



## Research article

# Factors determining peat thickness in secondary forest of Kuan Kreng peat forest, Southern Thailand

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**Article Info**
**Article history:**

Received 9 July 2019

Revised 13 May 2020

Accepted 19 May 2020

Available online 30 June 2020

**Keywords:**

Kuan Kreng

Peat swamp forest

Peat thickness

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**Abstract**

In Thailand, increased demand has forced the conversion of peat forest to agricultural area. As a result, drainage canals have been dug in peat forests without any control on their effect on the level of groundwater, increasing the risk of forest fire. Peat volume estimation as a fuel source for forest fires is required for specific prevention programs, such as fuel management. Inventories of peat depths and environmental factors such as forest stand biomass were made in the Kuan Kreng peat forest, Southern Thailand to evaluate the peat depth using estimated parameters instead of direct measurement. The results were tested against a dataset of 171 plots on a 1 km sampling grid. The average peat depth was 0.78 m with the deepest location estimated at 3.10 m. Peat depth could be modelled using vegetation data, combined with both litter mass (tonnes per hectare) and height of vegetation ground cover (meters). The regression model developed to predict peat depth was: Peat depth (m) = 0.436 + 0.19 (litter mass) + 0.236 (ground cover depth). In general, the predicted peat depth was over-estimated and at times, predictions were outside the observed data range. This was attributed to additional effects from both internal and external parameters on peat formation that had not been included in the model. In addition, it is important to maintain a certain height of water table to prevent fire and encourage natural revegetation.

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**Introduction**

In Southeast Asia, peat forests cover more than 26 million ha (69% of tropical peat lands), at altitudes from around sea level to about 50 m above sea level, mostly near the coasts of East Sumatra, Kalimantan, West Papua New Guinea, Brunei, Peninsular Malaya, Sabah, Sarawak and Southeast Thailand (Page et al., 2004). Peat soil contains more than 30% organic material in the upper soil profile (Food and Agriculture Organization of the United Nations, 1990). Tropical peatlands have high porosity and consequently, they have high water-holding capacity which helps to regulate the water function with respect to downstream tropical lowlands. Tropical peatlands

serve as reservoirs of fresh water, maintaining moderate water levels, reducing storm flows and maintaining river flows even in dry seasons and provide a buffer against saltwater intrusion. In peat forests, dead vegetation such as litter, fallen trees and roots are deposited in anaerobic floodwater, resulting in a low decomposition rate of organic matter under these conditions, which then accumulates to form a peat layer. However, when drained, the forest area can be converted into agricultural land and the peat quickly decomposes due to respiration of aerobic organisms, releasing greenhouse gases including CO<sub>2</sub> (Itoh et al., 2017; Könönen et al., 2018). Once drainage canals have been dug in a tropical peatland, where the canal construction does not take into account the need to control the function of groundwater levels, the risk of forest fire increases and uncontrolled fire can occur, associated with El Niño events (Langner and Siegert, 2009; Wooster et al.,

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<https://doi.org/10.34044/j.anres.2020.54.3.14>

2012). Moreover, drained peat is vulnerable to field fires during dry seasons and these fire events can accelerate CO<sub>2</sub> emissions. As much as 30 % of the total CO<sub>2</sub> emissions from land use, land use change and forestry have been attributed to current large-scale degradation of peatlands (Hooijer et al., 2006; Couwenberg et al., 2010). Tropical swamp forests growing on peatlands are exposed to various risks of deforestation (Murdiyarto et al., 2010).

The peat swamp forest of Thailand is estimated to cover 64,000 ha in small patches all over the country (Phengklai et al., 1989). These patches are mainly located in Southern Thailand (63,982 ha), particularly in the provinces of Narathiwat (30,969 ha) and Nakorn Si Thammarat (18,946 ha). Of the total area under peatlands in Thailand, only 9,031.5 ha are considered intact peat swamp forests, especially the Phru Toh Daeng peat forest in Narathiwat province. The remaining 55,523 ha are considered degraded peat swamp forest (Chukwamdee et al., 1995). It has been estimated that the maximum thickness of organic soil in the peat swamp in Thailand is 3.8 m (Nuyim, 2005), in contrast with the much thicker organic soils found elsewhere. When the soil organic level is repeatedly damaged by wildfires, nutrients in the flammable organic soil are burned completely, leaving the mineral soil intact with a high pyritic (FeS<sub>2</sub>) content (Vijarnsorn and Panichapong, 1987). Peat swamp forests in Thailand have been converted into agriculture since the 1970s through a process involving deforestation and drainage of water from the peat layers where the thickness of the peat layer reduces first due to discharge of water and later through aerobic decomposition of peat and soil respiration which releases greenhouse gases into the atmosphere (Gert et al., 2018). As the peat layer thins, the ground surface subsides. Many peatland conversions have not resulted in fertile agricultural lands and have been abandoned, leaving the areas degraded and eventually developing into secondary forest vegetation (Nagano et al., 2013). In the Southern Thailand, vast areas of peat swamp have been left as wastelands after unsuccessful attempts at agricultural activities (Nuyim, 2005). Severe fires in peat forests can ignite peat deposits, particularly after periods of extended drought or where the peat structure and moisture have been altered due to drainage or afforestation or both. The ignition of peat deposits can cause smoldering wildfires that can potentially release substantial amounts of carbon and cause environmental damage, with subsequent slow recovery (Davies et al., 2013).

Several environmental factors can affect the depth of peat including: soil disturbance and slope (Nicholas and Connolly, 2011; Parry et al., 2012); elevation (Jaenicke et al., 2008; Nicholas and Connolly, 2011; Parry et al., 2012; Rudiyanto et al., 2015); aspect, upslope contributing area and curvature (Graniero and Price, 1999); bryophyte cover (Weissert and Disney, 2013); wildfires (Nuyim, 2005); climatic conditions and sea level (Rene, 2012); or water table rise which depends on the magnitude of the excess water budget (Clymo, 1984). Winston (1994) assumed that the rate of peat accumulation is controlled by hydrological constraints imposed by the bog size and shape. However, such information has not been gathered for peat forests in Thailand. This study aimed to evaluate the relationship between peat soil depth and some environmental factors in the Kuan Kreng peat forest, Southern Thailand. Such estimates of

peat volume as a forest fire fuel are needed to determine the effect of fire intensity and to develop forest fire prevention strategies.

## Materials and methods

### Study site

Kuan Kreng peat forest is located in Nakorn Si Thammarat province, Southern Thailand. The area of 32,000 ha under peat forest comprises a wildlife sanctuary and national forest reserves area. In the dry season (June to September), the peat water level decreases due to excessive evaporation as well as increased water demand for agricultural purposes. Therefore, the peat dries up and then burns as fuel in forest fire events. In 2012, the water level in the Kuan Kreng peat forest was substantially reduced when forest fire occurred and 2,000 ha of peat forest was burnt (Office of the Royal Development Projects Boards, 2015). The current study was conducted on an area classified as a secondary swamp forest, which had been disturbed annually by forest fire. After the peat layer had burnt out and disappeared, the soil became strongly acid. Subsequently, the forest cover changed to a degraded forest dominated by *Melaleuca cajuputi* (Chukwamdee et al., 1995).

### Data collection

A field sampling strategy was developed to determine the relationships between peat depth and the presence of vegetation and litter cover in terms of accumulation and biomass. The vegetation data were used as a source of organic matter in the ground cover and litter depth, biomass of *Melaleuca cajuputi* stand, ground cover and litter. The distance of sampling plots from a water source related to the deposition of alluvial deposits caused by frequent stream flooding was included as a predicted parameter. A square sampling grid was used to provide a sample representative of the dataset, with 282 sampling plots separated by 1 km on the grid. The peat depth was recorded using a 4.0 m steel probe which was pushed in until it met with resistance. Quadrant plots (15 m × 15 m) were established at each grid point and three peat depths were recorded from each plot. Some sampling points were inaccessible due to flooding or land use change to urban and agricultural areas (paddy field or palm oil plantation). In such cases, the sampling points were either re-allocated or removed if a suitable replacement could not be found. The vegetation survey was done in the dry season during times of lowest water level. On each plot all trees and saplings were measured for their height and their diameter at breast height over bark. Ground cover (shrubs and herbs and *Melaleuca cajuputi* seedlings) was recorded in a 4 m × 4 m plot in terms of average height from ground level. The dry mass of ground cover was analyzed based on five plots (four plots at the corners and one plot at the center of the 15 m × 15 m plot). Plant samples were taken back to the laboratory and were oven dried and their dry weight was determined. The ground cover depth was estimated using a measuring pole at the center of each plot. Similarly, five plots of size 1 m × 1 m were established to determine litter properties

(litter mass and the depth of litter layer). Litter samplers were determined for their fresh weight and some were oven dried to estimate their dry weight. The average dry mass of litter was calculated for each plot. The average litter depth was measured using a stainless ruler at three points in each plot. Tree biomass was calculated using an allometric equation for Kuan Kreng peat forest (Wanthongchai et al., 2014). The distance from the closest natural stream was estimated using a GIS software package.

#### Data analyses

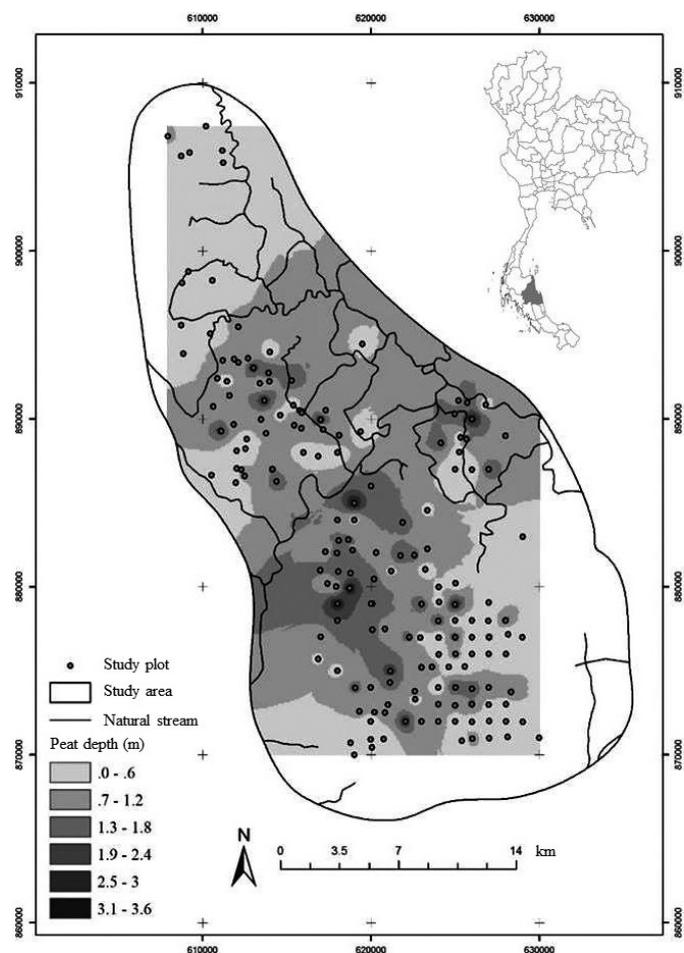
Descriptive statistics were calculated for all parameters. Multiple linear regression models were developed using stepwise method for: peat depth (measured in meters), litter depth (measured in centimeters), litter mass (measured in tonnes/ha), ground cover depth (measured in meters), biomass of ground cover (measured in tonnes/ha), stand biomass (measured in tonnes/ha) and distance the nearest stream (measured in meters) from the peat sampling point. Analysis of variance was determined using the SPSS software package (SPSS, Chicago, IL, USA). All statistical analyses were tested at a significance level of  $p < 0.05$ .

## Results and Discussion

#### Descriptive peat depth statistics

During the field survey, several points could not be sampled as a result of changed land use to urban, paddy field and palm oil plantation areas. From the 282 sampling points, 111 points were discarded and the remaining 171 sampling points were used. The maximum peat depth was 3.10 m, with a minimum of 0.02 m and an average ( $\pm$ SD) of  $0.78 \pm 0.77$  m. It should be noted that the standard deviation for the average peat depth was large. Litter depths were in the range 0–14.00 cm with an average of  $2.50 \pm 2.49$  cm. The ground cover depth (defined in this study as the height of shrubs and saplings) was in the range 0–2.57 m with an average of  $0.61 \pm 0.49$  m. The average dry mass values for the litter and ground cover were  $10.79 \pm 11.03$  tonnes/ha and  $4.58 \pm 6.25$  tonnes/ha, respectively. Stand biomass varied with the density and abundance of trees, with *Melaleuca cajuputi* dominating. The results showed that the stand biomass ranged from 0 tonnes/ha in abandoned crop land to 161.41 tonnes/ha in dense mature stands. The average stand biomass was  $33.04 \pm 32.11$  tonnes/ha. Distance from the nearest natural stream, which is considered important in determining

the deposits of vegetation debris, varied from 0 m to 2,607.34 m (mean =  $690.57 \pm 644.11$  m). All data averages had associated large standard deviations. All descriptive statistics are shown in Table 1 and the peat depth mapping shown in Fig. 1. From this information, it can be seen that the depth of peat in Kuan Kreng peat forest was mostly less than 2.5 m. In addition, the peat gets deeper from the edge of the peat margin to the center of the peat forest. However, shallow depths were observed at some sampling points.



**Fig. 1** Peat depth mapping in Kuan Kreng peat forest showing peat depth profile, location of study plots and natural streams

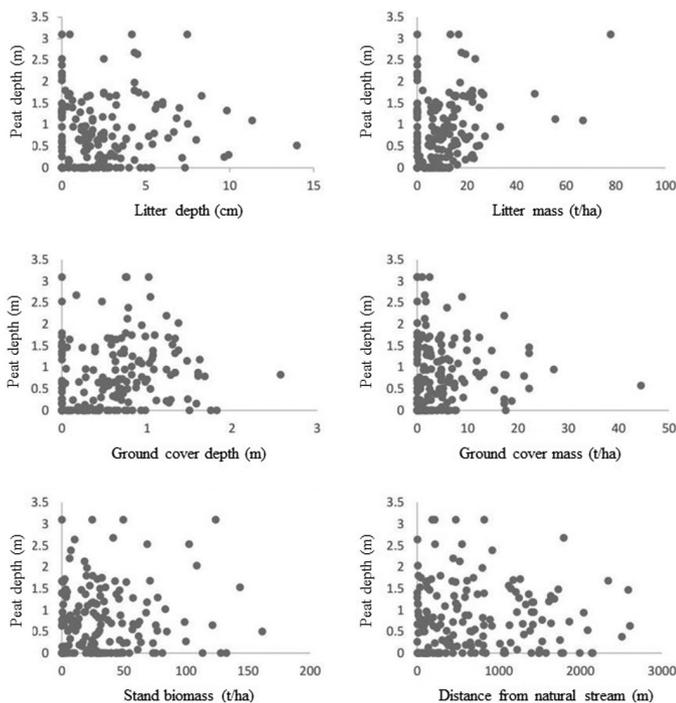
**Table 1** Descriptive statistics for peat depth, litter depth, litter mass, ground cover depth, ground cover mass, stand biomass and distance from stream in Kuan Kreng peat forest

Value	Peat depth (m)	Litter depth (cm)	Litter mass (t/ha)	Ground cover depth (m)	Ground cover mass (t/ha)	Stand biomass (t/ha)	Distance from stream (m)
Maximum	3.10	14.00	77.92	2.57	44.42	161.41	2,607.34
Minimum	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.78	2.50	10.79	0.61	4.58	33.04	690.57
SD	0.77	2.49	11.03	0.49	6.25	32.11	644.11

### Relationship between peat depth and environmental parameters

Scatter plots between peat depth and the various parameters mentioned above are shown in Fig. 2. The scatter plots do not indicate a clear relationship. Therefore, multiple regression analysis using a stepwise method was used to determine the relationship between peat depth and the given environmental parameters (distance from natural stream, stand biomass, litter mass, litter depth, ground cover depth and ground cover mass). Non-significant relationships were found between the peat depth and the distance from natural stream, stand biomass, litter depth, and ground cover mass; these parameters were excluded from the regression models. On the other hand, litter mass and ground cover depth were selected as predictable variables in building the peat depth model. The first model, with only litter mass as a predictable variable had a lower coefficient of determination ( $R^2$ ) values compared to the combination of litter mass and ground cover depth (0.081 and 0.104, respectively). However, both regression models had a significant relationship ( $F = 14.97, p < 0.01$  and  $F = 9.765, p < 0.01$ ).

Litter mass and ground cover depth were included in the regression model. The constant term in the regression model and beta factors



**Fig. 2** Scatter plots showing relationship of individual environmental variables and peat depth

**Table 2** Coefficients of peat depth regression models

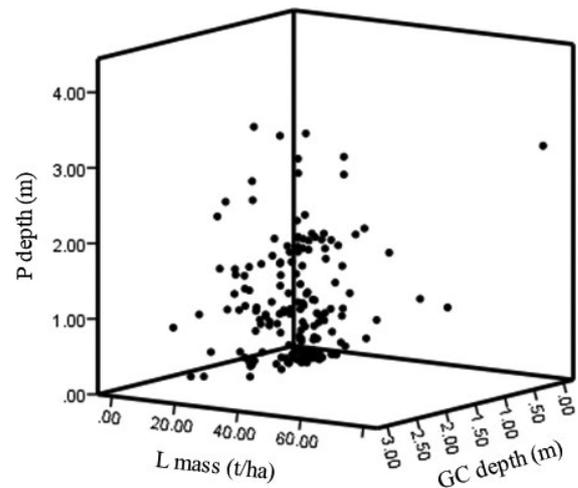
Model		Unstandardized coefficients		Standardized coefficients	t	p Value
		B	Std. Error	Beta		
1	Constant	0.567	0.079		7.202	.000
	Litter mass	0.020	0.005	0.284	3.866	.000
2	Constant	0.436	0.100		4.338	.000
	Litter mass	0.019	0.005	0.268	3.658	.000
	Ground cover depth	0.236	0.114	0.152	2.072	.040

are shown in Table 2. The multiple regression models are shown in Equations 1 and 2:

$$\text{Peat depth} = 0.567 + 0.20 (\text{litter mass}) \quad (1)$$

$$\text{Peat depth} = 0.436 + 0.19 (\text{litter mass}) + 0.236 (\text{ground cover depth}) \quad (2)$$

Kuan Kreng peat forest is located in the coastal area at a slightly elevated height. The water sources are a combination of precipitation and surface runoff. The peat depth determined in this study (0.02–3.10 m) was comparable to many previous results reported from Thailand and other countries. For example, Suzuki and Niyomdham (1992) studied un-drained natural peat swamp forest in Narathiwat province, Thailand. They indicated that the thickness of the peat layer was 1.0–5.0 m. Yoshino et al. (2002) reported that in degraded peat forest at Bancho, in Nakorn Si Thammarat province, Thailand with land use changes to agriculture 30 years ago, the peat thickness was 1.0–3.0 m. Rudiyanto et al. (2015) reported that peat depth in South Sumatra was 0.5–10 m, while a depth in the range 3.65–5.40 m was reported by Jaenicke et al. (2008) in a lowland peat dome in Central



**Fig. 3** Multivariate scatter plot (regression model with  $p < 0.05$ ) for litter mass (Lmass) and ground cover depth (GCdepth) as the explanatory variables for peat depth (P depth)

Kalimantan, South Sumatra and West Papua, Indonesian. Vijarnsorn and Panichapong (1987) found that the maximum thickness of organic soil in peat swamps in Thailand was 3.8 m, which was comparable to results obtained in the current study. Lahtreenoja and Roucoux (2010) reported that peat deposits in the peatlands of the Western Amazon basin can be up to 6 m deep. The average peat depth ( $0.78 \pm 0.77$  m,  $n = 172$ ) estimated in the current study was in contrast with much thicker organic soils found elsewhere (Wetlands International, 2004). There are differences in the accumulation of peat layer in the tropics compared with temperate zones and this can have a significant effect on the rate of peat accumulation as biomass production is many times greater than that in temperate regions (Andriess, 1988). On the other hand, oxidation and decomposition are also enhanced in the tropics due to relatively higher temperatures (Krishna and Mohan, 2017). In the current study, the undisturbed, intact peat forest converted to secondary forest area dominated by *Melaleuca cajuputi*. These small shrub-like trees are affected by frequent forest fires resulting in a low amount of litter with a high decomposition rate and subsequently a thin peat layer.

The relationship between peat depth and the combination of litter mass and depth of ground cover had an  $R^2$  value of 0.104 compared to 0.081 obtained from the regression model with only litter mass as the independent variable. However, a low  $R^2$  value of 10.4 % indicated that the litter mass and depth of ground cover were not distinguishing parameters influencing the peat depth. Peat formation may well involve other factors that in turn influence peat depth. The depth attained by peat is determined by both internal development processes and external forces. Hilbert et al. (2000) based their analysis on a non-linear interaction between peat growth and water table depth. Belyea and Baird (2006) reported that peatland might increase in depth during a spate of wet years when the mean water tables are relatively high, only to be reduced in a dry year through aerobic decay of the litter lying above the water table. They also indicated that sufficient decay can occur in one drought year to consume all the excess litter accumulated in 10–30 normal years. Page et al. (2004) reported that a combination of low topographic relief, impermeable substrates and high effective deposits of woody debris during rainfall events can provide suitable conditions for slow decomposition of organic material and the accumulation of peat depth (often by more than 10 m). Staub and Esterle (1994) reported the occurrence of coastal peatland along maritime fringes and in deltaic areas where the peat developed over marine sediments that were inland of accreting mangrove and Nipa palm swamps. The current study demonstrates the relationship between litter mass and depth of ground cover depth which were increased with increased peat depth. Tallis (1991) explained that the genesis process of peatland formation is the local variability in the initiation of peat formation. Therefore, some areas of peatland will have been developing for longer periods and will be deeper than relatively younger sites. Rene (2012) found that peat accumulation in Southeast Asia was in the range 0.54–1.90 mm/year. At such a rate, the peat formation in the Kuan Kreng peat forest could be attributed to approximately 1,500–6,000 years of accumulation. Therefore, peat depth can be affected by other factors that are either

effective now or were in the past. The use of present variables is not appropriate as a predicted variable for peat depth. Furthermore, litter mass and ground cover depth are good indicators as litter is a very important organic factor in peat formation. In addition, ground cover depth produces enormous amounts of organic matter, especially in degraded peat forest areas. However, other factors must be taken into account, such as the scale of any erosion or evidence of present or past management practices. Fig. 4 indicates that for the current study, the peat depth predicted from parameters was overestimated compared to the data measured from field surveys.

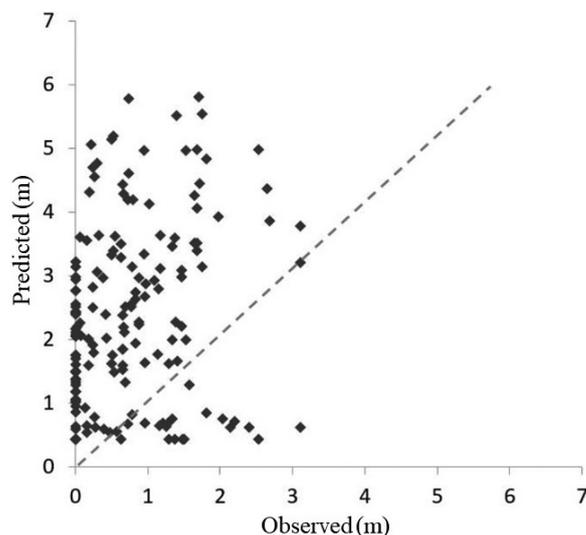


Fig. 4 Scatter plot showing relationship between observed and predicted peat depth (dotted line indicates a 1:1 relationship) for the current study

## Conclusion and Recommendation

The results from the study showed that peat formation was generally at a depth of 0.78–3.10 m and was highly compact and dried out due to drainage and expose to sunlight. Peat material is very dry and extremely combustible in a forest fire. Peat depth as fuel load was predicted via variables that can be easily and practically measured by local government staff. Statistical analysis could express the multivariate relationship of peat depth with litter mass and ground cover depth using linear regression models. However, the developed model over-estimated the peat depth and at times predictions were outside the observed data range. Therefore, further study is required based on data on additional internal and external parameters that can potentially affect peat formation should be included such as the depositional environment, climate and distribution of surrounding sediment types. Water level is a key factor in the prevention of peat fire and fire management. Uncontrolled and excess drainage from peatland due to agricultural practices can lead to lowering of the water table and the subsequent drying of the peat. Therefore, it is important to maintain a predetermined height for the water table to prevent fire damage and to encourage natural revegetation.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

## Acknowledgements

The authors thank the staff at the Kuan Kreng Forest Fire Patrol Station, Royal Forest Department, for their help in the field work. The Faculty of Forestry, Kasetsart University, Bangkok, Thailand provide accommodation and laboratory access throughout the project period. The research was funded by the National Research Council in grant year 2013.

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