Accuracy testing of Wolf von Wulfing stand table in estimating teak stand volume

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Abstract. The Wolf von Wulfing (WvW) stand table made in 1932 is commonly used to estimate the volume of teak stands at a certain class of site quality (bonita) and age. A state forest enterprise (Perum Perhutani) usually uses the WvW table to estimate the volume of stands at the end of the cutting cycle or in other words used to determine the annual allowable cut (AAC). The accuracy level of estimated stand volume using WvW table still needs to be tested. This study aims to test the accuracy of the Wolf von Wulfing stand table in estimating the volume of teak stands (Tectona grandis), using measurement results data on teak stands in the Forest Management Unit (FMU) of Ciamis (West Java) and Randublatung (Central Java). We conducted an analysis by comparing the stand volume using the WvW table with the stand volume obtained using the local volume table (TVL) that already available in each study location. Data analysis was performed using simple linear regression: Y = β₀+β₁X; X = Volume WvW; Y = Volume TVL. Regression analysis results showed that the relationship between Volume WvW (X) and Volume TVL (Y), expressed through the equation of Y = -2.83 + 0.88X, with the value of R²adj=0.94. Hypothesis testing results on the value of β₀ and β₁, states that the value of β₀=0 and β₁≠1, so that it can be concluded that the alleged results with the WvW table are overestimating. Alleged overestimate results can cause overcutting so that forest management is not sustainable.

1. Introduction

The concept of the normal forest is a concept that has an important role in forestry practices, forestry-related regulations, and various fields in forestry science [1]. Normal forests can be interpreted as forests that can achieve "degrees of perfection" and can be maintained as forests to meet the provisions following the objectives of the forest landowner [2]. A normal forest can also be used as a reference that can be used to find out the shortcomings of forest management, and to realize sustainable forest management [3]. Forest product regulation is a classic forestry approach in regulating and scheduling forest product harvesting to realize normal forests [4]. Forest product management tries to regulate land so that each year the forest products obtained are at least the same or higher than the yields of the previous year. The concept is commonly called the concept of sustainability of results. The concept of yield sustainability is one of the criteria that must be considered in sustainable forest management in addition to other criteria [5].

The description of the normal forest in certain species is realized in the form of a table which is usually called a normal yield table or a normal stand table. The normal stand table reflects estimates of how the forest stand will grow in the future by looking at how the stand grew well in the past [6] [7].
Stand tables are tables that present information data about the dimensions of the stand that are normal for a particular type [8]. The normality of an actual stand is measured by the dimensional criteria found in the normal stand table, such as volume, base area, number of trees per hectare, etc.

The normal stand table is arranged specifically for a stand type based on periodic observations. In general, the normal stands are used in the age-old forest management activities to determine the level of normality of stands at a certain age, and help determine the amount of annual felling (AAC). One of the stands for teak is a normal stand table compiled by HE Wolf von Wulfing in 1932. The normal stand table is known in Indonesia as the WvW Table.

Teak (Tectona grandis) is one of the species that mostly grow on Java Island and has been managed since the Dutch East Indies government until the current state forest enterprise (Perum Perhutani) era [9]. Teak plantations in Java are currently experiencing a decrease in productivity and have an abnormally wide forest structure indicated by dominant young stands (aged 1-20 years) [10] [11]. Many factors cause a decline in productivity and abnormal structure of teak plantations, including: improper forest planning systems, decreased quality of growing areas, and wood theft.

Perum Perhutani as a teak forest manager in Indonesia, has been using the WvW table for a long time to estimate the volume of teak stands at a certain class of quality of growth and age. The use of WvW tables in the field can speed up the process of determining the volume of standing trees. However, to date there has been no study of the accuracy of teak stand tables in estimating teak stand volumes, these estimates are used to determine the annual allowable cut (AAC). Errors in estimating the volume of teak stands can cause overestimate or underestimate. Overestimate estimation will cause AAC to be greater, so that there will be the potential for overexploited forests. Meanwhile, underestimate estimation will result in smaller AAC, so there is a possibility that the stand should be harvested (felled cooking), but not harvested. Therefore, testing is needed regarding the accuracy of the use of Wolf von Wulfing teak stand tables in estimating teak stand volume. This study aims to test the accuracy of the Wolf von Wulfing stand table in estimating the volume of teak stands. The hypothesis formed in this study is that "the alleged volume of teak stands using the Wolf von Wulfing (WvW) table does not differ from the actual volume estimated with the local volume table (TVL)".

2. Material and Method

Data collection and field observations were carried out from January to March 2017, at the FMU Ciamis, West Java and the FMU Randublatung, Central Java. The data in this study consisted of primary data and secondary data. Primary data are the data obtained directly in the field, such as diameter of the tree at breast height (130cm from ground level), and the height of the tree data in each measuring plot. Secondary data in this study are data on the general condition of the study site, planting year of stands in each plot (age), bonita based on maps, and maps of the work area, as well as local volume tables from each research location.

2.1. Data Field Collection

2.1.1. Shape and Size of Plot

The field data was collected by establishing 30-35 circular plots in each FMU. The area of plot adjusts to the rules used at Perum Perhutani, which is 0.02 hectare (radius = 7.89 meter) for age class II; 0.04 (radius = 11.28 meter) hectare for age class III, and IV; and 0.1 (radius = 17.84 meter) hectare for age class V and so on.

2.1.2. Plot Location Selection

The plot locations at each FMU were selected using a purposive sampling technique, with the criteria for the measurement plots spread evenly in KU II, III, IV, V, and so on, as well as in plots with bonita 3, 3.5, and 4. The plot takes begins by randomly determining the first center point of the plot. The distance of the center of the plot (plot) from the edge of the plot boundary of at least 50 meters. The distance between the center points of the plot in the same plot is 100 meters.
2.2. Data Analysis

2.2.1. Development of Regression Model, Model of Relationship between Volume WvW and Volume TVL. Regression models are compiled using simple linear regression to determine the relationship between the estimated volume and the WvW table and the actual standing volume obtained by estimating the local volume table. We conducted an analysis by comparing the stand volume using the WvW (Volume WvW) table with the stand volume obtained using the local volume table (TVL volume) that was available at each study location. It was hypothesized that the WvW Volume is equal to the TVL volume, so that if both values are plotted into the X and Y-axis coordinates they will form a line with an angle of 45°.

Model Yi = β0 + β1Xi

Where: Yi = Volume TVL (m³/ha) in plot i
Xi = Volume WvW in plot i
β0, β1 = regression parameter
α = 5%

2.2.2 Hypothesis test.

1) Hypothesis testing the significance of the regression model.
Hypothesis testing of H₀: β₁ = 0 vs H₁: β₁ ≠ 0
Criteria of the test:
If the value of $F < F_α (dbR, dbS)$ accept $H₀$
If the value of $F > F_α (dbR, dbS)$ decline $H₀$
Regression model significance if hypothesis $β₁ ≠ 0$ be accepted

2) Hypothesis testing the similarity of Volume WvW with Volume TVL.
Hypothesis $H₀ : Y = X$ vs $H₁ : Y ≠ X$, divided into 2 hypothesis testing as follows:
a. Hypothesis testing of the regression coefficient $β₀$
Hypothesis $H₀ : β₀ = 0$ vs $H₁ : β₀ ≠ 0$
Criteria of the test:
If value of $|t| = |b₀/Sb₀| < t_{α/2} (dbS)$, accept $H₀$
If value of $|t| = |b₀/Sb₀| > t_{α/2} (dbS)$, decline $H₀$

b. Hypothesis testing of the regression coefficient $β₁$
Hypothesis $H₀ : β₁ = 1$ vs $H₁ : β₁ ≠ 1$
Criteria of the test:
If value of $|t| = |(b₁-1)/Sb₁| < t_{α/2} (dbS)$, accept $H₀$
If value of $|t| = |(b₁-1)/Sb₁| > t_{α/2} (dbS)$, decline $H₀$

If the hypothesis testing of regression coefficient $β₀$ and $β₁$ obtained test result which state accept $H₀$ ($β₀ = 0, β₁ = 1$), so hypothesis $Y = X$ is accepted. However, if one or all of the hypotheses testing of $β₀$ and $β₁$ obtained the results decline $H₀$, so the hypothesis $Y = X$ cannot be accepted.

2.2.3. Validation of WvW Volume Accuracy Testing in estimating TVL Volume
Validation is done using 3 criteria, namely aggregate deviation (SA), average deviation (SR), and root mean square error (RMSE). The equation for calculating SA, SR, and RMSE values is as follows:
SA = \[\Sigma Y_t^i - \Sigma Y_a^i]/(\Sigma Y_t^i)\]

Where: \(Y_t^i = \) Volume WvW
\(Y_a^i = \) Volume TVL
Tolerance of SA → -1 < SA < 1 [12]

SR = \{\Sigma[|Y_t^i - Y_a^i|]/n\} 100%

Where: \(Y_t^i = \) Volume WvW
\(Y_a^i = \) Volume TVL
Tolerance of SR = max 10 % [12]

RMSE = \{\Sigma[(Y_t^i - Y_a^i)^2]/n\}^{0.5} (100%)

Where: \(Y_t^i = \) Volume WvW
\(Y_a^i = \) Volume TVL
RMSE <20% (smaller value is better) [12] [13]

3. Result

3.1. Model of Relationship between Volume WvW and Volume TVL

Analysis of the relationship between Volume WvW (X) and Volume TVL (Y) is done by compiling a simple linear regression equation. The regression analysis was performed using Microsoft Excel 2016 software and performed on all data that had been obtained from observations in the field at FMU Ciamis and Randublatung. The model of the relationship between TVL Volume and WvW Volume obtained from the regression results in Table 1.

\[
\text{Table 1. Model of the relationship between Volume WvW and Volume TVL} \\
\begin{array}{|c|c|c|c|c|}
\hline
\text{Regression equation} & R^2 & R^2_{adj} & F & F_{\alpha} (\alpha=5\%) \\
\hline
Y = -2.83 + 0.88X & 0.94 & 0.94 & 955.73 & 3.99 \\
\hline
\end{array}
\]

Based on the results of the regression analysis in Table 1, the value of F > F\(_\alpha\), it showed that the results of the regression model are significant. Therefore, testing can proceed to hypothesis testing of the regression coefficients \(\beta_0\) and \(\beta_1\). Table 2 shows the t-value (t-student) of \(\beta_0\) and \(\beta_1\) obtained from the regression results, and the results of the test decision on the two regression coefficients.

\[
\text{Table 2. Test results for regression coefficients} \\
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Regression coefficients} & \text{Value} & t & t_{\alpha/2} (\alpha=5\%) & \text{Test decision} & \text{Test conclusion} \\
\hline
\beta_0 & -2.83 & -0.56 & 1.99 & \text{accept } H_0 & Y \neq X \\
\beta_1 & 0.88 & 30.91 & 1.99 & \text{decline } H_0 & \text{} \\
\hline
\end{array}
\]
The results of hypothesis testing on the regression coefficients $\beta_0$ and $\beta_1$ indicated that the final decision of testing the hypothesis is that Volume WvW is not the same as Volume TVL. That means, based on these tests, the volume of the WvW table is inaccurate in estimating the volume of teak stands. Also besides, if WvW Volume and TVL Volume are plotted into Cartesian X and Y coordinates (Figure 1), information is obtained that the volume estimation using the Wolf von Wulfing stand table is inaccurate, and tends to produce overestimate results. This is in line with the results of previous studies conducted at the FMU Cianjur [14], and the FMU Madiun [12], that the WvW volume in estimating the volume of TVL tends to overestimate. Therefore, if the stand table is still used in determining the annual allowable cut (AAC) by Perum Perhutani, it will result in the AAC being greater than the expected value (overestimate). This causes the sustainability of forest products will be disrupted because the logging activities carried out will exceed the existing stock stands.

3.2. Adjusting the estimated volume of the WvW table with the Correction Formula.

Based on the results of testing the hypothesis and the results of the graph (plot), it can be said that the volume estimation using the Wolf von Wulfing table (Volume WvW) produces greater value than the estimation of the actual volume (TVL volume), or in other words produces an overestimate value. The difference in WvW volume and TVL volume can be caused by TVL volume using only one variable, which is the diameter at breast height. In contrast, WvW volume uses age and bonita variables. Also besides, the stand table (Wolf von Wulfing Table) is arranged in a normal stand state, where KBD is worth 1 (one), and the bonita remains throughout the cycle. Therefore, a volume adjustment is needed that can cover the excess volume estimate from the Wolf von Wulfing teak stand table. There are three possible adjustments to the correction formula used in determining the corrected WvW Volume ($V_{WvW}^\prime$) value, as follows:

1. If $\beta_0 \neq 0$ (decline H0) dan $\beta_1 \neq 1$ (decline H0)
   
   $$V_{WvW}^\prime = \beta_0 + (\beta_1 \times V_{WvW})$$

2. If $\beta_0 = 0$ (accept H0) dan $\beta_1 \neq 1$ (decline H0)
   
   $$V_{WvW}^\prime = V_{WvW} \times \beta_1$$

3. If $\beta_0 \neq 0$ (decline H0) dan $\beta_1 = 1$ (accept H0)
   
   $$V_{WvW}^\prime = V_{WvW} + \beta_0$$

Based on the results of the hypothesis testing of the regression coefficients $\beta_0$ and $\beta_1$, the correction formula was chosen for adjustment of WvW volume, the second correction formula. The volume of alleged results with the WvW table must first be multiplied by the value $\beta_1 = 0.88$. Therefore, the adjustment equation for WvW Volume becomes $V_{WvW}^\prime = V_{WvW} \times 0.88$. 

Figure 1. Graph the distribution of Volume WvW and Volume TVL in the Cartesian diagram
3.3 Validation of the accuracy of the estimation of the WvW table in estimating TVL volume, after adjusting the formula

Testing the accuracy of the estimation of the WvW table in estimating the final volume of the cycle is also tested using the aggregate deviation criteria (SA), average deviation (SR), and root means square error (RMSE). The accuracy of this model can be measured based on Aggregate Deviation (SA), Mean Deviation (SR) and Root Mean Square Error (RMSE) [12] [13]. Table 3 shows the SA, SR and RMSE values from testing between WvW Volume and TVL Volume both before and after being corrected by the adjustment formula. It can be concluded that after adjusting to the correction formula, the values of SA, SR, and RMSE decreased dramatically. The values of SA, SR and RMSE which are within tolerance limits after adjusting the WvW Volume with this correction formula show that the corrected WvW Volume (VWvW') has high accuracy in estimating the final volume of the cycle. This shows that the Wolf von Wulfing table that was made in 1932 needs an adjustment (correction).

Table 3. Differences in SA, SR, and RMSE values before and after VWvW adjustment with the correction formula

| Criteria     | The alleged volume of WvW tables before adjustment | The alleged volume of wvw tables after adjustment |
|--------------|---------------------------------------------------|--------------------------------------------------|
| SA           | 0.14                                              | 0.02                                             |
| SR (%)       | 15.07                                             | 8.06                                             |
| RMSE (%)     | 22.23                                             | 11.29                                            |

The result of estimating the volume at the end of the cycle with the WvW stand table is inaccurate, it can be caused by the assumptions in the WvW table having a fixed bonita throughout the cycle. In addition, the approach used in estimating the age of the cycle with a WvW table is bonita with heightening parameters and plant age only. However, it should be remembered that natural conditions cannot be assumed to be constant, bonita can change in certain time conditions [16]. In addition, the estimation of actual volumes with local volume tables can also lead to inaccurate results.

4. Conclusion

The Wolf von Wulfing table that was made in 1932 needs an adjustment (correction). The alleged results with the WvW table are overestimating. Alleged overestimate results can cause overcutting so that forest management is not sustainable.

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