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ESTIMATION OF ABOVE GROUND BIOMASS AND CARBON OF *Pinus caribaea* IN BULOLO FOREST PLANTATION, PAPUA NEW GUINEA

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ABSTRACT

Planted forest plays vital role in tree biomass which stored as carbon through carbon sequestration process and help reduce global warming and climate change effect. Estimation of biomass volume is the important process to determine the carbon contents stored in planted forest trees. Study was conducted to estimate the biomass and carbon content of *Pinus caribaea* trees using allometry models at Bulolo forest plantation in Morobe Province of Papua New Guinea. Study involves center plot of the cluster design in order to collect field data as sample size The field data was collected by measuring stem of *Pinus caribaea* tree species using two variables, diameter at breast height (DBH) and height. Finding reveals that first and highest rank biomass stem content and carbon stocking was 472,4 biomass/ha, followed by 407,076 biomass/ha and the least was 320,97 biomass/ha. Study reveals that biomass stem content and carbon stocking with 407,076 biomass/ha was the more suitable and applicable model for calculation of *Pinus caribaea* in Bulolo forest plantation. Study recommends the log formula derived from the biomass stem content and carbon stocking of 407,076 biomass/ha, as the reliable model to be used for estimation of biomass content and carbon stock of *Pinus caribaea* tree species Bulolo forest plantation and else way in Papua New Guinea.

Keywords: Allometry models, biomass volume, carbon sequestration, carbon stock, climate change mitigation process, planted forest.

INTRODUCTION

Research background

Forest trees and its biomass plays vital role in mitigating global warming and climate change effect through carbon sequestration process. Indeed, biomass is the weight of a living tissue of trees which is stores carbon and it is generally expressed in metric tons. As was highlighted by Zell *et al*. (2014), the two global developments that biomass plays towards climate change were first, the changes in biomass of forest corresponds directly to the changes in carbon absorption or release to the atmosphere and, secondly, the increasing demand for forest fuel wood energy. Biomass studies also provide detail of forest productions for individual tree species particularly in plantation forestry in which it requires accurate quantifying of biomass for tree species using a site specific allometric models.

Plantation forestry and to some lesser extent social forestry is currently a much anticipate topic globally due to its ability to absorbed carbon dioxide which produces biomass and stored as carbon during photosynthesis and carbon sequestration process that further contribute towards mitigating climate change effect. According to Adams (2012), planted forest covers 264 million ha, almost 7 percent (%) of the total global forest cover.

In Papua New Guinea, a country with vast landmass covered with tropical rainforest, have a total forest

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cover of 33,6 million hectares (Timber Trade Portal 2016) with a biomass of between 4724 to 4735 million metrics tons (MT) of carbon stored in primary forest (PNGDSP 2010). Plantation forestry started early 1960's (Yati *et al*. 2004) in Papua New Guinea and so far established 62000 ha of planted forest (PNGDSP 2010) through both private and public sector. Papua New Guinea Forest Authority (PNGFA) who is the statutory body that governs the forest resource for the state of Papua New Guinea, currently, manages around 35000 ha of plantation forest. Study by Yati *et al*. (2004) shows that there are three commercial plantations covering around 33000 ha in which Pinus tree species plantations covers about 16300 ha land area. Yati *et al*. (2004), further elaborate that this figure may increase due to new annual plantings and plantation development projects over the last 14 years.

Problem statement

Regardless of previous, current and on-going progress of forest plantation development and management in Papua New Guinea; there was no research study undertaken to calculate the biomass content and carbon stocking of planted forest including carbon sequestration potential of plantations species. In addition, existing equations for biomass of plantation species in Papua New Guinea is non-existence and needs further research on species specific allometric models. In fact, there is a need for species specific equations in Papua New Guinea and Pacific as higher priority at this stage, not only for usage in plantation management but also for the monitoring and verification exercises for United Nations Reduce Emission Deforestation and Degradation (UNREDD+) activities in order to comply with Kyoto protocol (Rojas-García *et al*. 2015). Therefore, a species specific allometric model has to be developed as a tool for managing plantation of *Pinus caribaea* sustainably and to meet the United Nations Framework on Climate Change (UNFCC) guidelines on the reporting of country specific inventory data. This study was based on estimation of above ground biomass and carbon of *Pinus caribaea* in Bulolo Forest Plantation of Morobe Province, Papua New Guinea.

Significance of the study

The importance of the study is to provide vital information and data about biomass content and carbon stocking, the rate of carbon sequestration process for the planted forest in Papua New Guinea. The study further helps create allometric model and formula that enable to replicate and calculate the existing biomass and carbon stocking in plantation forest for large scale carbon credit and accounting process in Papua New Guinea.

Objective of the study

This study was conducted to test whether biomass equations developed for *Pinus caribaea* in Sri Lanka and the (Brown and Lugo 1992) can be used to calculate biomass and carbon stock for Bulolo *Pinus caribaea* forest plantation. The study aims to estimate the above ground biomass of *Pinus caribaea* stands in Bulolo plantation.

Research hypothesis and research question

This paper is based on the hypothesis that the biomass calculation for *Pinus caribaea* tree species in Bulolo forest plantation can be influenced by integrated and modified version of existing generic and allometric models. In addition, the paper seeks to answer the following research question: "What is the biomass content and carbon stocking for *Pinus caribaea* tree in Bulolo forest plantation"? "What will be the appropriate allometric equations applicable for biomass calculation and assessment for *Pinus caribaea* tree species in Bulolo forest plantations"? and "Is allometric model and equation developed in Sri Lanka for calculating biomass of *Pinus caribaea* suitable and more appropriate for *Pinus caribaea* tree species in Bulolo forest plantation"?

MATERIALS AND METHODS

Study site and species selection

Study was conducted at Bulolo Forest Plantation, a state-owned plantation run by Papua New Guinea Forest Authority (Figure 1). The site is located about 150 kilometers South-West of Lae (7,1994_South and 146,6370_East) in Morobe Province, Papua New Guinea. It has an extended area of approximately 12000 ha with an elevation ranging from 600 metres to 1500 metres above sea level (Karmar *et al.* 2013) and the plantation is located in the vicinity of Bulolo mining town that connected to Lae city of Morobe Province.

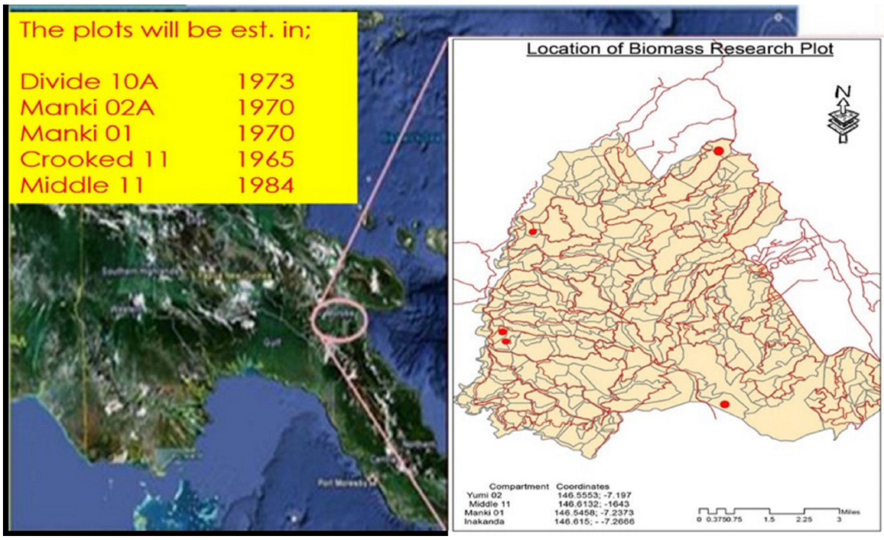


Figure 1: Location of Bulolo forest plantation and the study site

The species selected for this study was Pinus trees. Pinus tree is the introduced (exotic) plantation tree species in Papua New Guinea. Caribbean pine (*Pinus caribaea*) is a rapidly growing species originated from Central America, where it grows between 18-degree (º) North (Belice) to 12 º North (Bluefields, Nicaragua), at 850 above sea level (asl) and mean rainfall of 950 millimeters (mm) to 3500 mm per year, exhibiting a dry season of two to three months and temperatures between 24 Celsius degrees (°C) and 27 °C (Greaves *et al*. 2015). There are three varieties of the Pinus tree species; *Pinus caribaea var. hondurensis* from Honduras, *P. caribaea var. caribaea* from Cuba and *P. caribaea var. bahamensis* from Bahamas (Lamb 1973).

In this study, *Pinus caribaea* tree species was selected to conduct biomass and carbon stock calculation, especially for the estimate of above ground biomass.

Methods

The initial plot design was a circular cluster plots consisting of three subplots, but as the study progressed, the plot was redesigned and only the center plot of the cluster design was chosen and selected as sample size for collecting the field data. During the study and data collection, four *Pinus caribaea* compartments of Bulolo forest plantation was selected; two compartment were from 49 years old and then a single compartment each from 38 years old and 24 years old plantation. The assessment was carried out within 20-meter radius of proposed and marked out *Pinus caribaea* tree species plot. The actual field data was collected from demarcated or marked out plot by measuring stem stand of a tree using two variables; diameter at breast height (1,3 m), and the height using clinometer reading (Figure 2) and then jotted the data on a field data collection spread sheet. In the process, the height was calculated using tangent formula for height (Equation 1):

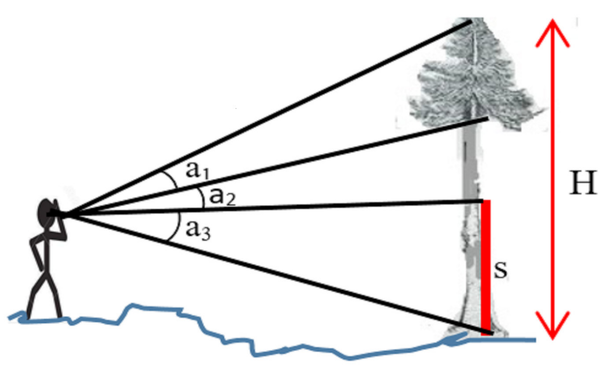


Figure 2: Diagrammatic representation of height reading

$$H = S\left(\frac{tan\ (a_1) - tan\ (a_3)}{tan(a_2) - tan\ (a_3)}\right) \quad (1)$$

Where; H is the total height in meters (m), S is the distance of 10m pole on stem in meters, tangent (θ°) of inclination, angle (a_1, a_2, and a_3) are the angle of inclination readings taken using clinometer. Tan (a_1) angle to the top of tree, Tan (a_2) angle to the merchantable height of tree, Tan (a_2) is angle is angle to the bottom of the tree

The field data were further computed to calculate the standing volume of each compartment using volume table and Equation 2 created and developed especially for the *Pinus caribaea* of Bulolo forest plantation. The volume table equation for *Pinus caribaea* for Bulolo plantation (Karmar *et al*. 2013)

$$V = 10 - 4{,}49241\,x\,DBH\ 1{,}78711\,x\,Ht\ 1{,}19868 \quad (2)$$

Where; V is standing volume (m^3/ha), DBH is diameter at breast height of 1,3 metre in centimeter (cm), Ht is total height of tree in metre (m).

The estimation of stem biomass was carried out for each compartments using Equation 3 (Brown and Lugo 1992), Equation 4 (Curtis 1967) and Equation 5 (Subasinghe and Harpriya 2014) as listed below;

(i) The (Brown and Lugo 1992) for conifer trees*;*

$$ABG = Vol\ x\ wsg\ x\ bef\ x\ cf \quad (3)$$

Where; ABG is above ground biomass (kg/ha), Vol is the stand volume (m^3/ha), WSG is the wood specific gravity (kg/m^3), BEF is the biomass expansion factor and CF is the carbon fraction or carbon content ratio (t-C/m^3).

(ii) (Curtis 1967):

$$Ln\,Y = \frac{\beta^1 + \beta^2}{DBH + \varepsilon} \quad (4)$$

Where; Ln is Natural logarithm, Y is the tree biomass (m^3/kg), β^1 and β^2 are the parameters, DBH is diameter at breast height of 1,3 metre in centimeter (cm) and ε is the random error.

(iii) (Subasinghe and Harpriya 2014):

$$\sqrt{}\,Y = 0{,}736\,DBH - 44{,}9(1/h) \quad (5)$$

Where; Y is tree biomass (m^3/ha), DBH is diameter at 1,3 metre in centimeter (cm) and h is total tree height in metre (m).

The three existing mathematical models; UNFCC Generic Equations for conifer trees, (Curtis 1967) and, Subasinghe and Harpriya (2014) were integrated to build a modified version in which tested to select the most appropriate model to be used for the estimation of biomass for *Pinus caribaea* tree species in Bulolo forest plantations. In order to design a new model; regression test was carried out through the application of mini-tab statistical software and at the same time generate a residual chart. The models used for testing was based on higher R^2 value and the residual distribution of biomass and error from the predicted value. The most appropriate models were chosen and selected based on its higher R value and plotted residuals in order to test the reliability of the equations. The same method was used by both (Subasinghe and Harpriya 2014) in Sri Lanka and, (Coutinho *et al*. 2018) in Brazil for the calculation of biomass content.

Findings for this study is centered on two set of analysis; the hypothesis tested and the research questions answered:

(i) Hypothesis: "Biomass calculation for *Pinus caribaea* in Bulolo forest plantation is influenced by predicted formulae or derived formulae from modified version of allometric models."

(ii) Research Question: "What is the biomass content and carbon stocking for *Pinus caribaea* tree species in Bulolo forest plantation?"; "What will be the appropriate allometric equations applicable for biomass calculation/assessment for *Pinus caribaea* in Bulolo forest plantations"? and "Is allometric model and equation developed in Sri Lanka for calculating biomass of *Pinus caribaea* suitable and more appropriate for *Pinus caribaea* tree species in Bulolo forest plantation"?

RESULTS AND DISCUSSIONS

Test of hypothesis

"Biomass calculation for *Pinus caribaea* in Bulolo forest plantation is influenced by predicted formulae or derived formulae from modified version of allometric models."

The hypothesis tested is based on calculating carbon storage and stem biomass content of *Pinus caribaea* in Bulolo forest plantation and, further tested three existing generics and allometric models in order to predicted formulae or derived formulae. To test this hypothesis, it involves several steps: First, we identify/select compartment for collecting field data, computing and calculating compartment volume. Secondly, we carried out statistical analysis through four process for biomass content calculation of *Pinus caribaea* in Bulolo forest plantation. And then finally, we test the modified version of existing generic and allometric models through variance analysis in which computing the field data on statistical analytic software.

In the first step, study selected four compartment of *Pinus caribaea* in Bulolo forest plantation as sample size, field data collected, computed and the total volume for compartments was 1061,62 cubic metre per hectare (m^3/ha), with an average of 265,405 m^3/ha as shown on Table 1.

Table 1: Volume of *Pinus caribaea* of the compartments studied.

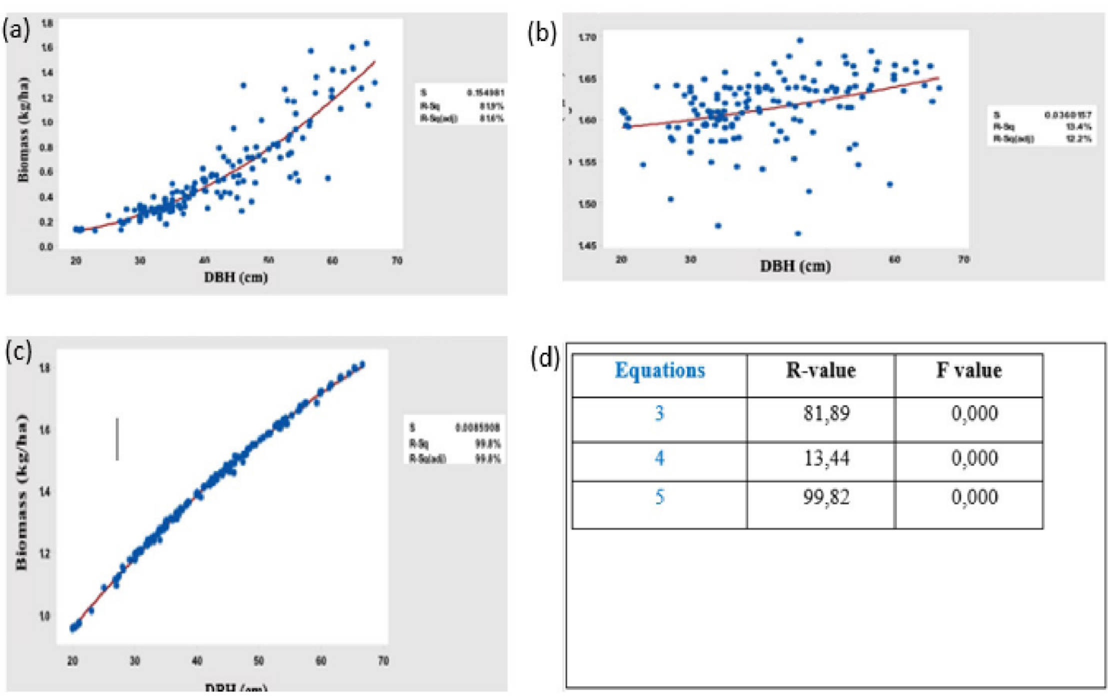
Compartment	Area (ha)	Volume (m^3/ha)	Age (years old)
Inakanda 11A	13,1	532,522	38
Manki 01	18,8	657,482	49
Manki 2A	26	341,70	49
Middle 11A	48,3	160,23	24
Total	106,2	1691,934	

In order to calculate carbon storage, stocking and stem biomass content of *Pinus caribaea*, study involves three main formulas: (Brown and Lugo 1992), (Curtis 1967) and then (Subasinghe and Harpriya 2014). Findings from Table 2 shows that first and highest rank carbon and biomass stem content was from the used of (Curtis 1967) formulae with 472,048 biomass/ha, followed by (Subasinghe and Harpriya 2014) with 407,076 biomass/ha and the least was (Brown and Lugo 1992) with 320,97 biomass/ha.

Table 2: Biomass and carbon of *Pinus caribaea* for the compartments studied.

Equation	Formulae	Biomass (ha)	Carbon (ha)
3	Brown and Lugo (1992)	320,97	160,485
4	Curtis (1967)	472,048	247,8252
5	Subasinghe and Harpriya (2014)	407,076	213,7149
6	Equation 6	407,242	213,8021

In the second step, statistical analysis was conducted through four process for biomass content calculation of *Pinus caribaea* in Bulolo forest plantation The first process for biomass content calculation of *Pinus caribaea* in Bulolo plantation and testing modified version of existing generic and allometric models was to conduct an analysis of variance through computing the field data on statistical analytic software Firstly, an analysis of variance was done on the data collected to find any relationship between DBH (Diameter reading at 1,3 m above ground level in cm) and biomass, however, all data shows significant relationship with p value of 0,000 at 95 % probability level. In the second process, actual results indicate significant difference with each formula was applied, hence a correlation test through regression analysis using mini-tab statistical software was conducted to evaluate any correlation and also if their R value can show any positive relationship. The third process involves Subasinghe and Harpriya (2014) allometric models in which R-value and all were recorded at above 90 percent (%). In the fourth and final process, the relations between DBH and volume of biomass were tested (Figure 2).



Equations	R-value	F value
3	81,89	0,000
4	13,44	0,000
5	99,82	0,000

Figure 3: Comparison of relationship between DBH (cm) and Biomass (kg/ha) for the different Equations.

Equation 6 in Table 2 is the formulae derived through regression analysis and further synthesis and comparison of three different allometry models: Equation 3 (Brown and Lugo 1992), Equation 4 (Curtis, 1967) and Equation 5 (Subasinghe and Harpriya 2014). It is the new version of allometry models which is more suitable and applicable for the calculation of biomass stem content and carbon stocking. Equation 6 is the synthesis and new version of allometry model more reliable for estimation of biomass content and carbon stock of *Pinus caribaea* tree species for Bulolo forest plantation and else way in Papua New Guinea.

As Figure 3 reveals, comparison of the formulae for three existing generics and allometric models have shown strong positive relationship between the predictor (DBH) and the response (biomass) Figure 3 (a), (b) and (c). When Equation 5 (Subasinghe and Harpriya 2014) allometric models was applied, the result shows a higher R sq. valued at 99,82 % which is almost close to perfect, without any outliers (Figure 3 (c). Likewise, Subasinghe and Harpriya (2014) tested seven models and derived a single modified model with a R squared result of 97,7 % which comprise of all components of trees (branch, needles and bark). In order to verify and confirm error associated with Equation 5, regression analysis was conducted to establish relationship between DBH and biomass for predicted formulae or (Equation 6). Error was calculated using Equation 5.

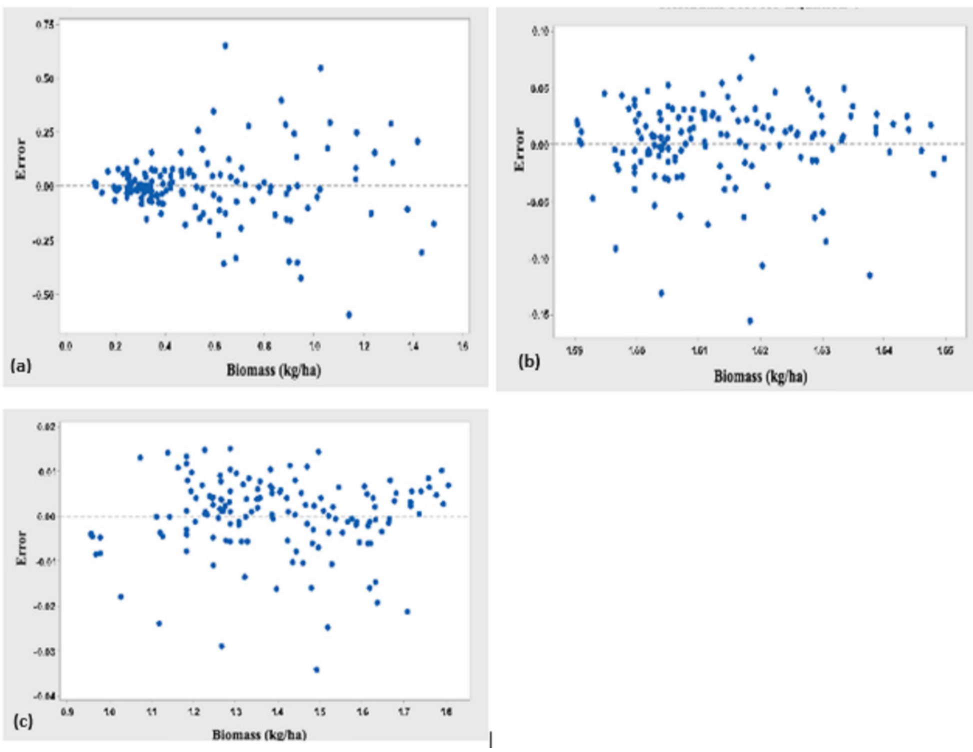


Figure 4: Residual Plots of the equations.

Figure 4 (a), (b) and (c), shows the statistical analysis of residuals for the three existing formulae and also indicate the trend of errors. According to the findings, trend of errors increases as value of biomass increases for both Equation 3 (Brown and Lugo 1992) Figure 4 (c), and Equation 4 (Curtis, 1967) Figure 4 (b). The result further found that in Equation 5 (Subasinghe and Harpriya 2014), different trend with errors clustered along the 0 error where it does not increase and remains constant as value of biomass increases. The outliers for Equation 5 lies between -0,04 and +0,02 Figure 4 (a) compared to other two equations (Equation 3 (Figure 4 (b) and Equation 4 (Figure 4 (c)) with much bigger error values.

Statistical analysis was also conducted for the different age grouping of tree species and the three formulae in order to verify and assertion the relevance of formulae across all age class as shown on the box plot (Figure 5).

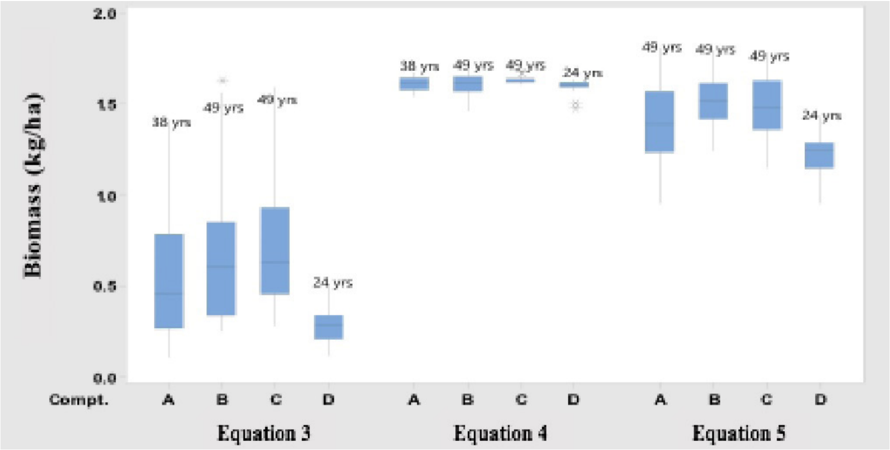


Figure 5: The relevance of variance between the Equation 3, Equation 4 and Equation 5.

As equality of variance (Figure 5) confirms, there was a lack of equal spread for the mean of biomass between the age group. Findings further indicates that the 24-year-old compartment has the lowest mean of biomass compared to the other three compartments.

However, the most interesting results was demonstrated by the fact that compartment with same age has the same mean difference and almost equal to each other. This clearly shows the relationship of age and biomass, meaning that, as trees grow older the more biomass and carbon can be produced.

Answering the research question

So far we have tested hypothesis by calculating biomass content of *Pinus caribaea* in Bulolo forest plantation and then testing three existing generics and allometric models in order to predicted and derived new modified formula. In the second part of this study is to answer the research question and it was centered on three main questions: “What is the stored carbon and biomass for *Pinus caribaea* tree species in Bulolo forest plantation”? “What will be the appropriate allometric equations applicable for biomass calculation/assessment for *Pinus caribaea* tree species in Bulolo forest plantations”? and “Is allometric model and equation developed in Sri Lanka for calculating biomass of *Pinus caribaea* suitable and more appropriate for *Pinus caribaea* tree species in Bulolo forest plantation”?

(i) “What is the biomass content and carbon stocking for *Pinus caribaea* tree species in Bulolo forest plantation?”

As *Pinus caribaea* being a coniferous, the tree species do not have huge branches and large amount of leaves, its carbon content concentrated on the stems. *Pinus caribaea* is also one of the fastest growing tree species in which the potential to produce high biomass content and carbon stocking in shorter time span superb most of forest plantation tree species. Ostadhashemi *et al*. (2014), stated about two methods of estimating biomass and carbon; first method was the destructive sampling in which whole tree is being cut down and all its components of leaves, branches, barks including roots and stems are being measured as weight dried and carbon is calculated directly from the components, Second method involves non-destructive sampling whereby uses measurable variables of a tree such as DBH and Height, and then develop an allometric model and equation to calculate and to estimate other trees in a stand for a particular species.

As since building modified version of species specific models from existing generics and allometric models is time consuming and very expensive exercise, allometric models that developed for a species is vital and it can be used for estimating biomass and carbon content easily from the measurable variables. This leads to the answering of research question 2.

(ii) “What will be the appropriate allometric equations applicable for biomass calculation/assessment for *Pinus caribaea* in Bulolo forest plantations”?

The three allometric models tested out for *Pinus caribaea* in this study was effective with a (p = 0,000) which indeed models were not suitable to species and site condition. As a result, further evaluation and trialing of these models using appropriate statistical method was carried out to identify best model that suitable for calculating carbon storage and stem biomass content of *Pinus caribaea* in Bulolo plantation. Testing and statistical analysis shows that the first two models were not suitable with a very weak correlation of biomass and dbh and lower R. sq. value. In this regard, the (Brown and Lugo 1992) is not suitable to be used when considering study site and the species selection, as also recommended by Coutinho *et al*. (2018) for Curtis log model. The study further explores whether allometric model and equation for calculating carbon of *Pinus caribaea* developed in Sri Lanka more appropriate for *Pinus caribaea* compartments in Bulolo forest plantation which leads to the answering of research question 3.

(iii) "Is allometric models and generic equations developed at Sri Lanka for calculating carbon and biomass content of *Pinus caribaea* is appropriate for *Pinus caribaea* compartments in Bulolo forest plantation"?

In this study, the biomass components and the study site may have caused the contortions of the final results. In fact, Subasinghe and Harpriya (2014), did the exact version of the study at the site that is more similar to Papua New Guinea, in Sri Lanka, and the components studied were same as this study, however; height was measured accurately using climbers as reveals when comparing Figure 4 and Figure 5.

This study established new allometric equation in order to determine and calculate carbon storage, stocking and stem biomass content of *Pinus caribaea* in Bulolo forest plantation. The new allometric equation was derived from synthesis of three main formulas: Brown and Lugo 1992; (Curtis, 1967) and then (Subasinghe and Harpriya 2014) and further compare and contrast of their carbon and biomass stem content. In this process, regression analyses was carried out to build the mathematical relationships between stem biomass and the DBH (diameter reading at 1,3 metre above ground level). Study reveals that new allometric equation for calculating and estimating stem biomass (SB) of *Pinus caribaea* tree species for Bulolo forest plantation is comprise of; 0,4250 + 0,02893 coefficient values of the allometric regression subtract (-) by 0,000123 R^2 at DBH as shown in the regression analysis and formulae (Equation 6) below.

Study recommend the *Log formula derived* from Subasinghe and Harpriya (2014), as the reliable model to estimate biomass and carbon stock for Bulolo forest plantation. The derive formula (Equation 6) from this study is presented below:

The regression equation is:

$$SB = 0,4250 + 0,02893\,DBH - 0,000123\,DBH2 \qquad (6)$$

SB = Stem Biomass

DBH = Diameter reading at 1,3 metre above ground level in centimeter (cm).

From the test result and discussion draws the conclusion and recommendation to the study.

CONCLUSIONS

Study reveals that log model and generic equation for calculating carbon stocking and biomass content of *Pinus caribaea* developed in Sri Lanka can more applicable for the estimation of above ground biomass and carbon of *Pinus caribaea* tree species in Bulolo forest plantation and else way in Papua New Guinea. It is also more efficient and effective as it is very practical to be used in Papua New Guinea and further it has minimum cost involved since the model can estimate the biomass and carbons as the function of DBH, which is easily measurable in the field.

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