Forest fire as a threat for biodiversity and urban pollution

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Abstract. Forest fire has contributed to ecosystem and environmental degradation. Every year forest fire occurs in Indonesia and causes great impacts on ecological, economic and social condition. A study of fire impacts assessment on vegetation biodiversity and air pollution was conducted in Tesso Nilo National Park (TNNP), Riau Province, Sumatera, Indonesia. This paper aimed to describe fire severities and fire impacts on species diversity and pollutant in urban areas surrounding the study location. Vegetation analyses and diversity analyses were conducted in the burned as well the unburned areas to calculate Important Value Index and Diversity Index. Fire severities were determined using vegetation condition approach. Pollutant data and public activity impacts were obtained from local government. Forest fire occurred in TNNP in July 2015 is classified as high fire severity. Species Diversity Index of burned area (0.96) is classified as “Not good” lower than that of in unburned area (3.05) which is classified as “Good”. The forest fire may decrease commercial tree species from 28 to 3 species including: Macaranga pruinosa, Diaphania costata and Shorea macroptera. Air Pollution Index in urban area surrounding study location seems to be in unhealthy even in dangerous level which cause great impacts to public activities.

1. Introduction
One of the important environmental problems in Indonesia is forest fire, which causes great impacts on forest ecosystem as well as surrounding environment including urban area. Being the highest hotspot number in the last two decades as fire indicator, 1997/1998 fire-episode has been a tremendous forest and land fire occurrences caused trans-boundary haze pollution in ASEAN region. The fire destroyed about between 10 and 11.7 million ha [1, 2]. The impacts of the fire not only are limited to ecological aspect but also to economic, social, and political aspects. About 75 million people were affected by trans-boundary haze pollution produced by the fire and caused total economy loss of about US$ 3.5-9.7 billions [3, 1].

Among various provinces in Indonesia, Riau Province ranks first in forest and land fires occurrences indicated by the highest hotspot number found in the province since the last two decades (figure 1). It is followed by Central Kalimantan, West Kalimantan, South Sumatera, and Jambi Provinces. In the last five years period (2010-2015), forest and land fires in Indonesia seem to increase significantly, which reached the peak in 2015. The immense haze impacts from forest and land fires clusters in Riau, South Sumatera and Jambi had implied to national disaster status of the three provinces. Thousands of people have been affected by air pollution produced by the fire occurrences, in term of health condition and daily activities such as schooling and working.
Figure 1. Hotspot distribution in various provinces in Sumatera and Kalimantan.

One of the forest fire sources in Riau is Tesso Nilo National Park, which is threatened by forest disruption and conversion. Tesso Nilo National Park (TNNP) has a total area of ±83,068 ha, located in two Districts of Pelalawan and Indragiri Hulu, Riau Province. It covers lowland tropical rainforest with high biodiversity, consists of 360 plant species (165 genera and 57 families), 107 bird species, 23 mammal species, 3 primate species, 50 fish species, 15 reptilian species and 18 amphibians species [4] and home for Sumatran elephants and tigers. However, threats from illegal logging and forest disruption that involves burning activities may destroy various plant species and also wildlife and their habitat.

Studies on fire impacts on biodiversity have been reported by various approaches, which resulted in various information and data. Fire effects on tropical forest biodiversity vary from low to high severity. Fire may kill plants and cause injury as direct effects to vegetation. Whereas, open wounds which attract pest and disease attack is indirect effects of fire to vegetation. Fires modify forest structure and composition as well, which the magnitude of fire effects on tropical forest biodiversity is influenced by several factors, namely: fire intensity, fire severity, soil types, post fire precipitation and burned area [5].

On the other hand, forest fire also contributes greatly to the carbon emission and air pollutant. The aim of the paper was to determine impacts of forest fire on biodiversity of vegetation in Tesso Nilo National Park and the possibility of its impact on urban area at surrounding area of TNNP.

2. Material and methods

2.1 Study area

Study on the impacts of forest fire on biodiversity was conducted at Tesso Nilo National Park (figure 2), which is burned in July 2015 at position of 101°57’90.98”East - 00°11’22.15”South (unburned area) and 101°54’28”East - 00°12’55.17”South and 101°54’26”East - 00°13’29.4”East (burned area).
Figure 2. Map of Tesso Nilo National Park, Riau Province.

Tesso Nilo NP covers lowland tropical rain forest with high biodiversity, consists of 360 plant species (165 genera and 57 families, 215 tree species, 107 bird species, 23 mammal species, 3 primates species, 50 fish species, 15 reptilian species and 18 amphibian species [4]. The National park is a home for Sumatran elephant and tiger, which is important for the ecosystem conservation.

2.2. Plot establishment
Three transect lines were established in burned area as well as in adjacent unburned area. Sample plots established along each transects consisted of three sample plots sized 2x2 m² for seedling analyses, three sample plots sized 5x5 m² for sampling analyses, three sample plots sized 10x10 m² for pole analyses and three sample plots sized 20x20 m² for tree analyses, in total there were 36 nested sampling plots for various tree growth levels.

2.3. Fire impacts on vegetation
Fire impacts on vegetation were approached by using vegetation analyses and fire severity assessment. Vegetation analyses were conducted in recent burned area (1-2 days post-fire) to calculate Important Value Index (IVI) as the sum of Relative Density, Relative Frequency and Relative Dominancy to determine diversity condition using Shannon Index of General Diversity [6]. Fire severity scoring level was obtained by the sum of three indicator scores, namely: 1) individual tree damage, 2) vegetation severity, and 3) vegetation diversity [7, 8]. Individual tree damage covered: trees death, damage type and location; Vegetation severity included: percentage of living trees post-fire, percentage of death trees, and percentage of survival trees. Total scores of the three indicators determined the fire severity as described in table 1.
Table 1. Fire severity scores in burned area

| Fire severity level of burned area | Total score of indicators |
|-----------------------------------|---------------------------|
| Very Low                          | 0 – 20                    |
| Low                               | > 20 - 40                 |
| Moderate                          | > 40 - 60                 |
| High                              | > 60 - 80                 |
| Very High                         | > 80 - 100                |

Notes: modification of [7,8]

2.4. Haze impacts
Meanwhile, study on haze impacts to the urban area close to the TNNP was conducted by analyzing trajectory haze data for July 9th-11th, 2015 period. Haze trajectory pattern was determined by using HYSPLIT software, which input featured meteorology data and hotspot sequential data. Attribute used from hotspot sequential data was coordinate point of latitude and longitude as initial point of haze trajectory. HYSPLIT also provided menu of concentration for pollutant concentration based on emission data and pollutant inputs of CO and CO₂. Output for these analyses comprised of information of time, location and pollutant concentration. Additional information on haze affected region was based on data from respective institution published in daily local news for July 2015 period.

3. Results and discussions

3.1 Fire types and severity
Forest fire occurred in Tesso Nilo National Park in July 2015 was estimated to affect about 500 ha of the lowland tropical forest. Fire severity assessment conducted in burned area showed that there were 35 individual trees with various burned condition lesser number than that of in unburned areas of about 81 individual trees in similar plot size. About 27 individual trees died (77.14%) and about 8 trees (22.86%) still remained alive. Most of the trees burned in lower and upper part, were charred and destroyed. Therefore, the burned area is classified as high fire severity, which <20% of undamaged trees and less than 40% of burned trees still survived (Ffolliot and Bennett 1996 in[9]. It was supported by the scores of the tree indicator as follows: individual tree damage [50], fire severity level for vegetation [15], and species diversity [9], means the total score is 74 which indicated high fire severity.

3.2 Impacts to the biodiversity
The fire is classified as surface fire which spreads out into crown fire. Forest fire may cause direct and indirect impacts on vegetation. Fire may kill or cause injury of vegetation as direct impact. Indirectly, fire may cause open wounds on vegetation which cause pest and disease attack [5]. The study indicated that there are 30 tree species found in unburned area, which were dominated by Ochansostachys amentaceae (IVI=38.16%), Syzygium cuminii (IVI=34.23%), and Quercus argintata (IVI=23.21%). Whereas, there were only 3 species found alive in burned area, namely: Shorea macroptera, Macaranga pruinosa, and Diaphaniacostata (table 2).

Table 2. Important Value Index of tree species in burned area.

| No | Local name     | Scientific name       | Total individual | RD (%) | RF (%) | RDom (%) | IVI (%) |
|----|----------------|-----------------------|------------------|--------|--------|----------|---------|
| 1. | Meranti Kunyit | Shorea macroptera     | 11               | 57.14  | 40     | 50.00    | 147.14  |
| 2. | Kedondong      | Daphania costata      | 3                | 14.29  | 20     | 17.14    | 51.43   |
| 3. | Mahang         | Macaranga pruinosa    | 6                | 28.57  | 40     | 32.86    | 101.43  |
Notes: RD=Relative Density, RF=Relative Frequency, RD=Relative Dominancy, IVI=Important Value Index.

In line to the IVI, the Diversity Index (H’) of burned area (table 3) is less than that of in unburned area (DI=3.05), means that forest fire has declined the diversity of tree species in the study area.

Table 3. Diversity Index and Eveness Index of tree species in burned area.

| No | Local name       | Scientific name  | H’ | E   |
|----|------------------|------------------|----|-----|
| 1  | Meranti Kunyit   | Shorea macroptera| 0.32 | 0.29 |
| 2  | Kedondong Hutan  | Daphania costata | 0.28 | 0.25 |
| 3  | Mahang           | Macaranga pruinosa| 0.36 | 0.33 |
|    | Total            |                  | 0.96 | 0.87 |

Notes: H’=Diversity Index, E=Eveness Index

Eveness Index in burned area of about 0.8 evidenced no significant differences than that of in unburned area of about 0.9. It means that both in burned as well as unburned area possessed good species eveness. Eveness Index ranges from 0-1, where value of 1 shows distribution of each species relatively similar in a certain community [6]. Grouping distribution implied on the relatively similar species distribution is a general phenomenon found in natural forest [10].

Fire effects on tropical forest biodiversity vary from low to high severity. Direct effects of fire may kill plants and cause injury. Indirect effects of fire to vegetation including open wounds which attract pest and disease attack. On the other hand, fire alters forest structure and composition. The magnitude of fire effects on tropical forest biodiversity is influenced by several factors, namely: fire intensity, fire severity, soil types, post fire precipitation and burned area [5].

3.3 Haze pollution and its impacts to urban area

Forest fire has undoubtedly caused great impacts on the environment through haze pollution, which spreads to the other region of fire source. The pollution may be experienced not solely by local community living surrounding the fire sources but also by others living hundreds kilometre away from the fire sources. The direction and velocity of fire spread seems to depend on various factors, including: wind direction and velocity, other weather factors (rainfall, temperature and humidity), air stability, and land features. Using HYSPLIT model, distribution of haze pollution was traced (figure 3). This study found that haze pollution produced by forest and land fires in Riau Province spread to various adjacent locations such as: Bengkalis, Dumai, Indragiri Hulu, Rokan Hilir, Pelalawan and got across to regions in neighbor country like Malaysia including: Batu Pahat, Johor Baharu, Keluang, Muar, Pontian, Bintulu.
Combustion process in forest fire as biomass burning produces a huge amounts of CO$_2$ and CO, besides other trace gases. Under ideal condition and complete burning process (flaming), biomass burning may produce carbon dioxide (CO$_2$) and water vapour (H$_2$O) [11]. Whereas in incomplete combustion (smoldering), biomass burning also results in carbon monoxide (CO), besides carbon dioxide (CO$_2$) and water vapour (H$_2$O). A relative amount of flaming phase and smoldering phase in forest fire is defined as combustion efficiency (CE) or modified combustion efficiency (MCE). Various studies investigated that complete combustion (flaming) is indicated by high value of CE and MCE [12, 13]. The values of CE and MCE close to 1 at flaming dominated—for example fine forest fuels such as grasses and conifer needles will have complete combustion (flaming), where value of MCE is about 0.99 [12, 13].

Emission measurement from peatland fire in Central Kalimantan [14] produced modified combustion efficiency (MCE) value ranged from 0.693 to 0.835 with average of 0.772 ± 0.053 (n = 35), showing smoldering combustion, though emission increased indirectly. The main gases emission were (EF in g kg$^{-1}$) carbon dioxide (1564 ± 77), carbon monoxide (291 ± 49), methane (9.51 ± 4.74), hydrogen cyanide (5.75 ± 1.60), acetic acid (3.89 ± 1.65), ammonia (2.86 ± 1.00), methanol (2.14 ± 1.22), ethane (1.52 ± 0.66), dihydrogen (1.22 ± 1.01), propylene (1.07 ± 0.53), propane (0.989 ± 0.644), ethylene (0.961 ± 0.528), benzene (0.954 ± 0.394), formaldehyde (0.867 ± 0.479), hydroxyacetone (0.860 ± 0.433), furan (0.772 ± 0.035), acetaldehyde (0.697 ± 0.460), and acetone (0.691 ± 0.356).

Table 4 indicates concentration of CO$_2$ was larger when compared to concentration of CO, which means that the fire was dominated by complete combustion process. CO$_2$ is one of the largest portions of greenhouse gases, whereas CO contributes greatly to human health.

**Table 4. Haze pollution concentration originated from Riau fire in various locations.**

| Location | Haze pollutant concentration (%) | Altitude (m agl) |
|----------|----------------------------------|------------------|
| Rokan Hilir | CO$_2$ (kg/m$^3$)/(%) | CO (kg/m$^3$)/(%) | 2.40 |
| Bengkalis | 0.000874/(67.87) | 0.000114/(71.41) | 33.44 |
Smoke haze comes from forest fire/biomass burning contain various components that disturb human health in the form of gas and particle. The gas components consist of carbon monoxide (CO), sulphur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), and aldehyde. Other several compounds such as ozone (O$_3$), carbon dioxide (CO$_2$) and hydrocarbon may also provide bad impacts to the lung [15].

### Table 5. Haze impacts reports during July 2015 fire period in Riau Province.

| No. | Date       | Location            | Notes             |
|-----|------------|---------------------|-------------------|
| 1.  | 30 June 2015 | Pekanbaru, Dumai, Bengkalis, Pelalawan | Low visibility |
| 2.  | 1-July 2015   | Pekanbaru          | Low visibility    |
| 3.  | 6-July 2015   | Rokan Hulu          | Respiratory diseases detected |
| 4.  | 9 July 2015   | Pekanbaru          | Low Visibility    |
| 5.  | 10 July 2015  | Pekanbaru          | Thick haze/unhealthy |
| 6.  | 22 July 2015  | Pekanbaru, Bangkinang, Kuantan | Thick haze/unhealthy |
| 7.  | 25 July 2015  | Pekanbaru, Dumai, Pelalawan, Rengat | Low Visibility |
| 8.  | 27 July 2015  | Pekanbaru          | Unhealthy         |
| 9.  | 28 July 2015  | Pelalawan          | Unhealthy         |
| 10. | 30 July 2015  | Indragiri Hilir    | Thick haze/unhealthy |

Source: compilation of daily news from Riaugreen.com in June-August 2015 period

Population living in hundreds kilometres away from forest fire sources can be affected. Daily reports (Table 5) indicated that haze produced by forest and land fires spread throughout several cities surrounding the fire sources and caused thick haze, low visibility and unhealthy condition. Fire impacts on health depend on individual condition such as age, previous respiratory problem, infection and cardiovascular, and particle size. Smoke may cause eye irritation, skin irritation, and respiratory tract disorders, reduced lung function, bronchitis, asthma exacerbations, and early death. Particulate matter may affect body immunity system and physiology. Particles from forest fires are generally less than 2.5 micrometres in size and fine enough to penetrate deep into the lungs. Most epidemiological studies suggested that particles from wildland fires mainly caused short-term respiratory impacts and few cardiovascular impacts. The population, including potentially vulnerable people such as those with respiratory problems, should remain vigilant during forest fire events and take steps to minimize exposure and thereby avoid an exacerbation of symptoms, possible hospitalization, and even death [16].

4. Conclusions
Forest fire occurred in July 2015 in Tesso Nilo National Park was classified as Surface Fire and Crown Fire. Based on the impacts on the vegetation, the fire is classified as High Fire Severity. Forest
fire has affected biodiversity, particularly tree species as indicated by death of trees and decreasing species diversity in Tesso Nilo National Park, Riau Province. Data mining approach revealed that forest fire occurred in Riau produced higher pollutant concentrations of CO, compared to CO, which indicated that the fire was dominated by surface fire. However, CO pollutant has contributed to unhealthy condition in urban areas. The forest fire has also contributed to haze problem in surrounding areas, especially in Indragiri Hilir and Pelalawan Districts.

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