Newsletter
Toward the Regeneration of Tropical Peatland Societies

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Regeneration of Tropical Peatlands

Inter-University Research Institute Corporation National Institutes for the Humanities
Research Institute for Humanity and Nature

Assessment of the health impacts of haze pollutants caused by peatland fires

Haze due to forest and peatland fires contains many air pollutants, such as particulate matter (PM), carbon monoxide (CO) and polycyclic aromatic hydrocarbons, and these air pollutants have caused adverse health effects in Southeast Asia. ***The new leader of Tropical Peatland Society Project (from April 1, 2019)****, Osamu Kozan, explains a research approach to assessing its health impacts.*

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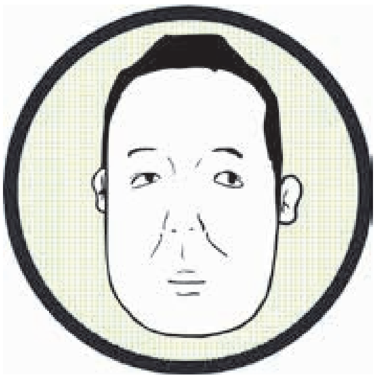
Background

The degradation of tropical peat swamps in Southeast Asia has increasingly become problematic in the context of international environmental conservation. Owing to their physical characteristics, tropical peat swamp forests are difficult to utilize, and therefore, have long been spared from develoPMent. However, drainage associated with plantation develoPMent of fast-growing and oil palm trees has led to a decrease in groundwater table levels and the drying of peat swamp forests.

This has in turn resulted in an increase in CO_2 emissions from peat decomposition and frequent fires. In Indonesia alone, an estimated 2.1 million hectares of forest, most of them peatlands, were burned in 2015. The resulting haze caused incalculable damage to the local economy and has impacted the health of not only the local people but also those in Malaysia and Singapore. In 2015, 0.5 million people in the region were diagnosed with upper respiratory infections. Haze has become a trans-boundary environmental, economic and political issue.

Smoke haze from forest and peatland fires in the Sumatra and Kalimantan Islands of Indonesia has repeatedly affected the air quality of nearby areas as well as neighbouring countries during the dry season since 1990s. In 1997, over 300,000 hectares were burned and the economy was seriously damaged owing to business shut downs and airport delays. The air pollution standard index reached 1800, which is an extremely hazardous level, in Palangka Raya in Central Kalimantan during mid-October in 2015. Haze due to forest and peatland fires contains many air pollutants, such as particulate matter (PM), carbon monoxide (CO) and polycyclic aromatic hydrocarbons, and these air pollutants have caused adverse health effects in Southeast Asia. Haze-related deaths and respiratory diseases have been reported during haze episode by the media, and there are increasing concerns about the health effects of serious haze.


Osamu Kozan*

Emission factors and emission ratios of PM from peatland fires

Haze from peatland fires is caused by PM. Understanding the emission of PM is one of the key factors required to understand wildfire haze. However, modelling studies for peatland fire haze in the region

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have consistently suggested that emissions of PM are underestimated (Marlier et al. 2013; Koplitz et al. 2016). The emission of PM is related to the fuel consumption during a wildfire via the emission factor (EF_{PM}). EF_{PM} is defined by the following equation:

$$EF_{PM} = \frac{\text{(Emission of PM)}}{\text{(Fuel consumption)}}. \quad (1)$$

Unfortunately, it is nearly impossible to quantify the 'emission of PM' or the 'fuel consumption' using field observation data. For this reason, the emission ratio is frequently used to constrain the emission of PM. The emission ratio of PM (ER_{PM}) is defined in the following way:

$$ER_{PM} = \frac{\text{(Emission of PM)}}{\text{(Emission of CO)}} \sim \frac{\text{(Concentration of PM)}}{\text{(Concentration of CO)}}. \quad (2)$$

Equation (2) shows that ER_{PM} can be constrained by conducting measurements of CO and PM. ER_{PM} can be converted to EF_{PM} by combining it with the emission factor of CO (EF_{CO}).

$$EF_{PM} = \frac{EF_{PM}}{EF_{CO}}. \quad (3)$$

EF_{CO} is defined by the following equation:

$$\begin{aligned} EF_{CO} &= \frac{\text{(Emission of CO)}}{\text{(Fuel consumption)}} \\ &\sim \frac{\text{(Emission of CO)}}{\text{(Total carbon emission} \times \text{1/Mass fraction of carbon)}} \\ &\sim \frac{\text{(Emission of CO)}}{\text{((Emissions of CO,}CO_2\text{ and }CH_4\text{)} \times \text{1/Mass fraction of carbon)}} \\ &\sim \frac{\text{(Concentration of CO)}}{\text{((Concentrations of CO,}CO_2\text{ and }CH_4\text{)} \times \text{1/Mass fraction of carbon)}}. \end{aligned} \quad (4)$$

Here, it is assumed that approximately all of the carbon (>99%) in the fuel is converted to CO, CO_2 and CH_4. This assumption has been experimentally validated. Equation (4) demonstrates that EF_{CO} can be determined by conducting atmospheric observations as long as the elemental compositions of the fuels are known. A caveat to the above discussion is that the atmospheric concentrations of both the gas species and PM in a wildfire plume are assumed to be significantly higher than the background concentrations. It is necessary to subtract the background concentration when it is not negligible.

EF_{CO} for tropical peatland fires in Indonesia has been measured multiple times in the last couple of years. For example, Nara et al. (2017) quantified EF_{CO} for a tropical peatland fire in the Riau Province in 2013 at 148 g kg^{-1}. Conversely, EF_{CO} for an intense wildfire event in 2015 was quantified at 255–291 g kg^{-1} (Huijnen et al. 2016; Stockwell et al. 2016). This variability in the EF_{CO} value may be caused by differences in the fuel composition as well as the combustion conditions.

Constraining PM Emissions via continuous atmospheric observations

Both CO and PM_{10} (PM smaller than 10 μm in diameter) are monitored by government agencies as a part of an effort to control the air quality. In the case of the peatland fire in Riau, air quality monitoring stations were located at Pekanbaru (Riau, Indonesia) and Muar (Johor, Malaysia) (Figure 1). These observation sites have measured haze from wildfires in Sumatra, especially those in Riau (Figure 2).

The wildfire events in June 2013 and February–March 2014 were especially pronounced. During these time periods, intense peatland fires occurred in Riau (Gaveau et al. 2014). As a result, the PM_{10} concentrations at these observation sites were higher than 500 μg m^{-3} and the maximum CO concentration exceeded 10 ppm. Importantly, the enhancements in the CO and PM_{10} levels were well correlated (Figure 3). The value of the

Figure 1. Locations of atmospheric observation stations: ●: Pekanbaru and ▲: Muar. Major cities in the region.

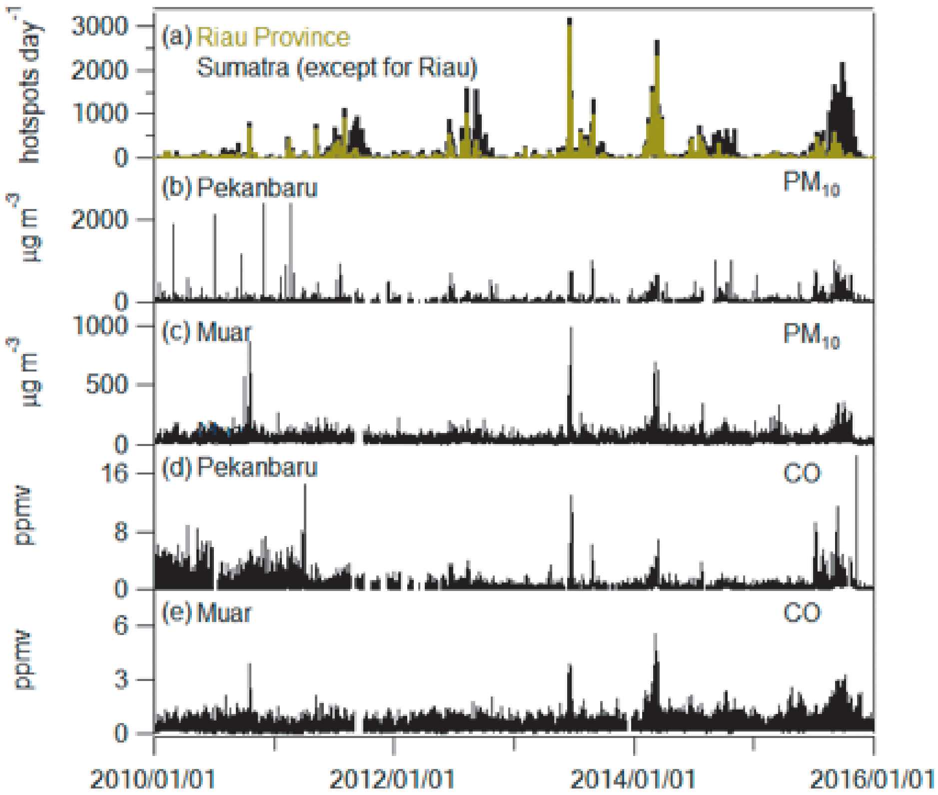

Figure 2. Time series for (a) the wildfire hotspot in the Riau Province and the rest of Sumatra, (b) the PM_{10} concentration at Pekanbaru, (c) the PM_{10} concentration at Muar, (d) the CO concentration at Pekanbaru and (e) the CO concentration at Muar.

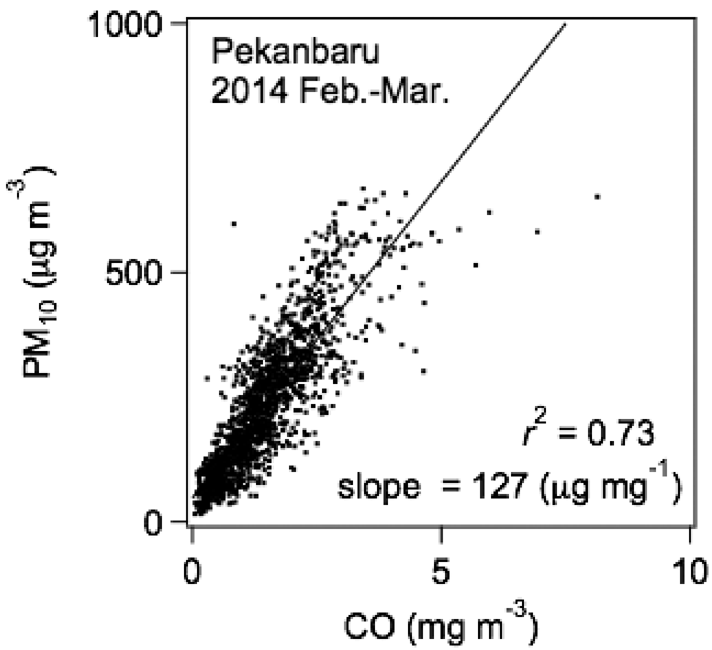

Figure 3. Correlation between the PM_{10} and CO concentrations observed at Pekanbaru during the peatland fire period in the Riau Province in February–March 2014.

slope in figure 3 provides the ER_{PM} value for the peatland fire event.

As detailed in Kuwata et al. (2018), the values for ER_{CO} were 87 ± 14 μg mg^{-1} and 127 ± 2 μg mg^{-1} for the peatland fire events in Riau during 2013 and 2014, respectively. These values can be translated to ER_{PM} values of 13 ± 2 g kg^{-1} (2013) and 19 ± 2 g kg^{-1} (2014). These values are 10–60% higher than the corresponding value for the current emission inventory (van der Werf et al. 2010), observationally demonstrating that PM emissions from peatland fires have likely been underestimated.

Assessment of health impacts

It has been reported that air pollution increases the occurrence of various diseases, including respiratory diseases, cardiovascular diseases and lung cancer. However, most previous studies have been conducted in North America and Europe where air pollution levels are relatively low. Such studies have focussed on the health effects of air pollutants from anthropogenic sources. There is very little evidence available to examine the health effects of exposure to haze due to wildfires, especially in Southeast Asia. Children are more susceptible to the harmful effects of air pollutants because they breathe more per kg of body weight and tend to be outside more than adults.

In the RIHN project, we are evaluating the health impacts of smoke haze caused by peatland fires in Indonesia. Specifically, we will conduct air quality monitoring during haze periods to perform proper exposure assessments and epidemiological studies. In the epidemiological studies, we will examine 1) the association between the number of hospitalizations and haze pollutants from forest fires in Palangka Raya and Pekanbaru and 2) the respiratory symptoms and pulmonary functions measured using peak flow meters for schoolchildren during haze periods in Palangka Raya and Pekanbaru.

Via this joint research project, we will quantify the health effects of haze pollutants caused by peatland fires. Using these results, we will estimate the disease burden due to haze from peatland fires. Such evidence is relevant from the perspective of public health and will contribute to future environmental policies to prevent peatland fires.

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The Fate of Termites and Ants in Tropical Peatlands

Termites and ants living in peatlands may have far-reaching impacts on ecological communities and ecosystem processes in tropical peat forest. Kok-Boon Neoh, an entomologist and our project member, explains the dynamics of ecosystem caused by them.

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General view of arthropod biodiversity in tropical forests

Tropical peatland is the dominant landscape in the Indo-Malayan region. It globally accounts for approximately 72% of tropical peatlands, stretching out over mangrove forests, peat swamp forests, and freshwater swampland forests. A recent statistic showed that these highly disturbance-sensitive forests are massively exploited, with a decline of 5.1 million hectares or 42% of the total current area of intact peat swamp forest, compared with the area of forests two decades ago. In the meantime, the area of abandoned secondary peatland increased twofold to 2.3 million hectares or 15% of the total area. The extensive anthropogenic activity in the form of deforestation for valuable logs and land conversion into agro-industrial plantations, together with the associated groundwater draining, increases the risk of peat fires. Furthermore, prolonged periods of annual droughts and floods may result in a drastic change in the environmental conditions of peatlands. As a consequence, peat swamp forests support lower species diversity than tropical rainforests. However, these forests are known to be the habitat of some ecological dominant terrestrial and aquatic species, particularly peat-dependent species, which potentially contribute to the regional beta-diversity.

▲**Figure. 1.** Termite is omnipresent in tropical peat forest ecosystem.

▲**Figure. 2**. Termite and ant surveys were conducted with the technical supports from Riau University. The author is at the center.

Biodiversity and the collapse of functional structure in fire-impacted peatlands

Termites and ants are highly abundant and diverse insect groups in tropical peat forest ecosystems (Figure 1). Termites are well known to play major roles as soil ecosystem engineers, helping soil fertilization, decomposition, and nutrient-carbon cycling. Similarly, ants act as seed dispersers, are mutualists with and direct prey of multiple taxa, and assist in soil processing and nutrient cycling. Recent studies on food webs at multiple trophic levels in tropical rainforests suggested that predators are highly dependent for their diet on ants and termites. Given their major roles as detritivores and herbivores, termites and ants may be vitally important for the food web dynamics in tropical peat swamp forests, maintaining the stability of ecological dynamics.

Since 2012, intensive arthropod surveys (Figure 2) have been undertaken in the transition zone of the Giam Siak Kecil–Bukit Batu Biosphere Reserve (0° 44'–1° 11'N, 0° 11'–102° 10'E), which lies between 0 and 50 m above sea level. The transition zone encompasses 304,123 ha or 43.1% of the total area of biosphere reserves. The transition zone is a major area for human settlement and agro-industrial plantations of oil palm, rubber, and fast-growing trees (i.e., *Acacia* and *Eucalyptus*). In this study, we evaluated three sites of peatland: one site that was burnt 6 months ago (Figure 3), one site that was burnt 8 years ago (Figure 4), and a burnt peatland cultivated with oil palm (Figure 5), which were characterized by moderate to high ecological degradation.

Overall, the termite species richness in fire-impacted peatlands decreased up to 40% of the total number of species found in peat swamp forests. The fires significantly changed the community structure of termites, with one family becoming dominant. In particular, only termites that nest inside wood (family Rhinotermitidae) survived through the fires. Termites that build mounds or nests in trees (family Termitidae) were absent from the fire-impacted peatland. Most wood-nesting termite colonies were detected inside incompletely charred tree branches and barks. This suggests that tree branches and barks might have provided the termites with refugia from heat during the fires and from flooding during the raining season. The high similarity in species composition in recently burnt peatland, long-ago burnt peatland, and peatland cultivated with oil palm trees implies low species turnover, regardless of how long ago the fire-impacted peatlands were abandoned or cultivated. This result does not necessarily imply that the fire-impacted peatlands did not favour the colonization of termites but instead that there is spatial dependence.

▲**Figure 3.** Peatland burnt 6 months ago.

▲**Figure 4.** Peatland burnt 8 years ago.

▲**Figure 5.** Burnt peatland cultivated with oil palm.

The impact of the fragmentation of peat forests on ant and termite is expected to be minimal. The species richness of ants in small remnant fragments of peat swamp forests surveyed in the present study was 30% lower than the species richness in previously studied Bornean tropical peat swamp forests of Central Kalimantan. The species richness of termites was 90% higher than that recorded in a near-natural peat swamp forest in Sarawak. In addition, the fragmented forests support disturbance-sensitive species of both taxa such as soil-feeding termites (*Subulitermes* group), specialist predators, and generalized Myrmicinae ants that were reported to be strongly associated with forest systems.

Given their rich biodiversity, these remnants of peat swamp forests can act as sources for recolonization of adjacent areas (Figure 6). This notion was proven in another study in which termites and ants were sampled in fire-impacted peatlands at varying distances from the remnant forests: sites close to the forests (10 to 1000 m) and sites distant from the forests (> 10 km). This study demonstrated a pronounced difference in functional group composition of termites. In particular, the fire-impacted peatlands close to remnant forests contained two additional termite functional groups and shared a similar composition structure with remnant forests but were significantly different from sites distant from remnant forests. Ants are apparently resilient to fire, as the similarity index revealed a high degree of similarity among ant communities in all land-uses surveyed. The evenness of termite and ant composition decreased with distance from the remnant forests, whereas the level of ecological degradation increased with distance. In general, in this study, both peat vegetation variables and ecological degradation were important in shaping the termite and ant communities of tropical peatlands, but their relative importance was not significant in fire-impacted peatlands, regardless of distance from the remnant forests.

▲**Figure 6.** Remnant forests play a role as biodiversity reservoir and natural buffer to enhance species diversity and the recolonization of forest-adapted species.

The importance of remnant forests in the restoration of biodiversity

Forest fragmentation is detrimental to the assemblage of local species if small fragments experience higher species loss than large fragments. However, in this study, the impact of fragmentation on the two taxa was minimal even though the peat swamp forest sites comprised only less than 5 hectares. Importantly, the fragmented forests support disturbance-sensitive species of both taxa such as soil-feeding termites, specialist predators, and generalized Myrmicinae ants that may be endemic in peat swamp forests. This highlights the importance of remnant forests as biodiversity reservoirs and natural buffers to enhance species diversity and recolonization of forest-adapted species.

The successional processes of termites and ants in tropical peat swamp forest ecosystem following disturbances have important implications for the restoration of ecosystem function and for the ecological dynamics of species. For example, soil-feeding termites were reported to increase soil pH, organic carbon content, and water content and to significantly modify soil composition. These features are vital for plant growth. The introduction of forest ant species from remnant forests indirectly alters the dominance structure of ants in fire-impacted peats and eventually promotes coexistence of species. However, maintaining fragmented remnant forests is not a priority in the land-use policy of Indonesia, where landowners prefer to convert tropical peatlands into more lucrative oil palm and timber plantations.

Future studies of tropical peatlands

Termites and ants are ubiquitous and may have far-reaching impacts on ecological communities and ecosystem processes in tropical peat forest ecosystems. Future studies to quantify termite and ant biomass in relation to CO_2 and methane gas emission following peat clearance events are important. Robust scientific evidence on the role of remnant forests in restoring the biodiversity of fire-impacted peatlands is required to emphasize the value of conserving remnant peat forests in Southeast Asia. Although we should harness the services termites and ants provide to natural ecosystems in degraded peatlands, we must not lose sight of the potential pest status of termites and ants. In particular, considering the ongoing conversion of peatlands into silvicultural plantations, some dominant species such as ***Coptotermes*** spp. are infamous for their pest status in Southeast Asian oil palm plantations.

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