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TIME CONSUMPTION AND PRODUCTIVITY OF TREE BUCKING OF SENGON (*Paraserianthes falcataria*) IN PRIVATE FORESTS

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ABSTRACT

Tree bucking is a forest harvesting phase that determines the quality of logs. Efficient tree bucking process is a prerequisite for sustainable forest harvesting. The study aimed to analyze the working time of tree bucking, measure productivity, and develop a regression model of the productivity of tree bucking using a chainsaw in private forests. The study was conducted in private forests planted with an agroforestry pattern in the Probolinggo district, East Java. Working time measurements were carried out based on analysis of video images recorded during data collection in the field. The number of tree bucking work cycles observed was 31 cycles. Regression analysis was used to analyze the relationship between the logs' diameter and length and the bucking's productivity. The average working time for bucking was 7.09 minutes per cycle, consisting of 77.84% time for working, and 22.16% non-working time. The average productivity of tree bucking was 2.51 m^3/hour. The study showed that the productivity of tree bucking was a function of log diameter and length. The study provided important empirical results regarding bucking's working time and productivity in private forests where the tree species felled was sengon. The results of study will be useful in improving planning and tree bucking techniques in private forests in Indonesia.

Keywords: bucking; logs quality; private forests; working time

INTRODUCTION

Private forests are growing rapidly in Indonesia to alleviate poverty and community development by providing various goods and services. There are three planting systems in private forests in Indonesia, namely monoculture, mixed forest, and agroforestry. Agroforestry patterns are the dominant type of private forests in Indonesia (Sanudin & Fauziyah 2015; Hasanudin et al. 2022). In the private forets planted with agroforestry pattern, forestry plants are planted with other plants such as multi-purpose tree species (MPTS) plants, plantation plants and agricultural crops in one unit of land. Each type of plant contributes significantly to the income and welfare of private forest farmers (Arinah et al. 2021; Anjarsari et al. 2022).

A total of 25 wood species are commonly planted in private forests in Indonesia. Of the 25 species, 9 species are most commonly found, namely sengon (*Paraserianthes falcataria*), teak (*Tectona grandis*), rubber (*Hevea brasiliensis*), jabon (*Anthocephalus chinensis*), mahogany (*Swietenia macrophylla*), mangium (*Acacia mangium Miller*), rosewood (*Dalbergia latifolia*),

pulai (*Alstonia scholaris*), pine (*Pinus Merkusii*) and suren (*Toona sureni*) (Hermudananto & Supriyatno 2019; Yuwono & Hilmanto 2015; Soendjoto 2008; Jariyah & Wahyuningrum 2008). Those wood species are a popular raw material for the sawmilling, plywood, and bare core industries, but sengon is the dominant tree species planted in the private forests in Indonesia.
Tree bucking is an important phase in forest harvesting operations and directly influences the profits of forest harvesting operation. The felled trees are cut into several logs with chainsaw or harvester (Akay 2009; Lotfalian et al. 2016). Optimal tree bucking will produce high income and recovery rate (Wang et al. 2007; Andayani et al. 2017). Tree bucking can be carried out at logging sites or the landing (Borz et al. 2023). The forest harvesting method used in private forests in Indonesia is short wood. In this method, the length of logs removed from the forest varies from 1 to 2 m (Budiaman & Komalasari 2012). Chain saw is a common tool in logs bucking in private forests in Indonesia (Gautama 2008; Mujetahid 2009).
Tree bucking generally requires a lot of time to process each fallen tree. A time study is needed to measure the distribution of time spent during the tree bucking process. Time study is a systematic and critical measurement, classification, and analysis of time, carried out to increase work efficiency by eliminating useless activities that consume time (Björheden & Thompson 1995). In addition, working time is needed to investigate the main factors influencing work productivity and to establish a basis for cost calculations, salaries, or wage payments, and used to improve forest harvesting operations (Numinen et al. 2006).
Studies that examine the analysis of work time and the work elements of tree bucking in private forests in Indonesia are still rare. Previous studies focused more on productivity and cost analysis issues. Therefore, the study aims to analyze the time consumption and productivity of tree bucking in private forests that cultivate sengon as the dominant tree species.

METHOD

Study site

The study was conducted on an area of 0.59 ha of private forests planted with an agroforestry pattern in Roto village, Krucil sub-district, Probolinggo district, East Java. The study site was located at 7º 53' 27" S and 113º 36' 41" E. The altitude of the study site ranged from 600-700 meters above sea level. The private forest stands observed consisted of forestry plants (sengon and balsa), multi-purposive tree species (banana, mango, and avocado), plantations (coffee), and agriculture crops (porang, cassava, gamal and elephant grass). The study was conducted from February to March 2023.

Worl element of tree bucking

A selective cutting system was used in the observed private forests. The tree bucking was carried out in the cutting area. The tree bucking was carried out by a team consisting of 1 operator and 1 helper. After the tree falls, the helper begins to measure the length of the tree and makes cutting line on the tree. The length of the stem was the same, namely 1.30 m. The chainsaw operator cut the tree and cleared the branches and twigs. The tree bucking started from the base to the top of the fallen tree. The chainsaw used was a Chinese manufacturer (Maestro 456), which has an engine capacity of 52 cc, weight of 10 kg, and bar length of 50 cm. The chainsaw operator had more than 10 years of experience working in the field of forest harvesting.
Working time measurements were carried out based on analysis of video images recorded during tree bucking operation in the field. A digital video camera equipped with an internal clock was used to record tree bucking process. The tree bucking at the study site consisted of three work

elements, namely walking towards the fallen tree, bucking tree, and cutting branches and twigs (Table 1).

Table 1 Working element of tree bucking in the study site

Work element	Starts	End
Walking towards the fallen tree	The chainsaw operator and helper begin to move toward the fallen tree	The chainsaw operator and helper arrive at the fallen tree
bucking tree	The helper begins to measure the tree length, and makes a cutting line on the tree, the chainsaw operator starts to cut the first stem	The chainsaw operator finishes cutting the tree
cutting branches and twigs	The chainsaw operator cuts branches and twigs	The chainsaw operator finishes cutting branches and twigs

Sample quantity

A preliminary study with 31 cycles was conducted to determine the number of samples for time study and identify the work element of tree bucking. The number of samples needed was determined by the formula of Sutalaksana (2006). The sufficiency of sample quantity was tested by comparing the minimum amount of data required (N') with the number of measurements in the preliminary study (N). The number of tree bucking cycles was considered sufficient if N' ≤ N. The test showed that with a 95% confidence level, and accuracy level of 10%, the N' value was 27. Thus, the number of measurements in the preliminary study was sufficient and can be used to analyze the working time of tree bucking.

The quantity of samples was determined using the following formula:

$$N' = \left(\frac{\frac{K}{S}\sqrt{N(\sum Xi^2) - (\sum Xi)^2}}{\sum X\,i} \right)$$

N': minimum amount of data required
N: number of measurements in the preliminary study
K: confidence level
S: accuracy level
Xi: i-th observation

Classification of tree bucking time

The working time classification used in this study adopted the working time classification from Bjorheden & Thompson (1995). The working time recorded in this study was the working time at the workplace (Workplace Time, WP). WP consists of Non-Working Time (NT), and Working Time (WT). WT includes Productive Working Time (PW) and Supporting Working Time (SW). PW consists of Main Time (MW) and Complementary Time (CW), while SW includes Preparation Time (PT), Supporting Time (ST), and Additional Working Time (AW). The observed activities according to the working time structure are presented in Figure 1.

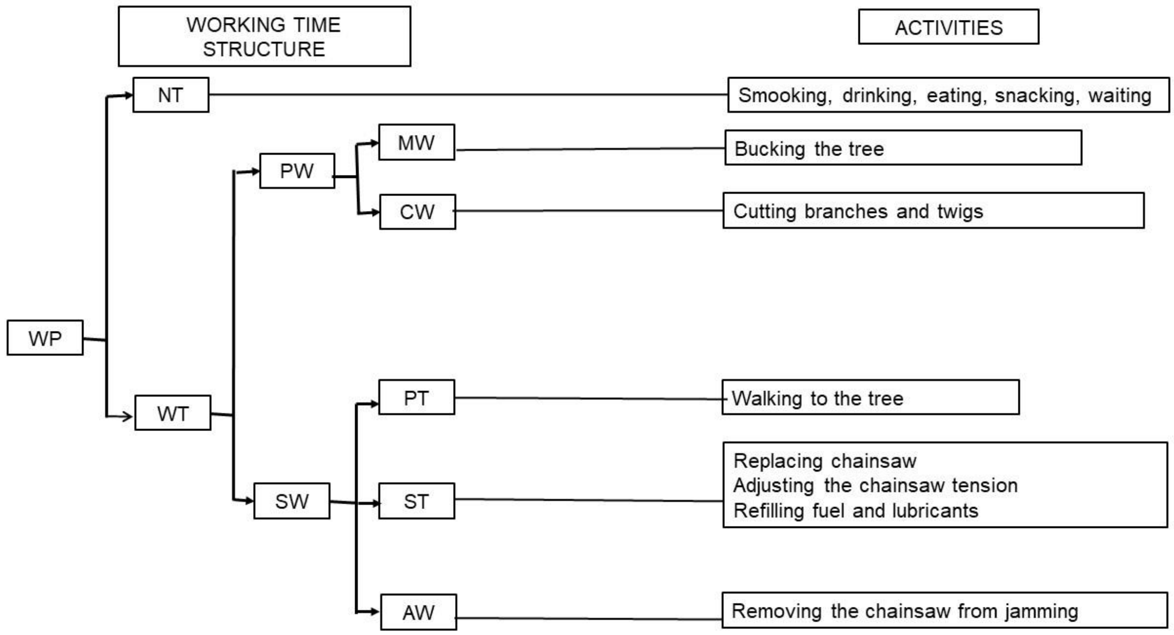

Figure 1 Structure of working time and work element of tree bucking in the study site.

Productivity

The productivity of tree bucking was determined by analyzing the amount of time for the tree bucking operation of the fallen tree. The tree diameter and length of each produced log were then measured to determine the production of tree bucking. The volume of each log was calculated using Brereton's formula (BSN 2020). The productivity of tree bucking was calculated based on log volume (m^3) and working time (hours) (Jourgholami et al. 2013; Lotfalian et al. 2016). The diameter of logs was determined using the following formula (SNI 8911 2020):

$$d = \frac{1/2\,((d1+d2)+(d3+d4))}{2}$$

d: average diameter (cm)
d1: shortest diameter at the base of the log (cm)
d2: longest diameter at the base of the log (cm)
d3: shortest diameter at the top of the log (cm)
d4: longest diameter at the top of the log (cm)

The volume of log was calculated using the following formula (SNI 8911 2020):

$$V = \frac{1}{4}\pi\left[\frac{1/2(Dp+Du)}{100}\right]^2 x\,P$$

V: volume (m^3)
Π: constant (3.14)
Dp: base diameter (cm)

Du: top diameter (cm)
P: log length (m)

The productivity of tree bucking was calculated using the following formula:
Menggunakan rumus:

$$P = \frac{V}{W}$$

P: productivity (m^3/hours)
V: log volume (m^3)
W: working time (hours)

Data analysis

The study used descriptive and regression analysis. Descriptive analysis is a statistical method that provides patterns or general descriptions of research subjects based on variable data obtained from certain subject groups (Hastono 2006). The data from the study were presented in the form of tables, histograms, average values , and percentages. Working time data was grouped based on work elements and working time structure. Regression analysis was used to analyze the relationship between dependent and independent variables in the tree-bucking productivity estimation model. Lotfalian et al. (2016) reported that the productivity estimation model for tree bucking using a chainsaw was linear regression. In the study, the dependent variable was the tree diameter and length of the logs, while the independent variable was tree bucking productivity based on effective working time. The confidence intervals were 95% (= 0.05, $p < 0.05$).

RESULT AND DISCUSSION

The average tree diameter of logs from tree bucking was 25.48 cm and the tree length was 18.95 m. The total number of logs produced from tree bucking was 393. The average number of logs produced per tree ranges was 13 logs. The average volume of logs per tree was 0.30 m^3 (Table 2).

Table 2 Statistics of logs of tree bucking in the study site

Variable	Average	Range
Log diameter (cm)	25.48	10.40-49.00
Log length (m)	18.95	2.60-37.00
Number of logs per tree	13.00	2-19
Volume per tree (m^3)	0.30	0.02-0.90

The average working time of tree bucking was 7.09 minutes per tree, consisting of a working time of 4.42 minutes (77.84%) and a non-working time of 2.57 minutes (22.16%). Non-working time includes operational delays, personal delays and equipment delays (Table 3). In terms of time for work, bucking the tree was the highest component of working time (2.89 minutes), followed by time for cutting branches and twigs (1.01 minutes), equipment delays (0.56 minutes), operational delays (0.54 minutes) and finally walking to the tree to be bucked (0.52 minutes).

Table 3 Work time distribution of bucking per cycle in the study site

Work element	Work time	
	(minutes)	(%)
Walking towards the fallen tree	0.52	7.34
Cutting branches and twigs	1.01	14.30
Bucking the tree	2.89	40.74
Operational delay	0.54	7.59
Personal delay	1.57	22.16
Equipment delay	0.56	7.86
Total	7.09	100

Based on the structure of working time, main working time is the highest component of tree bucking (40.74%), followed by non-working time (22.16%), complementary time (14.30%), supporting time (7.86%), additional time (7.59% minutes) and finally preparation time (7.34%) (Figure 2).

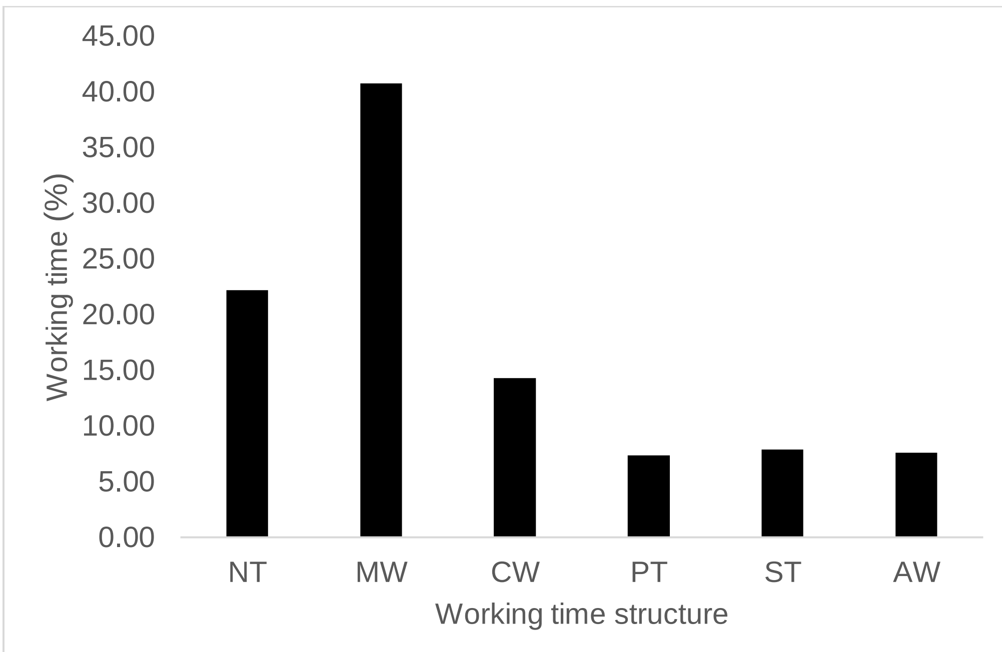

Figure 2 Distribution of work time of tree bucking in the study site. (NT: Time not for work; MW: Main time, CW: Complementary time; PT: Preparation time; ST: Supporting time; AW: Additional time).

The study showed that the average volume of log was 0.30 m^3. The average time spent for tree bucking per tree was 0.11 hours, while the average effective time for tree bucking per tree was 0.07 hours. Based on the total working time, tree bucking productivity at the study site was 2.51 m^3/hour, while based on the effective working time, the productivity of tree bucking was 4.07 m^3/hour. The estimation model of tree bucking productivity was Y= -2.91 + 0.21 log diameter + 0.23 tlog length, with an R^2 value of 0.81. Productivity of tree bucking generally increases with increasing log diameter and log length. Based on the analysis of variance, it was found that log diameter and log length were significant factors included in the regression model to tree bucking productivity (Table 4).

Table 4 Analysis of variant of tree bucking productivity in the study site

Source	df	Sum of square	Mean square	F	Probability
Regression	2	488,8735	244,4368	146,0286	1,54E-15
Error	28	46,8691	1,673897		
Total	30	535,7426			

The study of Borz et al. (2023) showed that the wood species does not significantly influence the working time and productivity of the tree bucking. On the other hand, scientific publications related to working time and productivity of tree bucking of sengon in private forests in Indonesia are not yet available. Therefore, the study was compared with previous study carried out on wood species other than sengon.

The study showed that most of the time spent for tree bucking sengon in private forests was work time, while the rest was non-work time. Non-working time was used for activities such as chatting, smoking, eating, drinking and waiting. The study obtained smaller working time compared to previous studies. The study showed that the time for working was 62%, while the time not for working reached 38% of the total time. Personal delays of chainsaw operator contributed up to 22.16% to the total working time of tree bucking. Gautama (2008) reported that the time to work for tree bucking of teak wood in private forests in South Sulawesi was 89.51%. Meanwhile, Matangaran and Saputri (2023) reported that the time for tree bucking of rosewood (*Dalbergia latifolia*) was 77.41%. Other studies in Italy and Albania produced similar data with the study. Kortoci & Kortoci (2020) reported that unavoidable time delays occurred in tree bucking was 21.35% in Monte Amiata, Italy and 36.93% in Dardhe Xhyre, Albania, respectively.

The study showed that the productivity of tree bucking of sengon at the study site was different from previous study. The productivity of tree bucking at the study site was 2.51 m^3/hour, while the productivity of tree bucking of teak wood Sulawesi was 1.42 m^3/hour (Mujetahid 2009) and 4.67 m^3/hour (Gautama 2008). The difference in the productivity of tree bucking was caused probably by the size of the log (log diameter and length), the type of chainsaw used, and the skill of the chainsaw operator. The study showed that the average log diameter and length significantly influenced the productivity of tree bucking. Cutting the tree into several logs was the most time-consuming element during the tree bucking process, and accounted for up to 41% of the total time per cycle. The productivity of tree bucking can be described well in a model with the average log diameter and length. Borz et al. (2023) reported that the most suitable model to explain the efficiency and productivity of tree bucking was a linear regression equation using log diameter and length as predictors. Besides, the success of tree bucking is also influenced by several factors, including worker skills (Borz et al. 2023), work experience, worker health, and the equipment used (Gautama 2008).

CONCLUSION

Most of the working time for tree bucking of sengon in private forests was time for work. The bucking of the tree was the most time-consuming work element of tree bucking. The productivity of tree bucking varied according to the log diameter and length. The productivity of tree bucking can be described well in the regression model with average log diameter and length as predictors. It is expected that the findings from the study will be useful for private forest harvesting managers to improve work systems and assist decision-making in private forest harvesting. The study can also be used by related parties such as the Ministry of Forestry, the forestry service, or researchers to simulate the productivity of tree bucking and to determine the need of training for forest harvesting workers in private forests.

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