Asian Journal of Plant Sciences

ISSN 1682-3974

science alert

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Asian Journal of Plant Sciences 10 (4): 238-244, 2011
ISSN 1682-3974 / DOI: 10.3923/ajps.2011.238.244

Impacts of Fire on SouthEast Asia Tropical Forests Biodiversity: A Review

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Abstract: Forest fires have affected millions of hectares of tropical forests and other vegetation types annually. Over the past decades, the increase occurrence of fires has caused degradation of the tropical forest ecosystem and caused impacts to the environment. The objective of this paper was to review the impacts of the fires to the tropical forest ecosystem in Southeast Asia. Forest fires affect vegetation by suppressing certain species and promoting other species causing changes in vegetation structure and altering successional pattern. It also rejuvenate tropical pines. Fire causes reduction in soil macroorganism diversity and change soil bacterial composition. Knowledge of fire effects on biodiversity may benefit forest managers. Fire adaptive vegetation can be used as important species in rehabilitation of burned area

Key words: Forest fire, haze, fire impacts, tree structure, succession

INTRODUCTION

Forest fire has been a common phenomenon occurring in South East Asia region since the last decade. The fire causes significant impacts to the environment (Lim *et al*., 2010; Movaghati *et al*., 2009) and the tropical forest ecosystem (Shlisky *et al*., 2007), particularly biodiversity of tropical forest. Furthermore, seasonal dry period (Ainuddin and Ampun, 2008; Syaufina *et al*., 2004) and human activities such as uncontrolled logging (Siegert *et al*., 2001) and drained tropical peat swamp forest (Ainuddin *et al*., 2006) further increase the risk of forest fire. Biodiversity varies from gene to ecosystem scale, play important role to balance the global environment. One of disruption factor to biodiversity is forest fire. It is an essential agent for biodiversity changes which has direct and indirect effects.

Several studies have been conducted to identify fire effects on biodiversity of tropical forest ecosystem, including flora (Wood, 1989) and fauna (Kinnaird and O'Brien, 1998; Adeney *et al*., 2006). However, studies in southeast Asian area are limited (SCBD, 2001). To what extent the impacts of the fire depend on fire intensity, fire severity and post fire observation. Fire intensity which can be derived by interaction of fuel load, calorific value and temperature or flame height influence the magnitude of fire effects on the ecosystem. In line with fire intensity, ecosystem shows various responses to fire behavior and fire severity indicated by post fire condition of vegetation, of soil characteristics and burned (Chandler *et al*., 1983). On the other hand, the observation period affect the performance of fire effects, as environmental factors differs over the time, especially the influence of post fire precipitation.

Studies about fire effects on biodiversity have been conducted in all over the world (Reich *et al*., 2001; Moretti *et al*., 2004; Sileshi and Mafongoya, 2006; Alderete-Chavez *et al*., 2008). Therefore, this paper attempt to compile and disseminate important findings related to the matter, particularly in tropical forest ecosystem. This study aims to briefly review the fire effects on tropical forest biodiversity

EFFECTS OF FIRE ON VEGETATION

Various responses of vegetation on fire have been observed (Wood, 1989; Ainuddin and Goh, 2010). Some plants died while some survived after fire (Phillips and Waldrop, 2008). Several factors influence the severity level of vegetation responses on fire, including: fire adaptive traits of vegetation, fire intensity, soil characteristics, burned area and post fire precipitation. As forest fuel heated up, lignin and hemicelluloses may start to be degraded at temperature of 130 to 190°C. The decomposition process may be accelerated at temperature of 200°C (Chandler *et al*., 1983). Forest fire can reach more than 1000°C in temperature (Pyne, 1984). Therefore, direct fire effects on vegetation may cause death or injury. On the other hand, fire may promote growth and spread of natural regeneration indirectly. A study by Slik *et al*. (2002) showed that fire changes in the forest structure by significantly reducing the numbers of trees and species in

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Table 1: Fire occurrence and effects on vegetation in Mahogany stand in Majalengka, West Java, Indonesia

Compartment area (Ha)	Burned area (Ha)	Fire detected	Stand age (yrs)	Percentage of trees death (%)	Damage
21.80	7.0 (32.11%)	11.30 AM	7	61	57% broken branches/died
36.30	8.0 (22.04%)	13.00 AM	8	21	88% broken branches/died
36.50	4.0 (10.96%)	09.15 AM	8	19	83% open wound, 13% broken branches/died

the forest area. Fire kills most smaller and moderate diameter trees but not larger, trees (Van Nieuwstadt *et al*., 2004) leading to some community changes especially species which have abundance of large individuals. Fire in peat forest may also enhance growth of grasses, further increasing the risk to forest fire (Goldammer, 1999; Ainuddin and Goh, 2010).

A study on fire severity using Forest Health Monitoring (FHM) methodology in Mahagony (*Swietenia macrophylla*) stand in Majalengka, West Java, Indonesia observed that burned area and stand age may have different responses to fire effects on vegetation. Larger burned area seems to cause more trees die and more severe vegetation damage (Table 1) (Syaufina, 2008). Similarly, the older the trees the higher the trees can survive.

Table 1 indicates that the highest percentage of dead trees (61%) is found in the highest percentage of burned area (32.11%) and the lowest dead trees (19%) is found in the lowest burned area (10.96%). Most survived trees have broken branches and open wound in stem. Fire may spread to crown area which cause broken branches or died branches. Besides, fire may cause open wound which stimulate pest or disease attack and rotten may occur in consequence.

Using the same methodology of FHM, the study on fire effects in pine forest in Gunung Walat Educational Forest (HPGW), West Java, Indonesia found that based on fire severity classification, the forest fire can be classified as low fire severity which cause low damage. There were 141 trees in the cluster plot of the burned area and 121 trees in that of unburned area. It was found one dead tree in each plot. About 82.14% of trees in the burned area was in health condition, 16.43% had low damage, 1.43% had moderate damage and 1 tree was dead (Syaufina *et al*., 2005).

Figure 1 shows that location of damages varies in burned as well as in unburned areas (Syaufina *et al*., 2005). Number of no damage trees is higher in unburned area when compared with that of in burned area. Whereas, damages in exposed root and stump, roots and lower bole, lower bole, upper bole and crown stem were higher in burned area than that of in unburned area. This is probably influenced by the type of fire occurred in the area as surface fire. Burned pine stands showed scars on the stems with the scars height ranged from 0.5-4.5 m and scars depth ranged from 0.1-1.7 cm (Syaufina *et al*., 2005). The height of scars is influenced by the resins produced by pine stem. However, the burning depth did not kill the cambium.

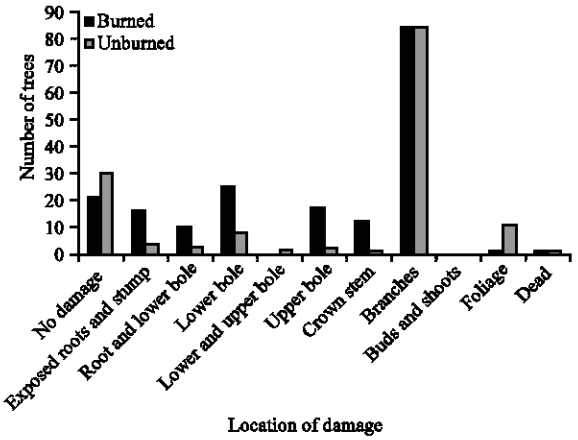

Fig. 1: Location of tree damage in burned and unburned areas

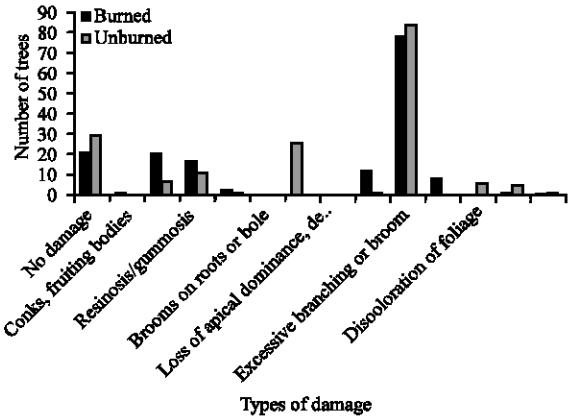

Fig. 2: Types of tree damage in burned and unburned areas

Fire can directly kill a tree when combustion process increases the tree temperature which lead to critical condition of plant cells and death. On the other hand, fire may cause physical damage of the tree, including wound, defoliation, stem damage and other damages. Furthermore, fire may indirectly cause the increasing of sensitivity of the tree to pest and diseases attacks. It is estimated that the fire occurred in Gunung Walat may indirectly cause other damages such as cancer, conk, brooms on roots or bole and excessive branching or brooms. Those damages were found in burned area only (Fig. 2) (Syaufina *et al*.,

Table 2: Tree species Richness Index Indeks before fire, 1 year after fire, two years after fire, three years after fire, four years after fire and five years after fire in Jasinga, West Java, Indonesia

Vegetation stage	1 yr after fire	2 yrs after fire	3 yrs after fire	4 yrs after fire	5 yrs after fire	Before fire
Seedling	0.805	1.44	1.846	1.359	1.059	4.13
Sapling	-	-	1.443	1.669	1.477	5.08
Pole	-	-	-	1.819	0.722	4.10
Tree	-	-	-	-	0	0.48

2005). Certainly, it is required to be studied more deeply in order to have better explanation on the indirect effects of fire.

Forest fire may alter forest structure and composition, including forest under storey. Most studies found that under storey vegetation increased after fire (Rahardjo, 2003; Priandi, 2006). They are pioneer shrubs species. It is shown by the increasing of species richness index. A study in HPGW, Sukabumi, West Java, showed that shrub species increased by 75% after six months fire. It was decreased after three years fire, though, it is still 25% higher than that of before fire (Fig. 3).

Based on vegetation analyses, species dominancy have changed after fire. *Melastoma malabathricum* Linn. *Selaginella plana* Hieron and *Curculigo latifolia* Dryand are among dominant species found in unburned area. Whereas, *Leucas lavandulaefolia*, *Paspalum conjugatum* Linn. and *Melastoma malabathricum* Linn. are that of in burned area. Those species have reproductive modes by seed or spores which is fire adaptive traits. Though, some species disappeared after fire, among them are: *Amorphophalus variabilis* BI, *Lastonia cilora*, *Piper aduncum* Linn., *Demosdium triquetrum* (L.) DC., *Erigeron sumatranensis* Retz., *Lasianthus purpureus* BI., *Peperomia pellucid*, *Urena lobata* Linn., *Ageratum conyzoides* and *Ottochloa nodosa*.

On the other hand, fire decreased tree species richness in several stages of vegetation growth. A study in secondary tropical forest in Jasinga, West Java indicated that fire has changed vegetation species richness as shown in Table 2 (Sinaga, 2005).

Before fire, sapling stage has the highest species richness (31), followed by seedling stage (30), pole stage (18) and tree stage (2)- *Schima walichii* and *Syzygium pycnanthum* (Syaufina *et al*., 2005). After two years fire, only seedling stage was found. Sapling stage appeared after three and four years fire. Decreasing species richness index is found in all stages of vegetation growth even until five years fire period. The highest decreasing in species richness is observed in tree stage (100%), followed by pole stage (82.39%), seedling stage (74.36%) and sapling stage (70.93%).

Other study in pine plantation Aek Nauli, North Sumatera (Pangaribuan, 2003) revealed that number of species decreased after fire by 27.5%, consist of 33.3% of tree species (in seedling stage) and 22.7% of shrub

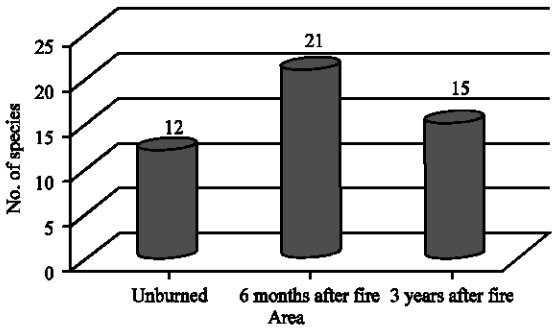

Fig. 3: Number of under storey species in burned and unburned area in HPGW, West Java, Indonesia (figure modified by authors from Rahardjo (2003) and Priandi (2006)

species. The important result of the study is the evidence that *Pinus merkusii* jungh et de Vriese grow in the area is adaptive to fire. Pine seedlings were found in burned area (180 individual/hectare) 4.5 times higher compared with that of in unburned area (40 individual/hec). The pine has fire adaptive traits, including bark thickness and cone breaking period.

However, when fire occur periodically in the same area, succession process may be retarded. A study in East Kalimantan (Magnolia, 2004) showed that repeated fire in large burned areas in 1998 caused slow process of succession and secondary vegetation level remain in a long period. In short period, fire may increase soil pH and enrich soil nutrients to support burned area rehabilitation. When fire recurred, its impacts on biodiversity may be unpleasant as disturb natural succession process.

EFFECTS OF FIRE ON SOIL BIOTA

Fire affects soil characteristics, including physical, chemical and biological, depend on soil characteristics, fire intensity and duration, fuel characteristics, time and intensity of post fire precipitation. It may change soil function in absorbing and hold water and also decomposition process of soil organic matter. This study discuss merely on fire effects on soil biological characteristics, including macrofauna.

Compared to the other two soil characteristics, physical and chemical, soil biological characteristics is the

most sensitive properties to fire. At temperature less than 100°C, soil biological characteristics will be destroyed. The present and functions of macrobiota such as insects, soil worm and plant roots and of microbiota such as algae, protozoa, fungi, bacteria and cyanobacteria are included in soil biological characteristics.

Fire effects on soil macrofauna were studied in two sites, namely Hunting Park of Masigit Kareumbi Mountain Block, Sumedang, West Java and Gunung Walat Educational Forest (HPGW), Sukabumi, West Java, Indonesia. Both fire occurrences were surface and crown fires in types. Based on fire impacts assessment, the fires has been assessed as low fire severity.

Study in Sumedang revealed that after two years fire burned pine stands in the hunting park, soil macrofauna have altered. Species richness index has decreased from 7.9662 in unburned area to 3.2018 in burned area, in which about 14 insecta order were found in unburned area compared to 8 ordo found in burned area (Abidin, 2005). Similarly, species diversity index in unburned area (1.582) was higher than that of in burned area (0.771). After fire, those insect spread out unevenly. It is shown by species evenness index in burned area (0.4661) is smaller than that of in unburned area (0.479).

Another study in HPGW, Sukabumi indicated that after three years fire in pine stands species diversity of soil macrofauna has been decreased, though total number of macrofauna increased. The fire caused decreasing number of order by 17.65%, decreasing of family by 23.33% but increasing individual by 51.49% (Syaufina, 2008). Furthermore, fire caused decreasing in diversity of soil macrofauna as shown in Fig. 4. Diversity Index in soil layer in burned area was 0.72 which means a low diversity (<1.5). It shows by uneven distribution of species abundance in the area. On the other hand that of in unburned area was 1.76 which shows a moderate diversity (between 1.5-3.5). Similarly, Diversity Index in litter layer in burned area (1.28) is lower than that of in unburned area (1.39) which are low diversity. Litter is one of soil fauna habitat. Litter decomposition produces organic matters which support soil biota. As litter covers the soil surface, it is sensitive to various disturbances including fire. The changes in litter layer will influenced soil fauna strongly. Besides, forest litter plays very important role in protecting forest land. Therefore, the presence of litter after fire will show fire severity classification.

In addition, statistical analyses on Richness Index shows a significant difference between the two areas in which Richness Index in soil in the burned area (0.87) was lower than that of in the unburned area (3.01). Similarly, Evenness Index in the burned area (0.34) was also lower when compared with that of in the unburned area (0.62).

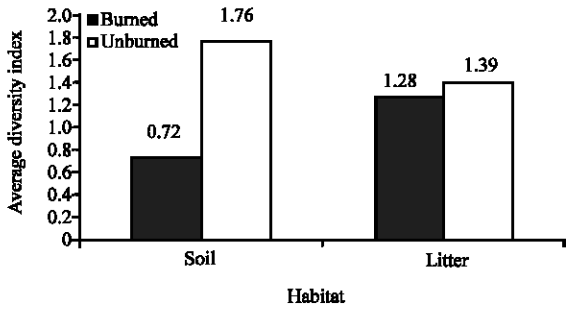

Fig. 4: Average Diversity Index of soil macrofauna in various habitat in burned and unburned areas in HPGW, West Java (Syaufina *et al*., 2005)

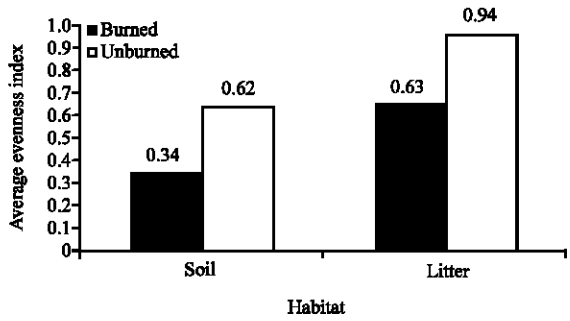

Fig. 5: Average Evenness Index of soil macrofauna in various habitat in burned and unburned areas in HPGW, West Java (Syaufina *et al*., 2005)

Statistical analyses on Richness Index in litter layer, likewise, shows a significant difference between the two areas in which Richness Index in the burned area (1.82) was lower than that of in the unburned area (1.9). Correspondingly, Evenness Index (Fig. 5) in litter in both areas has significant different in which the value of the burned area (0.63) was lower than that of in the unburned area (0.94).

On the other hand, fire caused macrofauna families loss including: Thripidae, Tetranichidae, Ellateridae, Staphylinidae, Scarabaidae, Julidae, Polydesmidae, Blattidae, Oedemeridae, Cercopidae, Mantidae, Tenebrionidae, Acrididae, Reduviidae, Scydmaenidae, Oxyopidae, Salticidae and Tetragnathidae. Moreover, Ordos loss after fire including Blattaria, Homoptera, Mantodea and Thysanoptera. On the contrary, there were new families found after fire, namely: Linyphiidae, Podoridae, Sminthuridae, Zetorchestidae, Ephylomatidae, Rhysotritiidae, Phytoseiidae, Argasidae, Veigaiidae and Nitidulidae (Syaufina *et al*., 2007).

Recent study of fire effects on soil bacteria in peatland in Riau, Indonesia indicates that fire decrease the number of bacteria cell. Heating process of peat causes

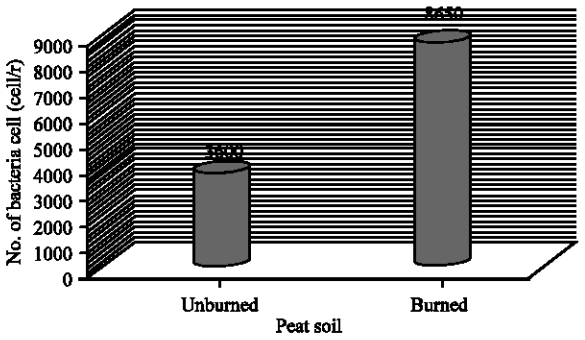

Fig. 6: Number of cell of phosphate solvent bacteria in burned and unburned peat (modified from Wiratama 2010

damage of soil biota, including bacteria. Temperature threshold for bacteria ranges from 100 to 120°C (Dunn and DeBano, 1977; De Bano *et al*., 1998). When bacteria is exposed to temperature higher than that range, the bacteria will be killed and cause decreasing in diversity. Fire alters environmental condition of bacteria such as temperature, oxygen, carbon dioxide, water and soil pH.

However, certain bacteria grow significantly after fire, such as phosphate solvent bacteria (Fig. 6).

It is triggered by the increasing phosphate content in peat after fire. It is supported by Nurhayati (2002), who observed the increasing phosphate content in burned peat by 240%. In addition, phosphate solvent bacteria such as *Bacillus* sp. and *Pseudomonas* sp. play very important role in providing availability of nutrients for plants (Premono *et al*., 1992). On the contrary, bacteria of Lactobacillus and Rhizobium decreased after fire (Wiratama, 2010). Those bacteria grow well in the condition with temperature optimum of 30-40 °C.

Fire effects in soil biota is a complex phenomenon, depends on interaction among soil characteristics. The important indicator to assess fire impacts on soil characteristics is condition of litter, fermentation and humus layers or duff layer. Those layers play very important role to protect soil surface. When duff layer destroy heavily by fire, soil layer below will have serious impacts. As consequences, soil biota will be killed, including their function will be loss. Therefore, fire severity from post fire soil condition point of view is mostly affected by fire intensity which is indicated by litter and duff layers condition.

CONCLUSION

Fire effects on tropical forest biodiversity varies from low to high magnitude. To vegetation, direct effects of fire may kill plants and cause injury. Indirect effects of fire to vegetation including open wound which attract pest and disease attack. On the other hand, fire alters forest structure and composition by increasing diversity of forest under storey and seedling. Furthermore, diversity of soil macrofauna decreased after fire eventhough, in some cases, new families of macrofauna appeared after fire. Fire may decrease certain bacteria such as *Lactobacillus* and *Rhizobium* but increased phosphate solvent bacteria. 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.

Knowledge of fire effects on biodiversity may benefit forest managers. Fire adaptive vegetation can be used as important species in rehabilitation of burned area. Besides, fire adaptive soil biota may have benefit to improve soil characteristics. Furthermore, fire prevention is a priority effort in forest fire control when protection of tropical biodiversity is a must.

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