in the forest ecosystem, expressed as mass per unit area (FAO, 2004). The aboveground biomass of the forest which is mainly made up of trees accounts for a large proportion of the total tree biomass (ICCP, 2006) as such majority of biomass estimation studies are concentrated on the aboveground biomass (Samalca, 2007). In terrestrial ecosystem, aboveground biomass is associated with components such as carbon cycle, soil nutrients allocation, fuel accumulation and habitat environment (Lu, 2005). The belowground biomass constitutes all the living roots (ICCP, 2006) and is said to accounts for approximately 30% of the aboveground biomass (Rey de Vinas and Ayanz, 2000). The belowground biomass is crucial in the carbon cycle because of the role it plays in transferring and storing carbon in the soil (Ravindranath and Ostwald, 2008). However, very little studies exist with respect to belowground biomass estimation in comparison to aboveground biomass; this could be largely attributed to the small percentage of tree total biomass belowground biomass are thought to account, financial burden and the rigorous nature of belowground biomass estimation.

Biomass estimation is crucial for resource use and environmental management (Samalca, 2007), in the case of resource use, it gives us an insight of the potential amount of carbon that can be emitted when the forest is destroyed as well as the amount of carbon that can be sequester from the atmosphere (Vashun and Jayakumar, 2012). For management purpose biomass estimation is important for determining the productivity and sustainability of forest ecosystems (Samalca, 2007)

Lu (2006) categorized aboveground biomass estimation methods into three (3) namely; Field measurement, remote sensing and geographic information system and the combination of field measurement and remote sensing. The field measurement has been proven to give accurate estimate but is destructive in approach (De Gier, 2003), time consuming and expensive (Vashun and Jayakumar, 2012). Remote sensing are non destructive and cover large area and greatly increase efficiency (Patenaude *et al*., 2005) thereby overcoming some of the challenges associated with field measurement. However, the technology might be expensive to acquire more especially in developing countries. The combination of both methods eliminates or reduces individual deficiencies. Several methods are available for belowground estimate, these includes; excavation of roots, monolith for deep roots, soil core or pit for non-tree vegetation, root to shoot ratio and Allometric equations (Ravindranath and Ostwald, 2008). The choice of these methods will depend on financial capability, availability of equipments/technology and workforce.

Although numerous studies abound with respect to biomass estimation, the choice of suitable method usually poised a challenge more especially in developing countries where technology and finance may be limited. This review is an attempt at highlighting the various techniques/methods of biomass estimation, merit and demerit with the view of selecting appropriate method when carrying out such assessment taking into consideration the desire for accuracy, available technology as well as financial capability.

METHODS OF BIOMASS ESTIMATION

Aboveground biomass estimation

Although aboveground biomass assessment as stated above was generally categorized into three (3) namely; Field measurement, remote sensing and geographic information system and the combination of the two (i.e. field measurement and remote sensing) (Lu, 2006), for the sake of clarity and convenience I categorized and discussed the methods involved as follows;

Destructive/Direct Method

Just like the name suggests, this method is destructive in nature. It is the most direct method of aboveground biomass estimation in forest ecosystem (Gibbs *et al.*, 2007). In this method all trees in a known area are harvested, the weight of the tree, trunk, leaves and branches are measured (Ravindranath and Ostwald, 2008), the components are then oven dried after which their weight are measured again (Liu and Westman, 2009) to determine the biomass. Although this method is regarded as accurate for a particular area, it is tedious, destructive (de Gier, 2003), expensive and is not applicable for a large scale analysis (Liu and Westman, 2009). Usually, this method is used for developing biomass equation to be applied for assessing biomass on a larger-scale (Navár, 2009)

Non destructive/Indirect Method

This method is non destructive in approach, tree biomass are estimated without felling. The method is suitable for protected ecosystem or ecosystem housing rare tree species (Liu and Westman, 2009). Although it is non-destructive in approach, to validate the estimated biomass the tree has to be harvested and weighted (Samalca, 2007).

The following are the methods used in non-destructive/indirect biomass estimation of aboveground biomass

Biomass Equations/Allometry Method: The estimation of biomass using allometric equation is regarded as a non-destructive method of biomass estimation because equations instead of felled trees are used to predict the tree biomass. The equations uses parameters such as diameter at breast height (Dbh), height, crown density etc. obtained from forest inventories (Vashun and Jayakumar, 2012) to develop the equations that could be used in estimating the biomass. Tree biomass is often estimated from the equations that relate Dbh to biomass only, although the in-cooperation of the two i.e. Dbh and Height as the independent variables has been reported to give better results (Pearson *et al*., 2007). The equation developed for single species and for mixture of species is then used to estimate the biomass for specific sites and for large scale global and regional comparisons (Vashun and Jayakumar, 2012). Different equations have been developed by various scholars for the estimation of biomass of different forest ecosystem. Generalized equations for biomass estimation have also been developed, however, the choice of allometric equation should be considered carefully because biomass estimate vary with age of the forest, site class and stand density (Montagu *et al.*, 2005). Site specific allometric equations are considered to be more accurate in predicting forest biomass because it takes into accounts the site effects (Kim *et al.*, 2011). When biomass allometry equations are not available for a given forest site, a simple height-diameter allometry is required to estimate the biomass from a plot (Vielledent *et al.*, 2012)

Models : Models are used to extrapolate biomass estimates over time/or space from a limited data which can be done with the aid of Computer software/programs developed for such purpose using empirical models that accumulated over time from measurement of relevant parameters (FAO, 2004). Most of these models are developed for specific tree species as well as environment as such may be inadequate for estimating other trees species. Models which take into account many environmental variable may be appropriate (Australian Greenhouse Office, 1999) however, these has to be tested. The use of multiple models such as the use of Bayesian model averaging and mixed model could also help in eliminating or reducing error (Henry *et al.*, 2015)

Regression Method: Regression equations are used in aboveground biomass estimation.

There are two types of regression method; linear and non-linear regression method. In this approach the choice of the linear regression equation is based on the condition of the study area (FAO, 2004). Although volume estimation using regression equation is thought to be slightly biased largely occasioned by logarithm transformation (Akca and Laar, 2007).

Table 1: Estimation of biomass of tropical forests using regression equations of biomass as a function of DBH (FAO, 2004)

Author	Equation	Restriction: DBH and climate based on annual rainfall
FAO	(FAO-1) $Y = \exp\{-1.996 + 2.32 \times \ln(DBH)\}$ $R^2 = 0.89$ $R^2 = 0.89$	5 < DBH < 40 cm Dry transition to moist (rainfall > 900 mm)
FAO	(FAO-2) $Y = 10$ ^ $(-0.535 + \log10(p \times r^2))$ $R^2 = 0.94$	3 < DBH < 30 cm Dry (rainfall < 900 mm)
FAO	(FAO-3) $Y = \exp\{-2.134 + 2.530 \times \ln(DBH)\}$ $R^2 = 0.97$	DBH < 80 cm Moist (1 500 < rainfall < 4 000 mm)
Winrock (from Brown, Gillespie *et al*., 1989)	(Winrock-1) $Y = 34.4703 - 8.0671\ DBH + 0.6589\ DBH^2$ $R^2 = 0.67$	DBH ³ 5 cm Dry (rainfall < 1 500 mm)
Winrock (from Brown, Gillespie and Lugo, 1989)	(Winrock-DH) $Y = \exp\{-3.1141 + 0.9719 \times \ln[(DBH^2)H]\}$ $R^2 = 0.97$	DBH > 5 cm Moist (1 500 < rainfall < 4 000 mm)
Winrock (from Brown Gillespie and Lugo, 1989)	(Winrock-DHS) $Y = \exp\{-2.4090 + 0.9522 \times \ln[(DBH^2)HS]\}$ $R^2 = 0.99$	DBH > 5 cm Moist (1 500 < rainfall < 4 000 mm)
Luckman	$Y = (0.0899\ ((DBH^2)^{0.9522}) \times (H^{0.9522}) \times (S^{0.9522}))$	Not specified

Note: p = 3.1415927; *r* = radius (cm); DBH = diameter at breast height (cm); *H* = height (m); BA = J × r^2; and *S* = wood density (0.61).

Tree biomass estimation can be made using any of the model method listed above by applying the corresponding regression equation.

Biomass Expansion Factor (BEF): Biomass expansion factor can also be employed in biomass estimation. To develop a biomass expansion factor tree volume and biomass equation are used (Eid *et al*., 2010). However accuracy of BEFs to apply is indeed dependent on the precision of the data used for the calculation of the biomass volume relationship (Liu and Westman, 2009). It is recommended to use age-dependent BEF's, this is because the use of a constant BEF results in bias and inaccurate estimates of total biomass (Soares and Tomé, 2004)

Remote sensing: Remote sensing is the process of acquiring information from a distant without direct contact with the source or area being examined (Vashun and Jayakumar, 2012). There are basically three (3) main approach of estimating biomass from satellite, the first method (indirect method) may use data such as from Lansat Thematic Mapper (TM) to determine the area of the forest, parameters such as tree height, crown size, forest density, forest type, forest volume, leaf area index etc are measured/assessed. These data are together with the field based measurements of the forest used to developed predictive model or allometric equations as discussed earlier for biomass estimation and validation after which it can be used to estimate the forest biomass of a large area (Lu *et al.*, 2012)

The second method uses a process model to estimate the amount and distribution of biomass, predicted from known relational variables to drive spatially continuous biomass estimate (Australian Greenhouse Office, 1999). Estimating vegetation height from light detection and ranging (LIDAR) or matching of multiview angle optical imagery can provide an additional variables for driving spatially explicit allometric equations for biomass estimation (Vazirabad and Karslioglu, 2011).

The third method uses actively transmitted microwaves sensors (SAR – synthetic aperture radar) microwaves interact with wet material such as leaves, branches and stems. The signal that is received by the sensor is related to vegetation biomass. With the help of allometric equations, images drives from such study are used to estimate the forest biomass (Balzter *et al.*, 2007). Remote sensing can be cost effective as well as less tedious compared to field measurement however field data are generally required in validating data generated from remote sensing. Interpretation of data could also be challenging (Ravindranath and Ostwald, 2008)

Belowground Biomass Estimation

Destructive/Direct Method

Monolith: Although this method is reported to be used in non forest land use system such as grass land (Ravindranath and Ostwald, 2008) it could be useful in estimating grasslike vegetation in the forest ecosystem occasioned by prevalence of gap. To estimate the biomass using monolith, a monolith of the soil is cut from which the roots are separated by washing (Ravindranath and Ostwald, 2008). The size of the monolith use depends on the species of plants being investigated. Water is used in washing sample so as to expose the roots for observation. Washed root samples can be stored in polyethylene bags for a short time in a refrigerator but preferably they should be stored in a freezer. The samples are dried for 5 hours to 105^{O}C in an oven the results can be expressed in dry matter per unit volume of soil (Liu and Westman, 2009). The major limitation of monolith is the possible loss of roots during washing. It is also tedious, expensive as well as time consuming (Ravindranath and Ostwald, 2008)

Single tree excavation method: This method as the name implies involves selecting a plot from which a tree is felled and the tree roots are removed from the soil and tracing each root individually from the stump to root tip (Liu and Wesman, 2009) from which roots volume are quantified. Equations or models can then be developed to use in estimating for the whole system. Although this method is destructive in approach as well as laborious, data generated from such studies can be used to develop equations which can be useful in root biomass estimate (Ravindranath and Ostwald, 2008). Although very few trees species are felled for such estimation thereby reducing destruction, it is not advisable for ecosystem housing rare tree species.

Sequential coring: Forest ecosystems are made up of predominately tree species, other vegetation such as herb, tree and shrubs may exist. Estimation of non tree vegetation in forest is also important since it also contribute to carbon pool of the forest ecosystems. Soil core is usually employed in such cases since it is not feasible to develop a relationship between above and belowground components of non tree plants such as herbs, grass and shrubs (Ravindranath and Ostwald, 2008). The biomass is measured at periodic interval.

Non-destructive/Indirect Method

Minirhizotrons/Imaging Methods: Minirhizotrons are transparent tube coupled with a camera for capturing fine root image belowground (Kirsch, 2013). This method is non-destructive and less tedious (Cheng *et al*., 1991) it also allow for repeated measurement over time without causing disturbance to the roots (Kirsch, 2013). Data generated can be analyse with the aid of Software packages developed for such purpose. However, temperature regimes and soil matrix resistance to root penetration can be alter by the installation of the minirhizotron tubes (Brunner *et al*., 2013) image processing could also pose a serious challenging for analysing such data.

Starch approach: Starch is a component of carbohydrate which is present in some biomass such as root. Roots tissues are reported to account for a large proportion of starch and serve as a carbon storage organ (Ludovici *et al.*, 2002) as such could be used for belowground biomass estimation. Since root need carbon for growth a correlation relationship can be drawn from which Regression equations can be used to estimate the belowground biomass (Vogt *et al.*, 1998)

Carbon flux approach: This approach makes use of data that has been collected from different part of the world for soil respiration or CO_2 efflux from the soil. By measuring CO_2 efflux and belowground litterfall inputs, total carbon allocation to roots (which includes belowground detritus respiration and root respiration) is estimated by the difference between input and output (Raich and Nadelhoffer, 1989).

Nitrogen (N) Budget approach: A relationship between the availability of nitrogen and root production is made to estimate belowground biomass. Information is therefore needed on N inputs into an ecosystem, N storage in all plant tissues and N mineralization rates in the soil (Aber *et al.*, 1998)

Correlations with abiotic variables: Correlations developed between fine root biomass and/or production and ecosystem level parameters indicative of the cycling of nutrients such as litterfall nutrients, forest floor nutrients, mean residence times at the ecosystem level with climatic variables such as precipitation, temperature, temperature/precipitation rations. However, studies are needed for ecosystems that are less studied in order to understand these relationships (Vogt *et al*., 1998).

Regression model: This is similar to the regression method discussed in aboveground biomass assessment where a regression model is developed for estimating the aboveground biomass. In this case a regression model is also developed for estimating the belowground biomass. For example the following regression model according to Cairns *et al*., (1997) can be used to estimate belowground biomass in different forest ecosystem

Boreal

BGB = exp (-1.0587 + 0.8836 x ln *ABD* + 0.1874)

Temperate

BGB = exp (-1.0587 + 0.8836 x ln *AGB* + 0.2840)

Tropical

BGB = exp (-1.0587 + 0.8836 x ln *AGB*

Where BGB = below-ground biomass density in tons/hectare (t/ha) AGB = above-ground biomass density (t/ha)

n = 151: r2 = 0.84

The major limitation of regression equation is that, even in a particular forest ecosystem there are variation with respect to site as such a generalised equation for a particular forest may still be deficient.

Root – shoot ratio: The relationship between root and shoot biomass is a useful means of estimating root biomass in plants (Mokany *et al.*, 2006) it has become one of the common method for the estimate of belowground biomass and carbon stocks for National greenhouse gas inventory purposes (Snowdon *et al.*, 2002). The amount of photosynthates generated between aboveground and belowground organs in plants are accounted by the relationship existing between root and shoot (Titlyanova *et al.*, 1999) thereby providing estimates of belowground plant biomass from aboveground biomass. The following are examples of root:shoot relationship developed based on the work of Mokany *et al.*, (2006) which can be used in estimating root biomass in different ecosystem

Tropical moist deciduous forest: R = 0.20 (0.09–25) for forests with above-ground biomass less than 125 t/ha

Tropical dry forest: R = 0.28 (0.27–0.28) for forests with above-ground biomass greater than 20 t/ha

Allometric equations: Equations are developed based on the allometric relationship between stem diameter and root biomass which can be used in estimating root biomass, such equations can also be derive for individual tree species or a forest type (Ravindranath and Ostwald, 2008). The relationship is described using a two-parameter power function to fit Allometric relationships between stem diameter and coarse root biomass as:

$$Y = aX^b$$

Where Y = coarse root biomass (kg),

X = diameter at breast height (DBH, cm),

a and b = fitted parameters known as the Allometric coefficient and Allometric exponent, respectively.

Logarithmic transformations are used routinely to fit Allometric equations, resulting in a linear model:

$$\log Y = \log a + b \log X$$

Log-transformation thus simplifies parameter estimation because simple linear regression procedures can be used. (Brassard *et al*., 2011; Lai *et al*., 2013)

CONCLUSION

Biomass estimation has generated a great deal of interest which will continue to rise because of the issue of global warming and its attendant consequences. The various methods employed in biomass estimation as discussed has their advantages and disadvantages, in some case it is about the accuracy of a particular method, while in other case it is the cost associated with carrying out a particular method, time and the laborious nature of the method employed. The problem of instruments or technology might be a problem more especially in developing countries. Attention should therefore be focus on choosing a method that is non destructive or less destructive, accurate, less time consuming, less stressful and accessible for all (develop and developing countries). The integration of some of these methods might be feasible and yield more accurate results.

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