速　報

# Volume table for Araucaria hunsteinii in Bulolo Wau forest plantations of Papua New Guinea [*1]

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Karmar M J, Yoshida, S., Mizoue, N., Murakami, T.：**Volume table for *Araucaria hunsteinii* in Bulolo Wau forest plantations of Papua New Guinea J.For.Res.　59：132－136，2006**　The volume equation for *Araucaria hunsteinii* (Klinkii) was developed using 196 stems data collected in 2002 from Bulolo Wau forest plantations in Papua New Giunea (PNG).The three formulae, that is Logarithmic, Combine Variable Formulae and Modified Combine Variable Formulae were nominated and used for the estimation of the volume regression using the sample to estimate volume of other DBH and height. To compare the precision of these three formulae Akaike's Information Criterion (AIC) was applied. The Combine Variable Formula was selected for the construction of volume table for Klinkii. The attained volume equation for Klinkii is V= 0.1089 + 0.000036 * $DBH^2$ * Height. This volume equation can now be used for estimating the volume for standing stand or stem of Klinkii given the required dimensions. Hence this volume table becomes a handy tool for Klinkii forest plantation managers, owners and industries where the data was collected.

**Key words**; Volume equation, volume table, Combine Variable formula, volume regression, *Araucaria hunsteinii,* Papua New Guinea.

## Ⅰ．Introduction

Since April 1995 collaborative work has progressed between Papua New Guinea Forest Research Institute (PNGFRI) and Japan International Cooperation Agency (JICA).Having realized the importance and need of volume tables for plantation trees in the nation JICA has positively intervened. To enhance the activities for constructing volume tables and it has become one of the very successful collaborative forest research activities by the end of JICA's term in 2002. As there were two publications, volume one and two on volume tables of selected plantation tree species of PNG. Most of the publication and other necessary expenditures were met by JICA. Hence, JICA was extremely forefront in the accomplishment of these research activities in terms of facilitating with appropriate work equipment, transfer of knowledge, training counter-parts and funding of supplementary activities. Some other volume tables produced about twenty to thirty years ago are now regarded as outdated and have to be revised. Those tables were constructed by Common Wealth Forestry Institute.

The intensive research of constructing volume table has commenced approximately ten years ago but there was no guarantee for consistency in the progress. Due to the national researchers (including the first author of this paper) were in the process of building up with knowledge on know how in constructing volume tables. Comparing with what has been accomplished and what is yet to be done the figure for yet to be done has super ceded. That is ten out of a hundred plus tree species in both natural and planted forests do not have their volume tables constructed. With such figures there is an urgency here to construct volume table for the remaining tree species as revealed by Asia Pacific Forestry sector Outlook Study 2005. That the only revenue generating government owned forest plantation is Bulolo Wau Pine project which provides logs at low cost to an antiquated (old fashion) and highly protected plywood mill. Replanting of this forest is below the sustainable level, at about 150 hectares per annum. Such unsustainable forest management notice proves that necessary knowledge and complementary information which could lead to sustainable management are not available to the forest managers. Construction of volume table for Klinkii in Bulolo Wau forest plantations will definitely play a major role in solving this hiccup.

Volume tables are surely very important tools for estimating forest yield and implementation of forest management approaches (Yelu and Omasa, 1998). Without volume table a yield of a forest stand can be over or under estimated and so the true value is denied. An accurate or even an approximate knowledge of volume or yield per hectare and average rate of growth per year tends to place forestry on a business basis

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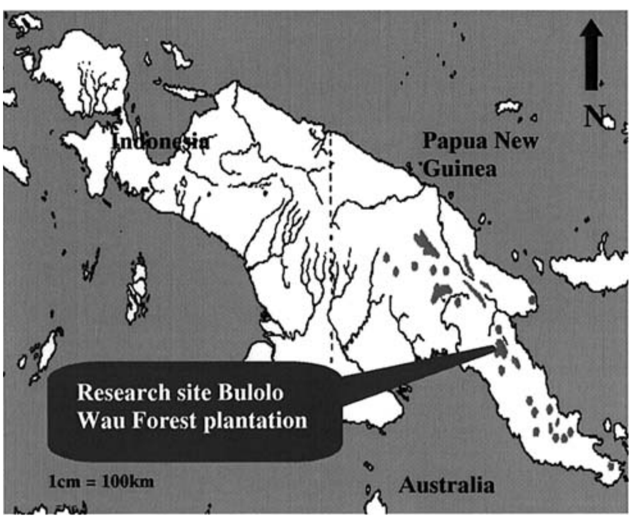
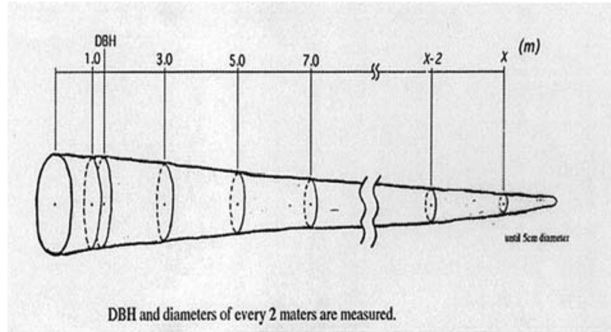
rather than one of blind speculations (Karmar, 2002). A volume table reduces time, cost and labor in the measurements of individual standing tree volumes. Klinkii is one of the conifers which are re-currently the most economical plantation tree species in PNG. For instance, the large stands are harvested in Bulolo and Wau forest plantations for utilization as plywood, furniture and structural timber. More than 1800 people are employees of this industry along (Gray 1973). Markets are done both domestic and abroad.
The objective of this study is to construct volume table for Klinkii and simultaneously study the methodology to construct future volume tables.

## Ⅱ. Study site

The distribution of the genus Araucaria internationally covering Argentina, Chile, Brazil Folkland Island in the western hemisphere and PNG, New Caledonia, Australia in the eastern hemisphere. The distribution in PNG is fairly scattered along and around the stretches of major ranges in the mainland of PNG pertain to Figure; 1. Some of the Araucaria dominant regions have not been reached by forest industries due to mainly geographical complications and financial constrains. At average the dimensions of this tree species from natural stands were triple compare to plantations. For instance average diameter from natural stand is 200 plus centimeter (de Laubenfels 1988) while plantation is around 50 at 45 years the cutting age.The parameters like age could be the main factor for this variance. The silvicultural component is comprised of commonly 883 stems per hectare, strip and ring tending and three to four thinning in which first thinning is always to waste at age between thirteen to fifteen and approximately ten years interval for later thinning.




Fig; 1 The spots on the map portray the distribution of natural stems of Klinkii. The study site was converted into plantation forest since 1950 covering an area of 12000 ha out of 59450 hectares of plantation forests in the country. The dominant tree species in the study site are *Araucaria hunsteinii* and *Araucaria cunninghamii* (Hoop).




Fig; 2 Indicates how field measurements were carried out. Butt logs were one meter and standard sections were two meters

## Ⅲ. Materials and method

### 1. Data collection

Field measurements data for 196 stems were gathered by PNGFRI and Bulolo Wau Pine Project. The basic data was from Bulolo Wau forest plantations as shown in Figure.1. The sampling was systematically covering every geographical condition of the plantations. The diameters at breast height (DBH) were taken while the stems were still standing. The butt logs were one meter and the successive sectional measurements commenced from there with diameter tapes until the last diameters were ten centimetres or less. The length of the tip of every stem was recorded. The volumes of the standard sections were calculated by applying Smalians formula and for butt logs were calculated by computing cross -sectional area and the volumes for the tips were moreover computed by cross-sectional area but multiplied by length and divided by three. Klinkii is an excurrent tree species and tips of most excurrent species are paraboloid frustums (Hush, Beers and Kershaw, 2003). Pertain to Figure; 2 for a better understanding. The heights were measured using measuring elastic tapes while stems were on the ground.

### 2. Volume formulae

In this study three formulas were applied and then compared to determine the most suitable volume equation. The first formula applied was the logarithmic volume equation introduced by Schumacher and Hall[3]. This formula is popular in PNG, Japan as well as other parts of the globe. The formula is detailed symbolically as;

$$\log V = a_1 + b_1 \log D + c_1 \log H \qquad \text{(A)}$$

where V denotes total volume, D denotes diameter at breast height, H denotes the total height, $a_1$ is regression constant and

$b_1$ and $c_1$ are regression coefficients. Utilizing the basic data $a_1$, $b_1$ and $c_1$ are determined by least-squares solution. Using the same notation as above, the combined variable formula is;

$$V = a_2 + b_2 D^2 \cdot H \qquad (B)$$

And the modified combined-variable formula is;

$$V = a_3 + b_3 D^{b1} \cdot H^{c1} \qquad (C)$$

The $b_1$ and $c_1$ are the regression coefficients obtained from the logarithmic or Schumacher formula;

**3. Comparisons of equations**

The procedure applied in the comparison was as follows:

1. Data check by both descriptive statistics and distribution of variables as shown in Table. 1.
2. The standard error of estimate and the standard errors of the regression coefficients were calculated for each of the three equations derived from the least-squares solutions using STATISTICA (version six) a statistical computer softwear.
3. The assessment of predictive strength of each formula by Akaike Information Criterion (AIC) a method that is embroiled to determine the suitable formula when models involved give results very much a like using the same data.

The AIC formula used is;

$$AIC = \frac{RSS}{\sigma^2} + 2p \qquad (D)$$

where, *RSS* denotes residual sum of squares and it is over variance, p denotes number of parameter that have been fitted in the equation.

## Ⅳ. Results and discussion

As shown on Table 2 the correlation coefficient for Logarithmic and Modified Combined-variable formulae have nearly excellent

Table 1. Frequency distribution of DBH and Height classes

| Sum of Count | DBH | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ht | 18-20 | 20-22 | 22-24 | 24-26 | 26-28 | 28-30 | 30-32 | 32-34 | 34-36 | 36-38 | 38-40 | 40-42 | 42-44 | 44-46 | 46-48 | 48-50 | 50-52 | 52-54 | 54-56 | 60-62 | 62-64 | Grand Total |
| 12－13 | | 1 | | | | | | | | | | | | | | | | | | | | 1 |
| 15－16 | 1 | | | | | | | | | | | | | | | | | | | | | 1 |
| 16－17 | 1 | | | | | | | | | | | | | | | | | | | | | 1 |
| 17－18 | | 2 | 1 | | | | | | | | | | | | | | | | | | | 3 |
| 18－19 | | | 2 | | | | | | | | | | | | | | | | | | | 2 |
| 19－20 | 2 | | 2 | | | 1 | | | | | | 1 | | | | | | | | | | 6 |
| 20－21 | | | | | | | | 1 | 1 | | | | | | | | | | | | | 2 |
| 21－22 | 1 | | 1 | | 1 | 1 | | | | | | | | | | | | | | | | 4 |
| 22－23 | | 1 | 1 | 1 | 1 | | | | | | 1 | | | | | | 1 | | | | | 6 |
| 23－24 | | | 1 | | 4 | 1 | | | | 1 | | | | | | | | | | | | 7 |
| 24－25 | | | | | 2 | 2 | 2 | | 1 | | | 1 | 1 | | | | | | | | | 9 |
| 25－26 | | | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | | | | | | | | | 6 |
| 26－27 | | | | | 2 | | 2 | | | 1 | 1 | | | | | | | | | | | 6 |
| 27－28 | | | | 1 | 1 | 4 | 1 | 1 | | | 1 | 2 | | | | | | | | | | 11 |
| 28－29 | | | | | | 1 | | 2 | 2 | | 1 | 1 | | 1 | | | | | | | | 8 |
| 29－30 | | | | | 5 | 2 | 7 | | 1 | 2 | 1 | 1 | 1 | | | | | | | | | 20 |
| 30－31 | | | | | 2 | | 2 | | 1 | | | 3 | | | 1 | | | | | | | 9 |
| 31－32 | | | | | 1 | 2 | 2 | | 1 | | 1 | 1 | | | | | | | | | | 8 |
| 32－33 | | | | | | 1 | 1 | 2 | 1 | 1 | 1 | 1 | | 2 | | | | | | | | 10 |
| 33－34 | | | | | | | 1 | 2 | 1 | 1 | 1 | | | 2 | 2 | 1 | | | | | | 11 |
| 34－35 | | | | | | | | 1 | 3 | | 5 | 3 | | 1 | 1 | | | | | | | 14 |
| 35－36 | | | | | 1 | | 1 | 4 | 2 | | 1 | 1 | | 1 | 3 | | | | | | | 14 |
| 36－37 | | | | | | | | | 5 | 1 | 2 | | | 1 | | | | | | | | 9 |
| 37－38 | | | | | | 1 | 1 | | | 1 | 1 | | 1 | | | 1 | | | | | | 6 |
| 38－39 | | | | | | | | | 1 | 2 | | | 1 | | 2 | | | | | | | 6 |
| 39－40 | | | | | | | | | | 1 | | 2 | 1 | 2 | 1 | | | | | | | 7 |
| 40－41 | | | | | | | | | 1 | 2 | | 1 | | | | 1 | | 1 | 1 | | | 7 |
| 41－42 | | | | | | | | | | | 1 | | | | | | | | | | | 1 |
| 42－43 | | | | | | | | | | | | 1 | | | | | 2 | | 1 | | | 4 |
| 43－44 | | | | | | | | | | | 1 | | | | 1 | | 1 | | | 1 | | 4 |
| 44－45 | | | | | | | | | 1 | | | | | | | | | | | | | 1 |
| 45－46 | | | | | | | | | | | | 1 | | | | | | | | | | 1 |
| 46－47 | | | | | | | | | | | | | | | | | | | | | 1 | 1 |
| Grand Total | 5 | 4 | 9 | 2 | 21 | 17 | 21 | 13 | 22 | 14 | 20 | 20 | 5 | 10 | 11 | 3 | 4 | 1 | 2 | 1 | 1 | 206 |

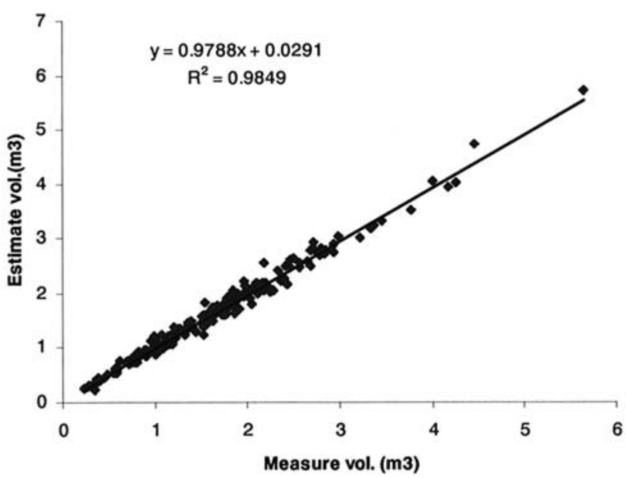
Table 2. Results among them being regression coefficients, residual sum of squares, standard error of estimate for Combined-Variable, Logarithmic and Modified Combined-variable formulae for computing total cubic-meter vzolume of trees

| FORMULAE | Logarithmic $LogV{=}a_1 + b_1 logD + c_1 LogH$ | | | Combined-variable $V = a_2 + b_2 D^2 H$ | | Modified combined-variable $V = a_3 + b_3 D^{b1} H^{c1}$ | |
|---|---|---|---|---|---|---|---|
| Parameter | $a_1$ | $b_1$ | $c_1$ | $a_2$ | $b_2$ | $a_3$ | $b_3$ |
| Regression constants and coeffcient | − 4.1101 | 1.8068 | 1.0044 | 0.1089 | 0.000036 | − 0.0051 | 0.000078 |
| Standard Error of estimate | 0.1083 | | | 0.1175 | | 0.1116 | |
| Residual sum of squares | 2.2992 | | | 2.7069 | | 2.4392 | |
| Akaike information Criterion（AIC） | 211 | | | 209 | | 213 | |
| $R^2$ | 0.9853 | | | 0.9827 | | 0.9849 | |

linear reliability than Combined-variable formula a percentage less should the $R^2$ values are rounded off to whole numbers.

To compare different models using the same data, Akaike Information Criterion (AIC) statistics is now considered preferable (Maindonald and Braun, 2003). The result of AIC analysis Combined Variable formula has the smallest value which means this formula has the best predictive power.

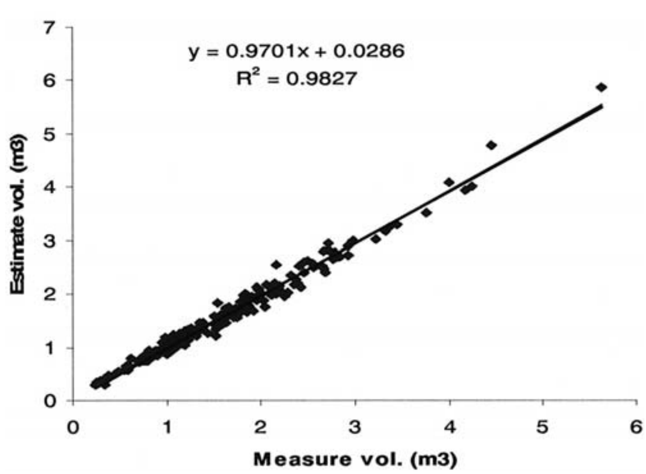
It is probable that the volume tables constructed from any of these three equation could be used with equal confidence because of not only by the adjusted $R^2$ values given by each formula but also based on estimated volume as evidenced in Figures.3.to 5 . The over all cubic meter volume for combined variable formula falls in between logarithmic and modified combined variable formula which means additional advantage for this formula.



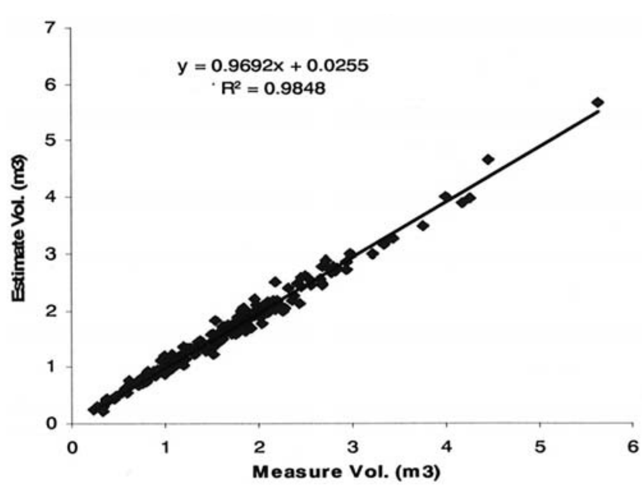

Fig; 3 The correlation between measure and estimate Volume using logarithmic formula

## Ⅴ. Conclusion and recommendation

The Combined Variable Formula ($V = a_2 + b_2 D^2 \cdot H$) provides the simplest, adequately precise method for the construction of the desired cubic volume table for Klinkii in Bulolo Wau forest plantations. Other forest researchers have also appreciated this formula. For instance Spur used different species from different regions and concluded that the combined variable formula gives the lowest standard error of estimate (Newnham, 1967). Beers and Gingrich (1958) had evaluated six different volume formulas to develop volume equation for Red Oak in Pennsylvania. The Logarithmic volume equation, the Australian formula and the combined variable formula were among the six formulas assessed. Their final remark was that the combined variable formula provides the simplest, sufficiently precise method for the construction of the desired volume cubic - foot volume for red oak in Pennsylvania. However, it is necessary to involve the three formulas if a different species is nominated for volume table construction and determine the formula that is sufficiently precise. The volume equation can be revised if necessary. The




Fig; 4 The correlation between measure and estimate Volume using combined variable formula




Fig; 5 The correlation between measure and estimate Volume using modified combined variable formula procedures used to develop these volume equations could be applied to construct volume tables for other plantation tree species as well as Klinkii growing in different sites and silvicultural treatments in PNG.

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