Method of estimating forest fire impact on vegetation

Iwan Hilwan
Department of Silviculture, Faculty of Forestry, IPB University

*E-mail: ihilwan@yahoo.co.id

Abstract. The most significant impact of forest fire can be seen on vegetation. Plants usually die instantly due to considerably severe forest fire. Impact of forest fire is difference in terms of values of several vegetation variables in the forest, before fire and those after fire. Therefore, estimation of magnitude of forest fire impact on vegetation was conducted by comparing vegetation condition in burned area with that of unburned area. The higher the level of severity and intensity of the fire, the greater would be the change occurring in the vegetation condition. The occurring change were in the form of among others change in species composition, stand structure, stand density and basal area. For assessing the magnitude of forest fire impact on vegetation, the very important first step is identifying the various vegetation variables which will exhibit value change. After these vegetation variables are known, there are afterwards observation and measurements in the field, and analysis, both in the burned forest area and in the unburned forest area. In the assessment of fire impact, the vegetation components being measured are: (1) change in size of land cover, with variables in the form of stand density, basal area size, number of species and status of species conservation; and (2) change in level of plant species diversity, with variables in the form of species diversity index, community similarity index, and number of species being lost and gained (diversity loss-gain). Based on difference in values of the two vegetation components, the magnitude of forest fire impact on vegetation can be classified into five levels, namely very small, small, moderate, large and very large.

Keywords: forest fires impact, land cover, species diversity, vegetation components, vegetation variables

1. Introduction
Forest and land fire is an event of forest and/or land being burned, either naturally or man made, which cause damage on environment and loss, ecologically, economically, socio-culturally and politically (Environment and Forestry Minister Regulation No. 32 Year 2016). Forest fire is defined as an event where fire rage on fuel in the form of vegetation, inside forest territory and spread wildly and unsuppressed, while land fire occurs in non-forest territory. Fire in Indonesia often burns forest area and non-forest area simultaneously due to fire originating from forest territory and spread to non-forest territory or vice versa.

Forest and land fire in Indonesia has occurred since the year 1877, followed then by those events in the year 1880s, 1915s, 1930s, 1958, 1982-1983, 1991, 1994, 1997-1998 [1], [2]. The most severe fire in Indonesia occurred in the year 1982-1983 in East Kalimantan because it destroyed around 3.6 million ha of forests with estimated financial loss of US$9 billion. Occurrence of fire in Indonesia increased
progressively. Data from Environment and Forestry Minister mentioned that in the year 2011, area size of fire reached 2612.09 ha and increased further, that in the year 2015, burned land reached 261 060.44 ha, with estimated loss reaching Rp.221 trillion [3].

The most significant impact of forest fire can be seen on vegetation. Plants usually die instantly due to considerably severe forest fire. There are researches in impact of forest fire on vegetation has conducted at several forest ecosystem. Those research showed that forest fires cause changed in forest structure and species composition. Impact of forest fire is difference in terms of values of several vegetation variables (parameters) in the forest, before fire and those after fire. Therefore, estimation of magnitude of forest fire impact on vegetation was conducted by comparing vegetation condition in burned area with that of unburned area. The higher the level of severity and intensity of the fire, the greater would be the change occurring in the vegetation condition. The research objectives are to identify important vegetation variables to estimating forest fire impact on forest vegetation, and determined method of estimating the magnitude of forest fire impact on vegetation.

2. Vegetation parameters which were affected by fire
Reference [4] has identified some variables for evaluated forest fire impact on vegetation. There are 18 variables vegetation has used to measure forest fire impact. The number of variables are too much and very complicated. The quantity of vegetation variables should be reduced, so the estimation of forest fire impact on vegetation was easier. Based on field experiences and research results by fire expert, there are only nine vegetation variables which are important to be known and measured in the field and analyzed for estimating the magnitude of forest fire impacts on vegetation (Table 1).

| No | Parameters | Variables | Data being recorded / analyzed |
|----|------------|-----------|--------------------------------|
| (1) Vegetation cover and conservation status | Plant density (D) | Number of individuals per species at: |
| | | - Tree strata |
| | | - Pole strata |
| | | - Sapling strata |
| | | - Seedling strata |
| | | - Undergrowth vegetation |
| | Basal Area (BA) | Stem girth or stem diameter at breast height (Dbh, cm) at strata of tree and pole. |
| | Plant species | Local / vernacular name or scientific name |
| | Status of species conservation | Plant species which are protected by Environment and Forestry Minister Regulation No. P.106/MENLHK/SETJEN/KUM.1/12/2018 |
| | | Plant species which are listed in IUCN Red List |
| | | Plant species which are listed in Appendix I CITES |
| (2) Diversity of plant species | Margalef Index of Species Richness (Dmg) | Density per plant species |
| | Shannon-Wiener Index of Species Heterogeneity (H’) | Density per plant species |

Table 1. Vegetation parameters affected by forest fire
2.1. Vegetation Cover and Conservation Status

2.1.1. Plant Density
Plant density is the number of individuals of a species per hectare ind/ha or stems/ha. After fire, all or several individuals of the plants undergo condition which range from damaged to death. Therefore in general, density of a plant species will decrease.

2.1.2. Basal Area (BA)
Basal area represents the area of forest crown cover. The clearest impact of forest fire can be seen from the decrease of forest crown cover area due to part of the forest stand being charred and burned. Decrease of crown cover constitutes the primary impact of forest fire which will create further impacts on components of soil and hydrology.

2.1.3. Plant Species
After the occurrence of fire, vegetation will follow gradual recovery process (succession). Not long after the fire, new species (pioneer species) will emerge with characters of fast growing and require full sunlight. Besides that, there is also possibility of loss of several tree species after the fire.

2.1.4. Conservation Status of a Plant Species
Forest fires can occur inside the territory of production forest, protection forest or conservation forest. Forest fires can occur on plant species which possess important conservation status, such as plant species being protected due to its natural population which has declined heavily, plant species which are threatened with extinction (CR, critically endangered, version of IUCN Red List), or those which have been listed in Appendix 1 CITES.

2.2. Diversity of Plant Species
Forest fire will have impact on plant species diversity. Parameters which can be used to assess change in plant species diversity level are among others: Margalef Species Richness Index (Dmg), Shannon-Wiener Species Heterogeneity Index (H’), Community Similarity Index (IS), and Plant Species being lost and gained (diversity gain and loss).

2.2.1. Margalef Species Richness Index (DMg)
Margalef Species Richness Index (species richness) functions to assess the species diversity based on number of species in an ecosystem [5]. Therefore, this index is very sensitive toward change (increase and decrease) of the number of plant species.

2.2.2. Shannon-Wiener Species Heterogeneity Index (H’)
Species Heterogeneity Index or Shannon-Wiener Diversity Index (species heterogeneity) shows heterogeneity or plant species diversity in a community being observed. The value of this index is highly affected by number of plant species and proportion of density of a particular species within the total density. The evener the proportion, the higher will be the H’ value.

2.2.3. Index of Community Similarity (IS)
Index of Community Similarity or Similarity Index (IS) is used to assess the level of community similarity between burned forest area and unburned forest area. If the value of this index approaches one, then the two communities being compared are similar to each other or identical. If the value approach 0 the two communities are different.

2.2.4 Plant Species being Gained and Lost (diversity gain and loss)
After fire, there will appear new plant species (pioneer species) which were previously absent, or on the other hand, there will be lost of several species in the burned area (diversity gain and loss).

3. Method of estimating the magnitude of fire impact on vegetation
The estimating the magnitude of fire impact on vegetation is allows can be done if several assumption are met namely: a) the availability of vegetation condition before fire/burning, b) the burned vegetation was completely extinguished, and c) the condition of vegetation after and before the fire is similar.

3.1. Method of Data Collection
Impact of forest fire is difference in terms of values of several vegetation parameters in the forest, before fire and those after fire. Therefore, estimation of magnitude of forest fire impact on vegetation is conducted by comparing vegetation condition in burned area with that of unburned area. Unburned forest area is determined on the basis of fulfillment of three requirements, namely: a) the location is side by side or adjacent or within one tract of land with the burned area, b) possess similar vegetation cover, and c) possess similar soil types.

3.1.1. Shape and size of sample plots
Collection of vegetation data, either in burned area or in unburned area is each conducted in a single plot. Sample plot in the form of single plot is very suitable to measure biodiversity. Shape and size of the single plots vary depending on forest ecosystem type in the observation site. Vegetation data from such one sample plot is considered to be able to represent biodiversity of forest vegetation community being observed, so that intensity of sampling is not considered relevant. In Table 1, several shapes and sizes of sample plots which are optimum to measure vegetation biodiversity are presented.

| No | Ecosystem Type | Shape of single plot | Size (m²) | Total area size (m²) | Vegetation strata | Source |
|----|----------------|----------------------|-----------|---------------------|-------------------|--------|
| 1. | Lowland rain forest | Square | 40 x 40 | 1600 | Sapling | [6] |
|    |                 |         | 113.4 x 113.14 | 12 800 | Tree | |
| 2. | Lower montane forest | Rectangular | 20 x 160 | 3.200 | Sapling | [7] |
|    |                 |         | 50 x 200 | 10.000 | Pohon | [8] |

For peat forest ecosystem, a forest area which often undergoes fire, so far there have been no any research results yet concerning the optimum shape and size of sample plots for measuring its biodiversity. For estimating impact of forest fire on peat forest vegetation, for the time being, results of research by reference [6] which were located in low land rain forest, can be used. Therefore, the optimum shape and size of single plot in peat forest is 40 m x 40 m for sapling strata and 113.14 m x 113.14 m for tree strata.
3.1.2. Materials and equipment which need to be prepared

Materials and equipment which need to be prepared for field data recording are among others: field map, compass and GPS, measuring tape of 1.5 m and measuring tape of 20 m, plastic rope, tally sheet or field book, herbarium equipment, machete and camera.

3.2. Analysis of Vegetation Data

Vegetation data which have been collected, both from burned forest area and unburned forest area are afterwards processed with formulas which have been valid up to present, and are then analyzed to estimate the impact of forest fire on vegetation. Data which should be processed comprise the following: Stand density (D), Basal Area (BA), Margalef Species Richness Index (Dmg), Shannon-Wiener Species Heterogeneity Index (H’), Community Similarity Index (IS), and plant species which gained and lost (diversity gain and loss), with the following formulas:

\[
\text{Density (D)} = \frac{\text{Number of individuals of a plant species}}{\text{Area size of sample plot}} \text{(stems/ha)}
\]  

(1)

\[
\text{BA} = \pi \times \frac{(d/2)^2}{\text{cm}^2}
\]  

(2)

\[
\text{Dmg} = \frac{S - 1}{\ln N}
\]  

(3)

\[
H' = - \sum \frac{n_i}{N} \ln \left(\frac{n_i}{N}\right)
\]  

(4)

\[
S = \frac{2C}{A + B} X 100\%
\]  

(5)

Notes:

d : tree diameter at breast height
S : Number of plant species
N : Total number of individuals
Ni : Number of individuals of \(i^{th}\) species.
A : Number of plant species in location A (burned area)
B : Number of plant species in location B (unburned forest area)
C : Number of plant species occurring in both locations of A and B

\[
G = \frac{SG}{Sa} X 100\%
\]  

(6)

\[
L = \frac{SL}{Sa/b} X 100\%
\]  

(7)
Notes:
G : Gain (% of number of plant species obtained)
L : Loss (% of number of plant species lost)
SG : Number of species obtained (in burned area)
SL : Number of species lost (in burned area)
Sa/b : Number of similar species in both locations (in burned and in unburned area).

4. Estimating the magnitude of forest fire impact on vegetation
Estimation of magnitude of forest fire impact on vegetation is calculating the difference between values of several vegetation parameters in the burned area and in unburned area. The magnitude of such differences were then given score or value of 1, 2, 3, 4 or 5 depending on the magnitude of the difference. Specifically, for parameter IS (Community Similarity Index), value of G (% of species being obtained), and value of S (% of species being lost), the values which are used are the values of IS, G, and S themselves, and not the difference. The magnitude of score being given are shown in Table 3. In assessing this magnitude of fire impact, score for each parameter is multiplied with its weight. Parameter of vegetation cover has weight of 50% and parameter of biodiversity has also weight of 50%.

| No | Magnitude of difference (%) | Score |
|----|-----------------------------|-------|
| 1  | ≤ 20                        | 1     |
| 2  | 21-40                       | 2     |
| 3  | 41-60                       | 3     |
| 4  | 61-80                       | 4     |
| 5  | 81-100                      | 5     |

Specifically, for vegetation parameters which if the difference is greater, the condition will be better, such as Community Similarity Index (IS) and number of species being obtained (G), then the order (sequence) of difference value is inversed, namely from large value to smaller one. Matrix for estimating the magnitude of fire impact on vegetation, can be seen in Table 4.

| No | Vegetation variables | Difference (%) | Score |
|----|----------------------|---------------|-------|
| A  | Vegetation Cover and Conservation Status (Weight 50%) |
| 1  | Stand Density (K)    |
|    | a. Tree strata       |
|    | ≤ 20                 | 1             |
|    | 21-40                | 2             |
|    | 41-60                | 3             |
|    | 61-80                | 4             |
|    | 81-100               | 5             |
|    | b. Pole strata       |
|    | ≤ 20                 | 1             |
|    | 21-40                | 2             |
|    | 41-60                | 3             |
|    | 61-80                | 4             |
|    | 81-100               | 5             |
|    | c. Sapling Strata    |
|    | ≤ 20                 | 1             |
|    | 21-40                | 2             |
| No. | Vegetation variables | Difference (%) | Score |
|-----|----------------------|----------------|-------|
|     |                      | 41-60          | 3     |
|     |                      | 61-80          | 4     |
|     |                      | 81-100         | 5     |
| d. | Seedling Strata      | ≤ 20           | 1     |
|     |                      | 21-40          | 2     |
|     |                      | 41-60          | 3     |
|     |                      | 61-80          | 4     |
|     |                      | 81-100         | 5     |
| e. | Undergrowth vegetation| ≤ 20          | 1     |
|     |                      | 21-40          | 2     |
|     |                      | 41-60          | 3     |
|     |                      | 61-80          | 4     |
|     |                      | 81-100         | 5     |

2. Basal area (BA)
   a. Tree strata  
      | ≤ 20  | 1     |
      | 21-40 | 2     |
      | 41-60 | 3     |
      | 61-80 | 4     |
      | 81-100| 5     |
   b. Pole strata  
      | ≤ 20  | 1     |
      | 21-40 | 2     |
      | 41-60 | 3     |
      | 61-80 | 4     |
      | 81-100| 5     |

3. Conservation Status
   a. Critical (CR)  
      | ≤ 5   | 1     |
      | 6-10  | 2     |
      | 11-15 | 3     |
      | 16-20 | 4     |
      | 21-25 | 5     |
   b. Endangered (EN)  
      | ≤ 5   | 1     |
      | 6-10  | 2     |
      | 11-15 | 3     |
      | 16-20 | 4     |
      | 21-25 | 5     |
   c. Vulnerable (VU)  
      | ≤ 5   | 1     |
      | 6-10  | 2     |
      | 11-15 | 3     |
      | 16-20 | 4     |
      | 21-25 | 5     |

B. Biodiversity (Weight 50%)
   1. Species Richness Index (DMg)
      | ≤ 20  | 1     |
      | 21-40 | 2     |
      | 41-60 | 3     |
      | 61-80 | 4     |
      | 81-100| 5     |
   2. Species Heterogeneity Index (H')
      | ≤ 20  | 1     |
      | 21-40 | 2     |
Based on Table 4, score for each vegetation parameter being assessed can be known. Afterwards, assessment of magnitude of fire impact on vegetation can be conducted by summing up all obtained scores which are then each multiplied by their weight. Magnitude of fire impact on vegetation is then determined based on total value from all vegetation parameters. The magnitude of impact is categorized into five categories, namely: very small, small, moderate, large and very large, with criteria shown in Table 5.

| No. | Vegetation variables                  | Difference (%) | Score |
|-----|--------------------------------------|----------------|-------|
| 1   | Community Similarity Index (IS)      | 81-100         | 1     |
|     |                                      | 61-80          | 2     |
|     |                                      | 41-60          | 3     |
|     |                                      | 21-40          | 4     |
|     |                                      | ≤ 20           | 5     |
| 4   | Number of species being lost (L)     | ≤ 20           | 1     |
|     |                                      | 21-40          | 2     |
|     |                                      | 41-60          | 3     |
|     |                                      | 61-80          | 4     |
|     |                                      | 81-100         | 5     |
| 5   | Number of spec. being obtained (G)   | 81-100         | 1     |
|     |                                      | 61-80          | 2     |
|     |                                      | 41-60          | 3     |
|     |                                      | 21-40          | 4     |
|     |                                      | ≤ 20           | 5     |

### Table 5. Criteria for magnitude of fire impact on vegetation

| No. | Magnitude of fire impact | Total value (Value of Parameter A x 50%) + (Value of Parameter B x 50%) |
|-----|--------------------------|--------------------------------------------------------------------------|
| 1   | Very small               | ≤7.5                                                                     |
| 2   | Small                    | >7.5 - 13.5                                                              |
| 3   | Moderate                 | >13.5 - 19.5                                                             |
| 4   | Large                    | >19.5 - 25.5                                                             |
| 5   | Very large               | >25.5                                                                    |

Assessment results of forest fire impact on vegetation can be used for various purposes and objectives, such as: (1) as a basis for recommendation of recovery of burned area, and (2) as a basis for recommendation in law enforcement in forest fire case to assess the loss due to forest fire [4].

### 5. Conclusion

In the efforts to estimate the magnitude of forest fire impact on vegetation, the important first step is accurate identification of various variables or parameters which will change if forest fire occurs. In the collection of field data, vegetation analysis is conducted in single plot with optimum shape and size. Some variables has to be measured in the field are plant density, diameter at breast height (DBH), and plant name. Vegetation analysis should be implemented more than a month after burning.

### References

[1] Vadya A. 1999. Finding causes of The 1997-1998 Indonesian Forest Fires: Problems and Possibilities (Jakarta: World Wide Fund for Nature Indonesia Program)

[2] Barber C and Schweithelm J. 2000. Trial by Fire: Forest Fires and Forestry Policy in Indonesia's
Era of Crisis and Reform (Jakarta: World Resources Institute)

[3] The World Bank. 2015. The Quarterly Development of Indonesia Economic: Reformation at Uncertainly Condition (Jakarta: The World Bank)

[4] Syaufina L. 2017. Method of estimating forest fire impact on vegetation (Bogor: IPB Press)

[5] Ludwig JA and Reynolds JF 1988 Statistical Ecology: A Primer in Methods and Computing (New York: John Wiley & Sons)

[6] Kusuma S. 2007. Determination os Shape and Size of Optimal Sample Plot for Plant Diversity Measurement on Lowland Rain Forest Ecosystem: Case Study at Kutai National Park (Bogor: Postgraduate School IPB)

[7] Nahla S. 2018. Determination of Optimal Sample Plot for Plant Diversity Measurement on Montane Forest ecosystem at Gunung Halimun-Salak National Park (Bogor: Faculty of Forestry IPB)

[8] Ali MA, Hikmat A, Santosa Y 2016 Determining of Shape and Dimensions Optimal Sampling Plot for Measuring of Plant Biodiversity in Highland Tropical Rain Forest. Media Konservasi Vol.21