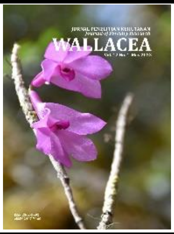

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Article

Impact of land slope, stand density, and basal area on fire intensity in Tusam (*Pinus merkusii*) plantation forest

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Abstract

Forest fires are not solely determined by the quantity and quality of plant debris as fuel, but also influenced by some extrinsic factors. This study aims to examine the effect of some factors (slopes, stand density, and tree basal area) on the intensity of forest fires. The study was conducted in a 1 ha (100 m x 100 m) plot in the Pinus merkusii plantation 10 months after the fire. The plot was divided into 10 m x 10 m subplots, therefore there were 100 subplots. Each tree over 5 cm in diameter found in the plot was numbered consecutively, recorded its species name, measured its diameter, and determined whether it was alive or dead. The slope level in each subplot was measured. Multiple regression analysis was used to detect the influence of slope level, stand density, and basal area on the number of dead trees in each subplot. Results show that slopes, stand density, and basal area influenced proportionally the intensity of forest fires (R^2 = 0,507; p<0.05). However, when the partial analysis was applied to detect the influence of each class factor, not all of the classes were found significant. These results reveal that there are several other factors that are not measured in this study that might also influence fire intensity, which we suspect include tapping holes.

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INTRODUCTION

Fire is one of the factors causing forest function decline. The impacts of forest fires include reduced forest cover, damage to soil ecosystems, and even reduced wildlife habitat (Njeri et al., 2018). Based on observations of forest fires in 1997/1998 in Indonesia, it is known that plantation forests rank 4th in terms of burned area (955,988 ha) after lowland natural forest (3,598,880 ha), agricultural land (3,496,808 ha), and peat swamp forest (2,124,000 ha) (IFFM 2003 in Akbar, 2007). The plantation forest that often experiences fires is the *Pinus merkusii* Jungh et de Vriese (Tusam) plantation forest. Rodrigues-Corrêa et al. (2013) and Rubini et al. (2022) reported that this tree species produce a flammable resin called oleoresin. The large use of pine trees in the form of tapping sap and as a tourist attraction increases the possibility of fires in pine plantations.

Reducing the accumulation of combustible materials in the forest is the most important step in reducing the potential for forest fires (Stephens et al., 2012). The accumulation of combustible material in question is a pile of litter in growing forests, stand density, and distance between tree crowns. Unlike natural forest, plantation forest has relatively the same spacing, so the density is higher. The higher the plant density, the higher the canopy density. Stand density also affects the total basal area of forest stands, which in turn will affect the duration of the fire (Song & Lee, 2016). Another factor that has the potential to affect the intensity of forest fires is topography. The slope can affect the direction and speed of the wind which will also contribute to the severity of forest fires (Syaufina & Sukmana, 2008).

Hasanuddin University Educational Forest has an area of Tusam plantation forest of approximately 306,61 ha. Weather conditions, people's behavior in using fire in the forest, and the topography of the forest area make this forest very prone to fires, especially during the dry season. Almost every year there are forest fires, especially in the Tusam plantation forest. In 2015 there were two forest fires occurrence, during September and November. The fire had devoured no less than 65 Ha of the Tusam plantation forest area at the time of the incident. This study aims to determine the impact of land slope (topography), stand density, and basal area cover on forest fire intensity in Tusam plantation forest in Hasanuddin University educational forest. We predict that higher-intensity fires will occur in areas with steeper slopes, and higher stand density. However, in the area with larger basal areas, the fire intensity will be lower.

METHODS

Study Site

This research was conducted in a burnt-over Tusam plantation forest located at the education forest of Hasanuddin University (4°59'38.354" – 4°59'35.195" South Latitude and 119°45'39.293" – 119°45'42.468" East Longitude) from June to August 2016. A 1-ha (100 m x 100 m) permanent plot was made with a horizontal projection. The plot was first created by setting the point X0Y0. Then the X-axis was made in the direction of the contour and the Y-axis was made to cut the contour towards the downslope. Distances along the X and Y axes are measured every 2.5 m and the difference in altitude (altitude) along the 2.5 m distance was measured and recorded (the "+ (plus)" sign was shown on the ascent and the "– (minus)" sign on descent). The X and Y axes were repeated every 10 m, so there were lines X0, X1, X2, X3, X4, X5, X6, X7, X8, X9, and X10, and lines Y0, Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, and Y10. Each X and Y axes will intersect and the intersection points are coded X0Y0, X1Y0, X2Y0, and so on up to X8Y10, X9Y10, and X10Y10. If we face the direction of the plot from the downslope, the X0Y0 intersection was at the top left of the plot, the X10Y0 intersection was at the top right of the plot, the X0Y10 intersection was at the bottom left of the plot, and the X10Y10 intersection was at the bottom right of the plot. Therefore, there were 100 subplots measuring 10 m x 10 m in the 1-ha permanent plot.

Each individual tree with a stem girth of >15 cm found in each subplot was numbered using an aluminum plate measuring 5 cm x 8 cm with an embossed number. In each subplot, each numbered tree was identified and recorded by its species name for non Tusam (several understorey trees are broadleaf species that invade this plantation forest.), then their stem girth was measured. The survival (alive or dead) of each species was also recorded. For individuals who are still alive, the condition of the crown (healthy or unhealthy) is also recorded. The measurement of the stem girth of the tree was carried out on the part of the trunk that was at the height of 130 from the ground. The part of the stem measured in girth was then marked with white paint circling the stem approximately 3 cm (1 in) wide. The number plate was mounted at a height of 30 cm above the part of the trunk where the girth is measured. The X and Y coordinates of each tree in each subplot were measured and recorded for mapping the position of the trees in the subplots. To test the impact of slopes on fire, the slope of each subplot was measured using a Sunto PM5 compass.

Data Analysis

Data analysis begins by first calculating the land slope, stand density, and total tree basal area in each subplot. From the number of trees found in each subplot, the number of dead and live trees was counted. Dead trees were differentiated into two categories, namely dead trees before the fire and dead trees after the fire. Post-fire dead trees will be an indicator of the intensity of forest fires. The land slope of each subplot, stand density per subplot, and basal area cover per subplot were divided into several classes. The slope of the land was divided into 4 classes (0-8°, 8-15°, 15-25°, and 25-45°). Density classes are divided into 3 classes (1-5 trees, 6-10 trees, >10 trees per subplot). The basal area was divided into three classes (< 5000 cm^2, 5000 – 10000 cm^2, and > 10000 cm^2 per subplot). Regression analysis was used to calculate the relationship between the number of dead trees per subplot and the slope of the land in each subplot, the density of stand per plot, as well as the basal area per subplot. Multiple regression analysis was applied to detect the simultaneous effect of land slope, stand density, and basal area cover on fire intensity as indicated by the number of dead trees. A single linear regression test was also applied to further examine the effect of each dependent variable on fire intensity as indicated by the number of dead trees. Statistical analysis was performed using the R application version 4.2.1 (R Core Team, 2021).

RESULTS

Overview of Plot

The slope of the land within the plots varies but is less than 45% overall (Fig. 1). The part of the plot

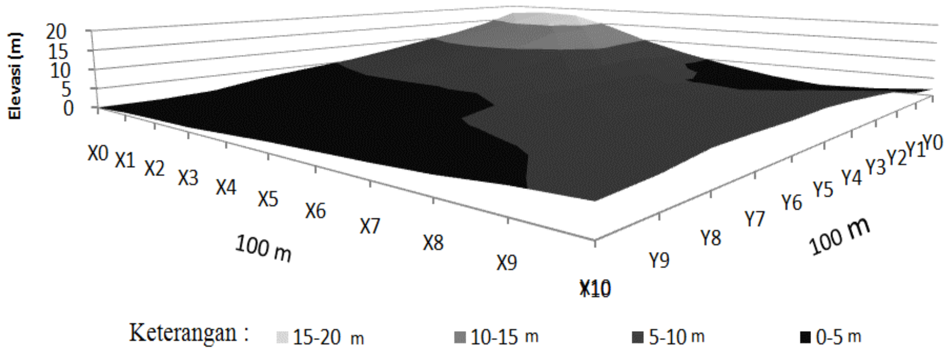

Figure 1. Research plot in three dimension

that is in the elevation area is located at the point X0 Y0 and its surroundings, while the part of the plot that is in the valley area is around the point X0Y10.

Land Slope vs Dead Trees

Among the 100 subplots, there were 33 subplots included in the 0-8% slope class, 36 subplots included in the 8-15% slope class, 21 subplots included in the 15-25% slope class, and the remaining 13 plots included in the 25-45% slope class. The average number of dead trees increased as the slope of the land became steeper (Table 1).

Stand Density vs Dead Trees

Stand density is the number of trees per unit area, where in this study the unit area used was subplots (10 m x 10 m). The total number of trees recorded in the plot was 855 trees consisting of 615 Tusam trees, 3 *Cinnamomum verum* trees, and 237 dead trees which were generally Tusam trees (Table 2). The average number of dead trees increased with increasing density. Fig. 2 shows the spatial distribution of trees in the plot. In general, trees appear evenly distributed, but dead trees appear to be clustered.

Table 1. The number of subplots in each slope class and the number of dead trees in the subplots in each slope class

Slope Class	Number of Plots	Number Dead Trees	Average of Dead Trees / Plot
0-8%	33	53	1.61
8-15%	36	68	1.89
15-25%	21	49	2.33
25-45%	13	46	3.33
Total	**100**	**216**	

Table 2. The number of subplots in each density class and the number of dead trees in the subplots in each density class

Density Class (Individual / Subplot)	Number of Subplots	Number of Dead Trees	Average Number of Dead Trees / Subplot
< 5	16	13	0.81
5 – 10	57	103	1.81
> 10	27	100	3.70
Total	**100**	**216**	

Basal Area vs Dead Trees

Basal area is the area of tree cover per unit area, where in this study the unit area used was subplots (10 m x 10 m). Most of the subplots are occupied by trees with a total basal area between 5,000 and 10,000 cm^2. Unlike the land slope class and stand density class, there is no clear pattern of relationship between basal area per subplot and the average number of dead trees. However, in the highest basal area class, it can be seen that the average number of dead trees is also the highest (Table 3).

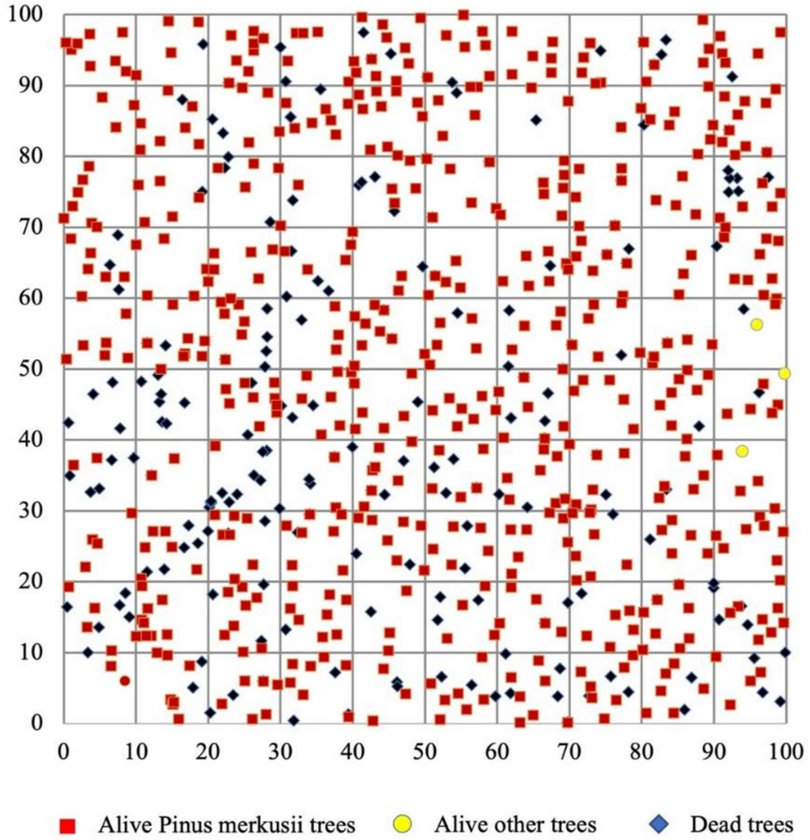

Figure 2. Tree spatial distribution in the plot

Analysis of the Effect of Slope, Density and Basal Area on the Number of Dead Trees

Assuming that the higher the fire intensity, the more trees die (Linder et al., 1998), then the fire intensity in this study was measured based on the number of dead trees. Dead trees in this study are trees that no longer have a crown and show no signs of regrowing after the fire. The results of multiple regression analysis showed that the three independent variables (slope class, density class and basal area cover class) analyzed had a significant positive effect on the number of dead trees as the dependent variable (Table 4).

Table 3. The number of subplots in each basal area class and the number of dead trees in the subplots in each basal area class

Basal Area Class (cm2 / Subplot)	Number of Subplots	Number of Dead Trees	Average Number of Dead Trees / Subplot
< 5000	22	57	2.59
5000 – 10000	72	131	1.82
> 10000	6	28	4.67
Total	**100**	**216**	

Table 4. The results of the regression analysis between the independent variables (land slope, stand density, and basal area cover) and the dependent variable (number of dead trees)

Independent Variables	Number of Dead Trees	
	Standard Error	**Probability**
Land Slope	0.071	= 0.008
Stand density	7.312	< 0.001
Basal Area Cover	0.000	< 0.001

DISCUSSION

The research plot was in an area with slope intervals ranging from 0% to 45%. Of the 855 trees over 5 cm in diameter recorded in the plots, higher stand densities were observed in areas with slopes ranging from 8% to 15%. It is confirmed that 237 of the total 855 trees recorded dead in the plot were Tusam. The number of dead trees per subplot is significantly and positively correlated to land slope, stand density, and basal area cover. This means that the steeper an area, the denser the stand, and the larger the basal area cover, the more trees will die from the fire. Given that the number of dead trees indicates fire intensity, the results of this study revealed that the increase in fire intensity in the Tusam plantation forest in the Hasanuddin University education forest is directly proportional to the slope level, stand density, and ground cover.

The significant role of slope as a stable environmental variable in affecting wildfire severity in bush and grassland areas has many been reported (Estes et al., 2017; Ghodrat et al., 2022). This study found that the slope also contributes significantly to increasing the severity of wildfires in the Tusam plantation forest. Since flames tend to point upwards, it makes sense that on steeper terrain, fire spreads more easily up slopes. In areas with steeper topography, the flames will accumulate to form taller flames with higher accumulated energy values. On steeper slopes, the tree crowns are arranged in a way that allows more sunlight to reach the forest floor. This allows the understorey on slopes to be denser and provide more fuel. In addition, as heat rises in front of the fire, it heats and dries the fuel on the upper slopes more effectively, making combustion easier, faster, and more energetic (Lecina-Diaz et al., 2014).

Another environmental element that affects forest fires is fuel load (Kreye et al., 2012). What is meant by fuel load is the abundance (density) of fuel and the size distribution of fuel (Diameter/basal area) in forest stands. The results of this study showed that the average number of dead trees in subplots was directly proportional to the stand density. The high density of the stand allows the fire to spread upwards through the interconnected branches and twigs so that areas with high density will experience of more fire intensity (see also Stephens et al., 2022). However, the results of further testing based on density classification show that not all density classes have a significant effect on fire intensity. Significant values were only detected between the number of dead trees and density classes of 6 - ≤10 individuals/100 m^2, and density classes >10 individuals/100 m^2 as well. This shows that there are inconsistencies in the results that can occur due to other factors that also play a role in each subplot but were not observed in this study.

Tree diameter is generally inversely proportional to density, meaning that the larger the diameter, the lower the stand density. Meanwhile, a larger diameter means a larger in basal area cover or volume of biomass (Brumelis et al., 2020). The results of this study revealed that the higher the density, the greater the number of dead trees. So the assumption is that if the density is high, which means the basal area is lower, then the number of dead trees will be greater. However, the results of this study are not in line with this assumption, where the basal area class also showed a significant and unidirectional effect on the number of dead trees, although with varying patterns. It is true that due to competition for space, the larger the trees the lower the density. Therefore, even though the density is low, a tree with a large diameter can have a large basal area, because the basal area is determined by the diameter.

Slope, stand density, and basal area cover may be the only three of the many factors that affect the intensity of forest fires. The finding that basal area cover has a unidirectional effect on fire intensity, which is inconsistent with the assumed relationship between density and basal area, may be due to other factors that we did not observe in this study. The Tusam trees in the forest that have experienced this fire are the trees that are being tapped for their resin. Our observations in the field showed that the bigger the tree, the more tapping holes were found. Zaluma et al. (2022) revealed that if a pine tree is tapped for a long time, especially if there are too many holes, the tree's health will decrease and it will be susceptible to pathogens. Trees that are tapped for too long with too many tapping holes may be not only weak against pathogen attack but also have weak resistance to fire.

The lower basal area in the subplot with higher stand density indicates that the tree size in the subplot with higher stand density is small. This can illustrate that at the same age of the stand, due to competition between individuals, the vigor of small trees is lower than that of large trees (see also Moreau et al., 2018). This could explain the findings of this study which showed that fire intensity indicated by dead trees increased with increasing stand density.

CONCLUSION

This research revealed that the slope (topography), stand density, and basal area cover had a significant effect on the number of dead trees, therefore these three factors affect the intensity of forest fires. The significant and unidirectional relationship between basal area cover that was found in this study is not in accordance with the assumptions built from the results of previous studies. This is probably due to the large Tusam trees in the research area being tapped for their resin so that the health of these trees decreases and causing them susceptibility to fire damage.

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