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Post forest fire management at tropical peat swamp forest: a review of Malaysian experience on rehabilitation and risk mitigation

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Abstract. Malaysian Peat swamp forests constitute a significant component with an estimated 1.54 million hectares remaining. More than 70% of these peat swamp forests are in Sarawak, less than 10% Sabah in and the remainder 20% in Peninsular Malaysia (UNDP, 2006). Peat swamp forest is the fragile unique forest ecosystem type that usually found in the lowland of tropical forest areas. Peat forest is exposed to the fire even especially during the dry season. The impact of forest fires at the peat swamp area not only destroys the above-ground biomass but also penetrates the underlying peat, resulting in undesirable environmental impacts, including high atmospheric emissions of carbon gases. Therefore, undertaking the rehabilitation and fire risk mitigation activities at burned peat land is very tough and challenges due to the massive destruction and changes in the ecosystem. This paper will emphasize more on restoration and rehabilitation as well as fire risk mitigation efforts on burn peat swamp forest in Malaysia. The issues and challenges encountered in order to restore the burn peat swamp forest area will also be addressed.

Keywords: Peat swamp forest, forest fire, forest restoration, forest rehabilitation, risk mitigation

1. Introduction

Since a decade, forest fire phenomenon in the tropical region has been in a place of prodigious concern to debate among the environmental scientists and researchers. A consequence of forest fire event especially on the peat swamp forest ecosystem can be significantly causing globally carbon dioxide (CO₂) emissions to the atmosphere hence to a major contributor to global warming [1], [2] stated that



warming of the Earth's climate systems and lowering of natural water table levels were believed to be responsible for the increasing frequency of peatland fires.

In order to overcome these impacts of fire events to the peatland, the forest ecosystem is recovered through the fast forest rehabilitation or forest restoration. Post-fire restoration and rehabilitation are among issues to be discussed due to fire event affected vegetation by suppressing certain species and promoting invasive species toward changes in vegetation structure and altering successional pattern [3]

However, the undertaking of restoration and rehabilitation in burned peat land is very tough and challenges due to entirely changes in the ecosystem. The previous research on the techniques and technologies required for forest restoration and rehabilitation on peat swamp forest were documented mostly focused in the Boreal and Temperate zones, which have different environmental conditions compared to tropical peat swamp forests [4], [5].

Tropical peatlands differ from Boreal as well as from Temperate peatland in several other important aspects, especially climate and peat-forming vegetation. Consequently, it is not always appropriate to transfer knowledge acquired from the restoration of northern peatland directly to tropical peatland situations [4]. There are also differences in the physical characteristics of the vegetation and the nature of the peat formed between tropical and boreal/temperate peatlands. As a result, tropical peat has a higher hydraulic conductivity than temperate peat, especially in the upper peat layer, owing to the larger, more open pore structure that results from the hemic and fibric remains of trees [4], [6].

Thus, there are enormous challenges for the restoration and rehabilitation of formerly forested, tropical peatland landscapes. Some progress has been made towards understanding the restoration of tropical forests on mineral (that is, non-peat land) soils, but at present very little is known about the restoration of large areas of degraded tropical peatland. Rehabilitation and restoration activities are still at an early stage and, to date, have been limited to a few forest trials [7] with limited attention paid to the restoration of key peatland ecosystem functions, for example, hydrology and carbon sequestration [4]. Therefore, this paper intends to merge as well as to disseminate the findings of related peat restoration and rehabilitation, particularly in the tropical region ecosystem.

2. An overview history of forest fire in Malaysia

About a total of 18.27 million hectares (ha) or 55.3% of Malaysia's land area is still covered with forest. [8]. Out of this area, it is estimated 1.54 million ha are covered with peat swamp forest, which is more than 70% available in Sarawak, less than 20% in Peninsular Malaysia and the remainder in Sabah [9]. The natural evergreen tropical rainforest forms the dominant forest cover in Malaysia, which is characterised by year-round sunshine and seasonal heavy rainfall. Under natural conditions, the forest has a unique structure of close canopy that provides minimum penetration of direct sunlight onto the forest floor and keeps the ground surface always in moist conditions. This characteristic provides natural immunisation to the incidence of serious uncontrolled fire outbreaks on the forest floor [10]. However, this natural capability is seen to be gradually depleted along with the changes in land use due to development as well as forest fire episodes.

Forest fire and smoke and haze pollutant problems seem to be increasing in intensity and recurring periodically in Malaysia. Most of the forest fires reported in Malaysia occurred in degraded or logged-over peat swamp forests, both in the East and West coasts of Peninsular Malaysia and the coasts of Sabah and Sarawak. The extent of peatland destroyed by fires is not known precisely, but a prolonged extremely dry period early in 1998 had exacerbated the resurgence of peat fires over a wide area in Malaysia. The worst forest fires experienced by Malaysia were in 1982/83 when almost one million hectares of natural forest were burned in Sabah. This was at the same time when numerous fires affected Borneo and 3.2 million ha in Kalimantan. However, for Malaysia, this was the only case where natural forest fires of this magnitude were ever recorded. Subsequently, forest fires continued to occur in Malaysia, but the extent was less and mainly located in secondary conversion forests, forest plantations, and degraded forests.

Prior to 1990, no major incidence of uncontrolled forest fire was reported in the natural forest of Peninsular Malaysia. Some isolated cases of uncontrolled forest fire outbreaks were reported in small

scale pine forest plantation (*Pinus spp.*) in the early 1970s and *Acacia mangium* plantation in the late 1980s [10], [2]. From 1991 onwards, the numbers of uncontrolled forest fire outbreak were generally increased not only at forest plantation but also in other forested areas including degraded peat swamp forest areas [9]. Referring to Table 1, between the years 2010 to 2016, a total of 119 reports on forest fire outbreak were recorded which covering a total area of 5,347.19 ha of the PRF in Peninsular Malaysia. Throughout the period, 2014 recorded the worst forest fire outbreak in Peninsular Malaysia with 56 cases, 2682.6 ha of PRF affected and 70% on peat swamp forest due to the prolonged dry and hot period.

Table 1. Number of incidences and extent of forest affected by the forest fire in Permanent Reserve Forest (PRF) in Peninsular Malaysia (2010–2016) according to forest type.

Area	2010		2011		2012		2013		2014		2015		2016	
	No*	A**	No	A	No	A	No	A	No	A	No	A	No	A
Dry Inland Forest	2	2.1	2	9	4	14.6	3	40	36	672.45	-	-	16	136.69
Peat Swamp Forest	-	-	-	-	5	436.5	18	1381.7	15	1878.8	1	180	6	383
Forest Plantation	1	45	-	-	-	-	3	14	5	131.35	-	-	2	22
Total	3	47.1	2	9	9	451.1	24	1435.7	56	2682.6	1	180	24	541.69

Source: Forest Department Peninsular Malaysia, 2017.

* No of Incidences; ** Area (ha)

3. Post-fire Restoration and rehabilitation: A case study at Raja Musa Forest Reserve (RMFR)

At present, some areas of peat swamp forest in Malaysia are protected by law. In Peninsular Malaysia, about 253,447 ha of peat swamp areas have been gazetted as Permanent Reserve Forest (PRF) under the National Forestry Act, 1984. However, these PRF are situated in the vicinity of human settlement areas and surrounded by agricultural activities. Many of these peat swamp forests especially the area that neighbouring to the agricultural area were degraded and highly prone to forest fire outbreak resulted from fire spread into the PRF from uncontrolled open burning activities in the agricultural areas. Besides that, drainage constructed at peat swamp forest (within and outside PRF areas) was among the main factors bringing many changes to the peat swamp forest and causing the organic soil to dry up and easily get burn when ignited. Forest fire at peat swamp forest often cause severely damage to the species composition and its ecology, thus classified as highly degraded peat swamp forest occupied by grass, especially *Imperata cylindrica* with no big trees and low residual vegetation [11]. In the event to wait for natural regeneration, these areas will only be colonised by pioneer species and very susceptible to the forest fire. When left untouched for a longer period, natural regeneration will take place however only at a certain area and it may take a longer time to success aside difficult to achieve [13], [14].

Raja Musa Forest Reserve (RMFR) is a peat swamp forest covering approximately 23,486 ha [15] and located in Kuala Selangor District of Selangor State in Malaysia. At the southeast portion of RMFR, about 1,000 ha were identified as degraded peat swamp forest and had been subjected to repeated forest fire incidences, depleting the seed bank embedded in the peat [16]. Thus, the Selangor State Forestry Department (SSFD) collaborated with a local NGO called Global Environment Centre (GEC) to rehabilitate these degraded areas. The rehabilitation of RMFR started in 2009 with a series of replanting suitable pioneer tree species that originated from RMFR, until 2014, over 250,000 saplings have been planted in the rehabilitation site [15], [16]. Prior to rehabilitation, SSFD had taken important action to restore the degraded peat swamp forest by rewetting and raising the water table through constructing blockage at the identified canal which actively drains out peat water from PRF. The efforts to restore and rehabilitate the degraded area of RMFR showed positive results, in which natural regeneration is

taking place in the areas where the water table has been raised and the incidence of forest fire has been greatly reduced [15]. A study done in 2003 at RMFR showed convincing results on the rehabilitation of highly degraded areas by using species originated from local peat swamp forest and also shows that open planting was the best planting technique to be used for rehabilitating highly degraded areas in the peat swamp forest [17].

4. Risk Mitigation on forest fire in Malaysia: A case study at Raja Musa Forest Reserve (RMFR)

A forest fire cannot be completely prevented; thus, it is essential to prepare for and ensure the most expedient prevention and response to reduce the cost of suppression and loss during the forest fire outbreak. According to study was done in 2005 fire management in Indonesia is focused more on suppression than on prevention [18]. These practices were also widely been practiced in Malaysia. Most government institutions will only take action to deploy funds, staff, and equipment when fire already occurred and reached minimum criteria (e.g.: area of fire), thus resulting in larger funding needed in order to suppress the fire. The economic and environmental costs due to damages caused by the fires will increase exponentially as the fire spread. Without proper preparation, the probability of it going out of control also increases and the fire becomes more expensive to extinguish due to the increased amount of time and resources required [19].

Selangor State Government has expressed interest and support in efforts to restore and rehabilitate the peat swamp forest (PRF area) in the state. Among the action taken is Selangor State Government committed to maintaining 30% of their total land as PRF and the 25-year moratorium on logging in the PRF came into force in 2010. Additional to that, Selangor State Government through SSFD has produced 2 management plan which focuses on peat swamp forest management including forest fire. The gist of this management plan is management through an integrated participation approach which required the active participation of all agencies in managing the peat swamp forest [20].

Both management plan known as Integrated Management Plan for North Selangor Peat Swamp Forest 2014–2023 (Volume 1&2) and *Pelan Pengurusan Kebakaran Hutan Bagi HSK Kuala Langat Utara & HSK Kuala Langat Selatan 2017–2021* (Forest Fire Management Plan for Kuala Langat North Forest Reserve and Kuala Langat South Forest Reserve 2017–2021) were still in force since it is introduced. Among the major improvement is, the SSFD together with the Fire and Rescue Department with local authorities will take immediate action to suppress the forest fire although it is relatively small and occurred outside the PRF (agricultural land). This action has successfully produced a positive result, which since 2014, the forest fire incidence within peat swamp forests has consistently reduced (Table 2).

Table 2. Statistic on forest fire incidences within Peat Swamp Forest in Selangor (2012–2018)

Locations	2012	2013	2014	2015	2016	2017	2018
Raja Musa Forest Reserve	407	690	1,300	200	150	100	-
Bukit Belata Tambahan Forest Reserve	-	19.4	210	-	-	-	-
Kuala Langat Utara Forest Reserve	50	82	132	-	-	95.6	-
Kuala Langat Selatan Forest Reserve	37	563.2	152	10	40	-	1.5
Sungai Karang Forest Reserve	-	29	12	-	1	-	1.5
Total (ha)	494	1,383.6	1,806	210	191	195.6	3

Source: Selangor State Forestry Department (SSFD), 2019

Basic principles in managing the peat swamp forest were divided into four, which are Prevention, Preparedness, Response and Recovery [19]. Details as follows:

Table 3. Basic principles in managing the peat swamp forest (PRF)

Integrated Fire Management	Action
Prevention	80% of resources (money and people) should be allocated towards fire prevention efforts such as awareness campaigns to reduce ignition sources, periodic patrolling, continuously monitoring water table, etc.
Preparedness	Maintenance including resupply of equipment and structure (e.g. canal block, water pump engine and etc), training for staff and etc.
Response	Quick response to suppress small fire (cheapest to extinguish).
Recovery	Access and report impact of forest fire; restoration and rehabilitation action.

Few other actions have been taken by the SSFD and other agencies on the ground especially at Raja Musa Forest Reserve to mitigate the forest fire outbreak as following below:

4.1 Installation of check dam and series of canal block at canal within the peat swamp forest.

Rewetting the degraded peat swamp forest is critical in any restoration and rehabilitation activity. Restoration of its hydrological regime can be done by keeping the peat soil wet, thus preventing further decomposition and peat soil subsidence and reducing the risk of fire outbreak. This process requires raising or maintaining the water table by blocking the canal. In RMFR, blockings have been undertaken inside and outside of the PRF to prevent further drainage of the area. In an area with good access, canal blocks were made using excavators, while in other areas it was done manually by using a bag filled with sand or peat, supported by mangrove poles. To date, a total of more than 800 blocks have been put in drains at the edge of the PRF.



Figure 1. Canal blocking installed at RMFR



Figure 2. Canal blocking installed at RMFR

*Photo credit: Selangor State Forestry Department & Global Environment Centre (GEC)

4.2 Installation of Clay Dyke.

A pilot test to use compacted clay (called as clay dyke) to stop water outflow was successfully completed in 2002 at RMFR. The purpose of clay dyke construction is to stop water flow or seepage of water from the peat swamp forest into the adjacent clay mining area. This was a 600 m long trench dug through the peat to the clay layer. The trench was filled with clay and compacted. This clay dyke has proved successful for both the mining operator and the peat swamp forest area. The mining operator no longer must run a set of water pumps continuously removing water from the mining area and the surrounding forest water levels have been raised and subsequently, a significant improvement to natural forest regeneration has occurred [21], [22]. A series of water outflow points have been established to manage the water levels to the desired height.



Figure 3. Clay dyke constructed between the degraded peat swamp forest and clay mine area



Figure 4. Clay dyke constructed between the degraded peat swamp forest and clay mine area

*Photo credit: Selangor State Forestry Department & Global Environment Centre (GEC)

4.3 Installation of High-Density Polyethylene (HDPE) Pipe to pump water from the nearby lake into the peat swamp forest.

Southeast area of RMFR was neighbouring with ongoing and ex-mining areas. These ex-mining areas mostly formed a huge lake and act as a water reservoir. The water from this ex-mining area was pump into the degraded peat swamp forest areas (which is undergoing rehabilitation programme) in order to maintain optimum water level within the forest. To do this, a series of HDPE pipes with a total length of more than 1 kilometre (km) long has been installed to connect the ex-mine area into the rehabilitation areas. Along the HDPE pipe, few outlets were made available in order to flood the desired areas. A high pressure water pump is required to pump the water from the lake into the forest area. Three retention ponds were also established to act as an emergency water source during the forest fire outbreak.



(a)



(b)

Figure 5. (a) and (b) HDPE pipe was constructed to pump water from the adjacent ex-mine lake into the peat swamp forest areas

*Photo credit: Selangor State Forestry Department & Global Environment Centre (GEC)

4.4 Boundary demarcation with a signboard

Boundary demarcation was done by installing signage along the PSF boundary. Clear and easy to read demarcation is important to let the public knows that entering the PSF without official permission from the Forestry Department is an offense.



Figure 6. (a) and (b) Signage installed as boundary demarcation

5. Discussions

The impact of forest fires at peat swamp area not only destroys the above-ground biomass but also penetrates into the underlying peat, resulting in undesirable environmental impacts, including high atmospheric emissions of carbon gases and particulate matter, impaired hydrology through loss of the water regulation functions of the near-surface peat layer, subsidence of the peat surface, loss of propagules for vegetation re-establishment (loss of seed bank and tree bases), and damage to human health and livelihoods through loss of natural resources and high levels of air pollution [4]. Even the smoke and dust from peat fires not only pose a severe health hazard to the local communities but usually develop into a more widespread haze with enormous potential for economic losses. Haze episodes in the last decade have demonstrated that citizens suffer illnesses from air pollution and that tourism arrivals plummet, with impacts on the overall economy [8].

In other to overcome these impacts of fire event to the peat swamps, the ecosystem is recovered through the fast forest rehabilitation or forest restoration. However, doing the rehabilitation or restoration at burned peat land is very tough and challenges due to totally changes in the ecosystem. The previous research on the techniques and technologies required forest restoration and rehabilitation at peat land was documented expertise mostly focused in the boreal and temperate zones which different environmentally and condition to tropical peat swamp forest. [23], [24]. Tropical peat lands are differing in several other important respects, especially climate and peat forming vegetation. Consequently, it is not always appropriate to transfer knowledge acquired from the restoration of northern peat land directly to tropical peat land situations. Tropical peat lands have formed under high precipitation–high temperature climatic regime, whereas those of the temperate and boreal zones are maintained under conditions of high precipitation and low temperature.

There are also differences in the physical characteristics of the vegetation and the nature of the peat formed between tropical and boreal/temperate peat lands. The former is dominated by peat swamp forest trees, which are the principal peat-forming species whereas, in the latter peat lands, bryophytes, sedges, grasses, and low-growing shrubs perform this role. As a result, tropical peat has a higher hydraulic conductivity than temperate peat, especially in the upper peat layer, owing to the larger, more open pore structure that results from the hemic and fibric remains of trees [25], [26].

6. Conclusion

There are enormous challenges for the restoration and rehabilitate of formerly forested, tropical peat land landscapes. Some progress has been made towards understanding the restoration of tropical forests on mineral (that is, non-peat land) soils, but at present very little is known about the restoration of large areas of degraded tropical peat land. Rehabilitations and restoration as well mitigation activities are still at an early stage and, to date, have been limited to a few forest trials with limited attention paid to the restoration of key peat land ecosystem functions, for example, hydrology and carbon sequestration. Therefore, further research needs to be done in order to achieve the successful objectives of restoration or rehabilitation of post fire peat swamp forest area in a specific area such as right planting technique & suitable trees species based on fire intensity or level of peat swamp forest degradation.

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