An Agent- Based Model on the Potential of a Dipterocarp Forest Fire

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Abstract

This study assessed the extent of flammability potential of a dipterocarp forest area considering the parameters on tree density and the probability of spread of fire. Specifically, it aimed to establish a picture on the potential of a dipterocarp forest fire with varied tree densities and probability of spread. The study also aimed to determine if there is a significant effect of tree density and the probability of the spread of forest fire to the percent of area burned, and creates implications for the planning of the intervention strategies for the control and prevention of forest fire. The Fire Simple Extension 1 Netlogo model of the Agent- Based Modeling was used in this study. This simulation system gave information as to the flammability potential of a forest, a dipterocarp forest in this case, taking into account the influence of tree density and probability of spread. The findings of the study revealed that the percent of area burned is dependent on tree density and the probability of spread. On the other hand, the spread of fire has a greater influence on the percent of area burned than the density of trees. If the probability of spread is low, the percent of area burned is constant in both low and high dense areas. With a very low percentage of the spread of fire, the fire will have a negligible effect(less than 2%) on a particular area regardless of tree density. Setting the density lower than 55% in the slider will result in a very minimal destruction of the forest. Data also reveal that a less dense area will have a greater surface area burned compared to a high dense area considering a low spread of fire.

Keywords: Agent-based model, probability of spread, tree density, forest fire, dipterocarp

Introduction

Mindanao Mountains, such as Mt. Apo in Davao and Mt. Kitanglad Range in Bukidnon have been in the news lately because of the occurrence of a forest fire. As reported in the Mindanews of April 2016, fire burned at least 50 ha of Mt. Kitanglad. According to Cochrane (2003), forest fires are increasing in size and frequency across the tropics. Forests have become increasingly susceptible to high severity fires which significantly affect the overall forest health and the ability of humans to enjoy it (Ingram, 2014). Each year wildfires affect more than 50 million hectares of forested land and about 600 million hectares of savannah and bushland within the tropical and subtropical regions of the world. A tendency towards wildfire occurrence will increase in the next decades (Goldammer, 2000).

The dominant presence of dipterocarps and other damar - producing trees could make the South-East Asian rain forests highly susceptible to fire, if not even highly combustible in the presence of unusually dry conditions. The damar resin is a fuel and has commercial value. Liquid resin is collected by firing after tapping (Ashton, 1982; Gianno, 1986). These damar are highly flammable. When lit, they burn continuously and the native people use them for torches or lighting (Gianno, 1986). In fieldwork, damar is usually used as a fire starter. Since it does not absorb water, it is not affected by rain. Because of this property, the dipterocarps and all other damar-producing trees are normally quite susceptible to fire.

A forest fire is probably the most documented among the various natural causes of forest degradation. While forest fires, in reality, are mostly human-initiated in the Philippines, natural factors such as dry weather conditions, high temperature, and strong wind velocity induce their occurrence and determine the extent of their damage (Rebugio et al., 2007).

The rise in the average atmospheric temperature with pronounced drought increases the possibility of forest fires. Early in 1999, dry season has begun in Southeast Asia. There was increasing evidence that forest fires will increase in number and size due to a link between climate change and the climate phenomenon called El Niño which caused the drought that affected much of the forest to catch fire in 1999 and 1998. The frequency and intensity of El Niño could increase which would mean that the world faces warmer, more violent weather, and more forest fires (Rowell & Moore, n.d.).

The potential for a fire to spread, according to Bormann and Likens (1979), is determined by factors. These are patterns of wind flow, distribution of water bodies (lakes, stream, and wetlands), topography and dryness of soil (due to texture, soil depth, slope and aspect). It also includes composition, accumulation and spatial distribution of organic fuel on the ground (Brookfield & Byron, 1993).

Wirawan (1983) and Wirawan (1985) postulate that swidden agriculture, logging activities, specific properties of the substrate, flammability of the biomass and change of climate are the five key factors that interact in the creation of forest fires. Trees differ in their susceptibility to fire, and dipterocarps forest is one example. This leading species group comprises 85% of the Southeast Asian forest. Of the 16% original forested area in Southeast Asia, less than 6% are in the Philippines. The Philippine archipelago is occupied primarily by tropical rainforest. To note, the dominant forest type in Mindanao and the rest of the Philippines is dipterocarp.

Pogeyed (2000) avowed that the Philippines still has about 5.49 million ha or roughly 18 percent of the total land area covered with forests. The remaining old growth, or primary dipterocarp forests, comprises only about 0.804 million ha, far from the 12 million ha of old-growth forest that existed 55 years ago. The southern part of the country (Mindanao) experienced the first large fire in the dipterocarp rainforest during the drought of 1983. The massive build-up of understory fuels, coupled with drought and the presence of a number of ignition sources resulted in an unprecedented fire situation in the Philippines and Southeast Asia.

As stated in the study of Amoroso et al. (2004), Mt. Kitanglad had the highest biomass density with 63.66 tons ha – 1, and was followed by Mt. Malindang, Mt.Apo, and Mt. Hamiguitan with 60.54, 50.64, and 41,71 tons ha- 1, respectively. Mt. Kitanglad has a 2,340 mean number of individuals followed Mt. Apo, Mt. Malindang, Mt. Hamiguitan with 1455, 1451, 1032 trees per ha, respectively.

Forests are said to comprise an indispensable resource especially in times of changing climate, especially when carbon sinks. Forests play a great role in the sequestration of carbon, thus mitigating the effects of climate change. Considering the ever increasing human population and increased human activities, the problem of global warming would still be on the rise.

Recently, PAG-ASA reported that for the last 15 years, the Philippines had experienced the highest atmospheric temperature this 2016. The temperature in some parts of the island, like General Santos City, has risen as high as 44°C. Because of this, some regions were declared under a state of calamity. If the temperature continues to climb, the forest will always be at stake. Losing our forest would critically affect not only humans but the balance of ecosystem as well.

Lately, the incidence of forest fires is very alarming. This prompted the researchers to investigate the percentage of a forest area burned considering the parameters on tree density and probability of spread. To accomplish this, the Fire Simple Extension 1 Netlogo model of the Agent- Based Modeling was used. Agent-based modeling is a rule-based, discrete-event and discrete-time computational modeling methodology that employs computational objects that focuses on the rules and interactions among the individual components ('agents') of system (Bankes, 2002). It starts with mechanisms or rules for behavior (albeit hypotheses in themselves) and seeks to reconstruct through the computational instantiation of those mechanisms the observed patterns of data (Revilla et al., 2005). This simulation system would give information as to the flammability potential of a forest, a dipterocarp forest in this case, taking into account the influence of tree density and probability of spread.

At present, there is not enough data available that fully explains the interaction of the two factors, namely, tree density and the probability of spread of fire which affects the percent of area burned in a forest, thus this study was conducted. This study is primarily a simulation, using NetLogo software. The result is validated with the actual historical data and the results in other similar studies. This study considered the three elements of fire: temperature, tree density, and amount of oxygen. This study also aimed to validate the result of the simulation in NetLogo versus the results in other similar studies.

This study assessed the extent of flammability potential of a dipterocarp forest area considering the parameters on tree density and the probability of spread of fire.

Specifically, this study aimed to:

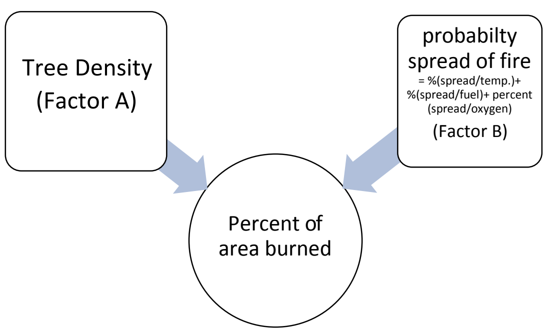
1. establish a picture of the flammability potential of a dipterocarp forest with varied tree densities and the probability of spread;
2. determine the effect of tree density and the probability of spread of forest fire to the percent of area burned;
3. determine if there is a significant effect of tree density and the probability of the spread of forest fire to the percent of area burned; and
4. create implications for the planning of the intervention strategies for the control and prevention of forest fire.

NetLogo Agent-Based Model

Wilensky (1999) proposed a multi-agent programming language and modeling environment for simulating complex phenomena called NetLogo. It is designed for both research and education and is used across a wide range of disciplines and education levels. It is particularly well suited for modeling complex systems evolving overtime. Badham (2015) stipulated that Netlogo has a well deserved reputation as special agent based modeling (ABM) software that is robust and powerful.

In this study, Fire Simple Extension 1 Model of the NetLogo is used. It simulates the spread of a fire through a forest. It shows that the fire's chance of reaching the right edge of the forest depends critically on the density of trees. This is an example of a common feature of complex systems, the presence of a non-linear threshold or critical parameter. Using the Fire Simple Extension 1 model, the fire starts on the left edge of the forest, and spreads to neighboring trees. The fire spreads in four directions: north, east, south, and west. Unlike the original model, this model allows the user to modify the probability-of-spread. As a result, the spread of the fire is probabilistic and affected by this slider.

The following are the parameters used in the study: Tree Density which refers to the number of trees (dipterocarps) in a given area; the spread of fire which refers to the interactions involving the three elements of fire in low, medium and high percentage (where low spread of fire is characterized with low temperature, low tree density, and low amount of oxygen; medium spread of fire is characterized with high temperature, low tree density, and low amount of oxygen; and high spread of fire is characterized with high temperature, high tree density, and high amount of oxygen); and the Percent of area burned which refers to the percentage area of a geographic region burned due to forest fire.



Based on the model above, the following hypotheses were formulated:

1. A dipterocarp forest with low tree density and low spread of fire will likely result to lesser percent of forest area burned.
2. A higher tree density with high spread of fire will likely result in a greater percent of forest area burned.
3. Probability of spread will likely have a greater effect on the percent of area burned than tree density.

Methodology

This study used the descriptive method to investigate the effects of the two independent variables, the density of trees (dipterocarps) and the probability of spread of forest fire, on the percent of the area, burned. Netlogo Fire Simple Extension 1 Model by Wilensky (1999) was used. The three components considered in the probability of the spread of fire are temperature, fuel/biomass, and the amount of oxygen.

The succeeding steps were used in simulating a forest fire of Netlogo Software 2.0.1 considering the factors on tree density and probability of spread to the percent of area burned of a dipterocarp forest.

1. Access the Netlogo and open the file Models Library. Click Fire Simple Extension 1 under Fire Extensions of Chapter 3 of IABM Textbook Folder.

    1.1 Click the SETUP button first, to set up the model. Move the density slider to a preferred number percentage and the probability of spread slider to a specific number percentage.

    1.2 Click the setup button to set up the trees (green) and fire (red on the left-hand side). Click the GO button to start the simulation and the percent of area burned is reflected in the area burned box.

    1.3 Set the Parameters at the following:

    The density slider controls the density of trees in the forest.

    1.3.1 Percent of Density slider set at 25 for low and 75 as high.

    1.3.2 Percent of the Probability of Spread at 16 for low, 59 for medium and 75 for high.

The probability of spread slider affects how the fire spreads from patch to patch.

2. Create six (6) scenarios from the Fire Simple Extension 1 NetLogo model by varying the two factors: Factor A-the tree density in a dipterocarp forest; and Factor B-the probability of spread. The following scenarios are:
   2.1 Factors A and B are Low;
   2.2 Factor A is Low and Factor B is Medium;
   2.3 Factor A is Low and Factor B is High;
   2.4 Factor A is High and Factor B is Low;
   2.5 Factor A is High and Factor B is Medium; and
   2.6 Factors A and B are High.
3. Simulate the scenario ten times for reliability and validity, at each time indicating the percent burned (ticks).
4. Use the Two-way Analysis of Variance (ANOVA) to understand if there is an interaction between the two independent variables (tree density and probability of spread) on the dependent variable(percent burned).

The statistical procedure used was six (6) factorial, with three (3) levels of the probability of spread: low, medium, and high set at values 16, 59, and 75%, respectively on the probability of spread slider. The two (2) levels of tree density: low and high were set at values 25 and 75% on the slider, respectively. Each combination was run in NetLogo software ten times. The resulting data (percent of area burned) were subjected to Two-way ANOVA. R-squared was determined to assess the interaction of the variables.

The results were strictly based on computer simulated data, not actual data. The model is primarily designed to simulate the spread of fire in a dipterocarp forest, but it did not identify a specific forest as the study site. The researchers adopted the model to suit the study considering the two factors only, tree density and spread of fire.

Results and Discussion

Table 1 presents the scenario of the extent of percent burned on an area considering the two parameters: tree density and the probability of spread of fire using The Fire Simple Extension 1 Model. This model has the following factors: (a) tree density which is described as being low and high. The low density was pegged at 25% in the slider and 75% for high, and (b) the probability of spread which is set as low at 16%, medium at 59%, and high at 75%.

Table 1. *Simulation Result of the Two Factors affecting the Percent of Area Burned*

Probability of Spread of Fire	Tree Density	
	Low (25%)	High (75%)
Low (16%)	1.7, 1.7, 1.7, 1.7, 1.7 1.7, 1.7, 1.7, 1.7, 1.7	0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6
Medium (59%)	1.9, 1.9, 2, 1.9, 1.9, 1.9, 1.9, 2, 1.9, 1.9	2.0, 3.0, 2.3, 2.1, 2.2, 2.6, 1.9, 2.7, 2.2, 2.5
High (75%)	2.1, 2.0, 2.1, 2.1, 2.0, 2.1, 2.0, 2.1, 2.1, 2.0	82.1, 79.1, 82.4, 81.7, 80.4, 81.9, 70, 77.3, 72.2, 79.4

Tabular data reveal that if the probability of spread is low, the percent of area burned is constant in both low and high dense areas. With a low percentage of the spread of fire, the fire will have a negligible effect (less than 2%) on a particular area regardless of tree density. Setting the density lower than 55% in the slider will result in a very minimal destruction of the forest. Data also reveal that a less dense area will have a greater surface area burned compared to a high dense area considering a low spread of fire. This result is attributed to the surface area of a low dense forest. According to sciencelearn.org.nz, the bigger the area of the surface of the fuel, the more oxygen molecules can collide with the surface. A forest that is less dense can allow greater surface area and lots of oxygen getting in and around compared to a high dense area. Since the spread of fire is slow, it will not progress much in a highly dense area. A low concentration of oxygen will slow the burning down.

Figure 1 shows the Agent Based Model Simple Fire Extension 1 Simulation data images of the six (6) scenarios with varying number percentage of the two (2) factors. The fire starts on the left edge of the forest (red colored), and spread to neighboring trees. The fire spreads in four directions: north, east, south, and west. Data show that in the medium and high probability of spread, the occurrence of the percent of area burned increases. Tree density will have a significant effect on the percentage of area burned if the percentage of probability of spread is medium to high. As gleaned from the table, the value of the percent of area burned is not constant, which means that the spread of burn advances from one area to another, thus the percent of area burned increases.

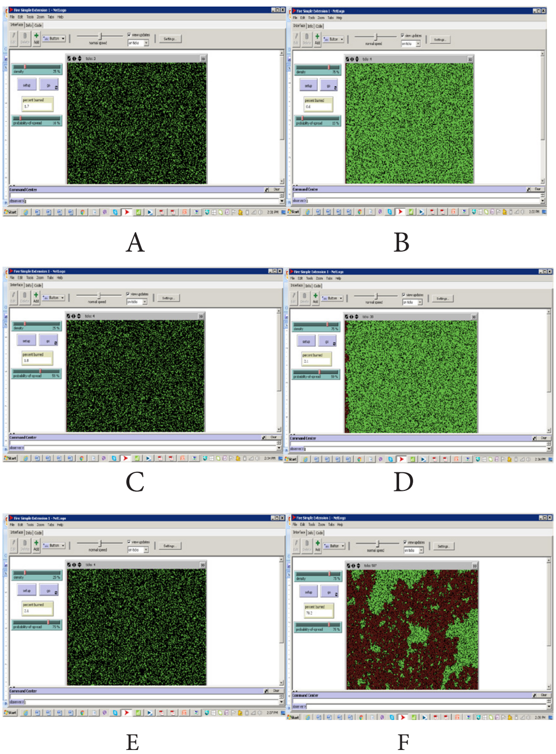


Figure 1: Screenshots from the Agent Based Model Simple Fire Extension 1Simulation on A. Low Tree Density- Low Spread of Fire; B. High Tree Density- Low Spread of Fire; C. Low Tree Density- Medium Spread of Fire; D. High Tree Density- Medium Spread of Fire; E. Low Tree Density- High Spread of Fire; F. High Tree Density- High Spread of Fire

According to Stanley, Trunfio and Taylor (1994), if you plant trees with low probability of growth, trees will usually be separated from one another resulting to low density, so the fire will not spread. As a result, not many trees will burn. These findings of Stanley is parallel with the results of this study based on the simulation run on a high dense forest with a high probability of spread. More so, if you use a high tree growth probability, the trees will typically be next to each other yielding high density, so the fire will spread across the forest. This statement supports the results of the data gathered based on the simulation run.

The high probability of the spread of fire will end in widespread wildfire if density is high. A more dense forest will have a greater percentage of area burned as long as optimum requirements for a fire to start are present. Based on the three categories on the probability of spread, an area with high density coupled with a high probability of spread shows the greatest percent of area burned. A greater area will be burned with increased temperature, high amount of oxygen and high fuel. According to an article on Air Pressure, Density, Temperature, Climate and Weather System, the effect of the level of oxygen on the probability of the spread of forest fire is high which will result to widespread wildfire. Also, when fuels are close together, the fire will spread faster (bcwildfire.com). Therefore, setting the density at the slider above 75%, and a high probability of spread, will likely result in the destruction of the whole forest.

The density of the shrubs and trees plays an important factor. No matter how hot the day, no matter how dry and flammable the growth in the environment, should the trees be sparse and shrubs and bushes few and far between, then the fire will be unable to spread over any considerable area. It is only once the plant life (the fuel) reaches a suitably high density, that the other factors play a more important role (Li & Magdil, 2001). This means that with low tree density, the fire will tend to starve, while a higher percentage of fuel will help ensure that the fire spreads in a healthy manner (for the fire) (Resnick, 1994).

Two- way ANOVA (Table 2) shows that the parameters on tree density and the probability of spread significantly affect the percent of area burned as reflected by the P value. Further, tabular data reveal a very high R-squared value which means that there is a significant interaction between the two (2) factors, that the percent of area burned is greatly dependent on tree density and probability of spread.

Table 2. *Two-way ANOVA: Percent Burned versus Tree Density, Probability of Spread*

Source	DF	SS	MS	F	P
Tree density	1	9606.4	9606.41	3069.32	0.000
Prob Spread	2	19991.8	9995.90	3193.77	0.000
Interaction	2	19730.7	9865.35	3152.06	0.000
Error	54	169.0	3.13		
Total	59	49497.9			
S = 1.769	R-Sq = 99.66%		R-Sq(adj) = 99.63%		

The studies of Rowell and Moore (n.d.) Bormann and Likens (1979), Pogeyed (2000), and Brookfield and Byron (1993) also investigated the factors leading to the probability of spread of fire. Factors identified were increase in environmental temperature, wind flow, distribution of water bodies, topography, dryness of soil, composition and spatial distribution of organic fuel, and presence of a number of ignition sources. The factors affecting the probability of spread of fire were thoroughly discoursed in the aforementioned studies, as compared to the NetLogo software. However, both NetLogo and the said studies showed a parallel result.

Conversely, aside from the factors mentioned, there are other causes of fire. This could be caused by human activities, such as campfires left unattended, the burning of debris, negligently discarded cigarettes and intentional acts of arson (Prestemon, 2013) .

Conclusion

Based on the findings of the study, the following conclusions were derived:

1. The percent of area burned is greatly dependent on tree density and the probability of spread.
2. There is significant effect of tree density and the probability of spread of forest fire to the percent of area burned.

Recommendations

From the results of the study, it is recommended that:

1. In planting trees, there should be a set limit of the distance of trees to be imposed by Department of Environment and Natural resources (DENR). This limit should be disseminated and mandated by the implementing agencies.
2. The forest biomass which fuels potential fires should be managed by the responsible implementing agencies like DENR, City Disaster Risk Reduction Management Center (CDRRMC), and Bureau of Fire Protection (BFP) and the local government units (LGU) where the forest is located
3. During dry spell or droughts, the responsible agency, that is, the Department of Environment and Natural Resources, should limit the number of mountain climbers who are potential initiators of spark/fire.
4. During dry spell or droughts, the number of forest fire rangers or forest watch personnel should be increased.
5. There should be continuous trainings and information dissemination to the locals living in the areas surrounding and within the forest zones by the LGUs.

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