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# TEMPORAL VEGETATION DYNAMICS IN PEAT SWAMP AREA USING MODIS TIME-SERIES IMAGERY: A MONITORING APPROACH OF HIGH-SENSITIVE ECOSYSTEM IN REGIONAL SCALE

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**Abstract**: *Peat swamp area is an essential ecosystem due to high vulnerability of functions and services. As the change of forest cover in peat swamp area has increased considerably, many studies on peat swamp have focused on forest conversion or forest degradation. Meanwhile, in the context of changes in the forestlands are the sum of several processes such as deforestation, reforestation/afforestation, regeneration of previously deforested areas, and the changing spatial location of the forest boundary. Remote sensing technology seems to be a powerful tool to provide information required following that concerns. A comparison imagery taken at the different dates over the same locations for assessing those changes tends to be limited by the vegetation phenology and land-management practices. Consequently, the simultaneous analysis seems to be a way to deal with the issues above, as a means for better understanding of the dynamics changes in peat swamp area. In this study, we examined the feasibility of using MODIS images during the last 14 years for detecting and monitoring the changes in peat swamp area. We identified several significant patterns that have been assigned as the specific peat swamp ecosystem. The results indicate that a different type of ecosystem and its response to the environmental changes can be portrayed well by the significant patterns. In understanding the complex situations of each pattern, several vegetation dynamics patterns were characterized by physical land characteristics, such as peat depth, land use, concessions and others. Characterizing the pathways of dynamics change in peat swamp area will allow further identification for the range of proximate and underlying factors of the forest cover change that can help to develop useful policy interventions in peatland management*



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## 1. INTRODUCTION

Information on ecosystem characteristics and its changes in a highly vulnerable land, such as peatlands, is the key to many aspects of global environmental change, environment adaptation and mitigation studies. Peatland ecosystems are vulnerable to changes in quantity and quality of their water supply, and it is expected that climate change will have a pronounced effect on peatlands through alterations in hydrological regimes with climate variability (Erwin, 2009).

The importance of peatland in the tropical environment has been studied by many researchers, such as the estimation of $CO_2$ emission released by forest fire (Page et al., 2011), the variation in its ecological function (Achard, 2002), the loss of biodiversity through land conversion (Myers et al., 2000) and the sustainable management of peatland (Hooijer et al., 2006). Moreover, as explained by Wösten et al. (2008) that inundated condition of peatland is recommended as a regional ecosystem conservation program and

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to reduce $CO_2$ emissions from the lands. As the importance role of peatlands and to prevent fires in peatland areas, the Indonesian government has a commitment to restore about two million hectares of peatland areas by 2020 due to the establishment of a peatland restoration agency (Wardhana, 2016).

In more complex tropical peatland areas in Indonesia, the peatland characteristics and its change are the results of many, non-linear, interactions between socio-economic and cultural conditions, biophysical constraints and land use history (Cole et al., 2015). The biophysical processes of peatlands ecosystem can be represented as interactions between different land use/cover types, biophysical conditions and spatial elements of the landscape (Evans & Moran, 2002).

This study examines the feasibility of using time series satellite datasets to recognize the changes occurred in the peat swamp ecosystem that would be possible to consider the peatland characteristics. A monitoring approach to recognizing the peatland characteristics and its dynamic changes on a regional scale is due to simultaneous analysis of land surface attributes from long-term data sets and seasonal variation. Monitoring of land surface continuously can provide information on the ecosystem characteristics, including the actual subtle nature of inter-annual change (Setiawan & Yoshino, 2014). This approach will provide information how the change occurred accurately as well as how big are these affected areas. Moreover, based on this information, we can choose the priorities for restoration and further research.

## 2. DATA AND METHODS

### 2.1. Study Site

The study site is the main island of Sumatra with an area of 473,481 $km^2$. The island is administratively divided into 8 provinces, namely Aceh, North Sumatra, West Sumatra, Riau, Jambi, Bengkulu, South Sumatra and Lampung (**Figure 1**). Sumatra has a mean annual rainfall mostly less than 3,000 mm, below 1,500 mm on the northeast coast, and below 2,000 mm in several intermontane basins from Aceh to Bengkulu. Over 4,000 mm fall on the off shore Mentawai Islands, on the Sibolga and Padang coasts, and around Mount Malintang and Mount Pantaicermin. On the mountain slopes of Bukit Amas and of northern Bengkulu mean annual rainfall exceeds 5,000 mm. The Eastern Islands receive 2,000 to 3,000 mm/year (Land Resources Department/Bina Program, 1990).

**Figure 1.** Study site (Authors, 2016)


### 2.2. Satellite Images

We used Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation index dataset derived from U.S. Geological Survey - Land Processes Distributed Active Archive Center (USGS LP DAAC, 2009). The composited 16-day product of MODIS vegetation index which is embedded in MOD13Q product contains various vegetation Indexes (VI), one of them is Enhanced Vegetation Index (EVI). The EVI is developed by The MODIS LAND Discipline Group (MODLAND) using the equation in Huete et al. (1999). We used the MODIS datasets acquired from January 2001 to December 2014. The datasets captured 322 time series data with an interval of 16 days. Such kind of the high temporal datasets are required to determine the vegetation dynamics change of peat swamp areas.

### 2.3. Maps Datasets

We used a map of land cover that provided by the Ministry of Forestry (2013) to describe the type of land cover in the Sumatran peatlands. This land cover map was produced based on visual interpretation of Landsat 5 TM/7 ETM+. The Ministry of Forestry classified the type of land cover into 23 types as follows: (1) Primary dry land forest (Hp); (2) Secondary dry land forest (Hs); (3) Primary swamp forest (Hrp); (4) Secondary swamp forest (Hrs); (5) Primary mangrove forest (Hmp); (6) Secondary mangrove forest (Hms); (7). Bush/slash (B); (8) Swamp (Rw); (9) Swamp bush (Br); (10) Savannah (S), (11) Industrial forest plantation (Ht), (12). Plantation (Pk), (13). Dry land agriculture (Pt); (14) Mixed dry land agriculture (Pc); (15) Rice field (Sw); (16) Fishpond (Tm); (17) Bare land (T); (18) Transmigration (Tr); (19) Mining (Tb); (20) Airport area (Bdr); (21) Built-up area/Housing (Pm); (22) Water body (A); and (23) Cloud cover.

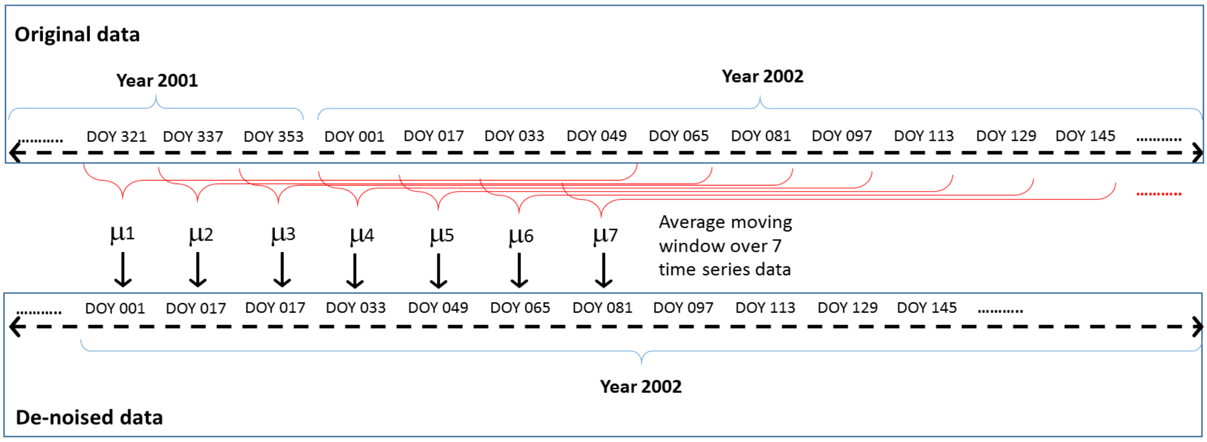
The land cover map provided by the Ministry of Forestry is concerned primarily with natural vegetation categories. Consequently, in the forest class, delineated polygons could be labeled with two codes, representing categories un-disturbed by human activities (primary type) and those disturbed (secondary type).

Moreover, some of thematic maps were used to characterize the complex situation of peat swamp ecosystem; such as: map of peat depth distribution, logging concession, wood-timber plantation concession (industrial forest plantation) and oil palm plantation. Those thematic maps were provided by the Global Forest Watch (2002). The peat depth was classified into 6 classes: (1) less than 50 cm; (2) 50–100 cm; (3) 100-200 cm; (4) 200-300 cm; (5) 300-400 cm; and (6) more than 400 cm. In this study, concession areas for oil palm and other timber plantations as well as conservation areas were also used to seek out any relationship with dynamic changes in the peatlands.

### 2.4. Image Processing

Although MODIS VI (MOD13Q1) data have some advantages in providing basic information related to vegetation pattern change, time-series of these data inevitably contain disturbances caused by atmospheric variability and aerosol scattering (Xiao et al., 2003). Therefore, noise reduction (de-noising) or fitting a model to observe data is necessary before vegetation dynamics pattern can be determined. In this work, we used the MODIS EVI datasets filtered by an average moving window over 3 months (almost equal to 7 time series) data in order to smooth and reduce the residual noise of these images (**Figure 2**).

**Figure 2.** Average moving window over 7 time series of EVI data
- an example for 2002 datasets (Authors, 2016)



## 2.5. Pattern Change Detection

In this study, we recognized the change of vegetation dynamics using a distance of average EVI values for two successive three months (January-March → April-June → July-September → Oktober-December). All pixels in the consecutive study years during periods from 2001 to 2014 were computed by a function shown in the equation below (Bouman, 2009):

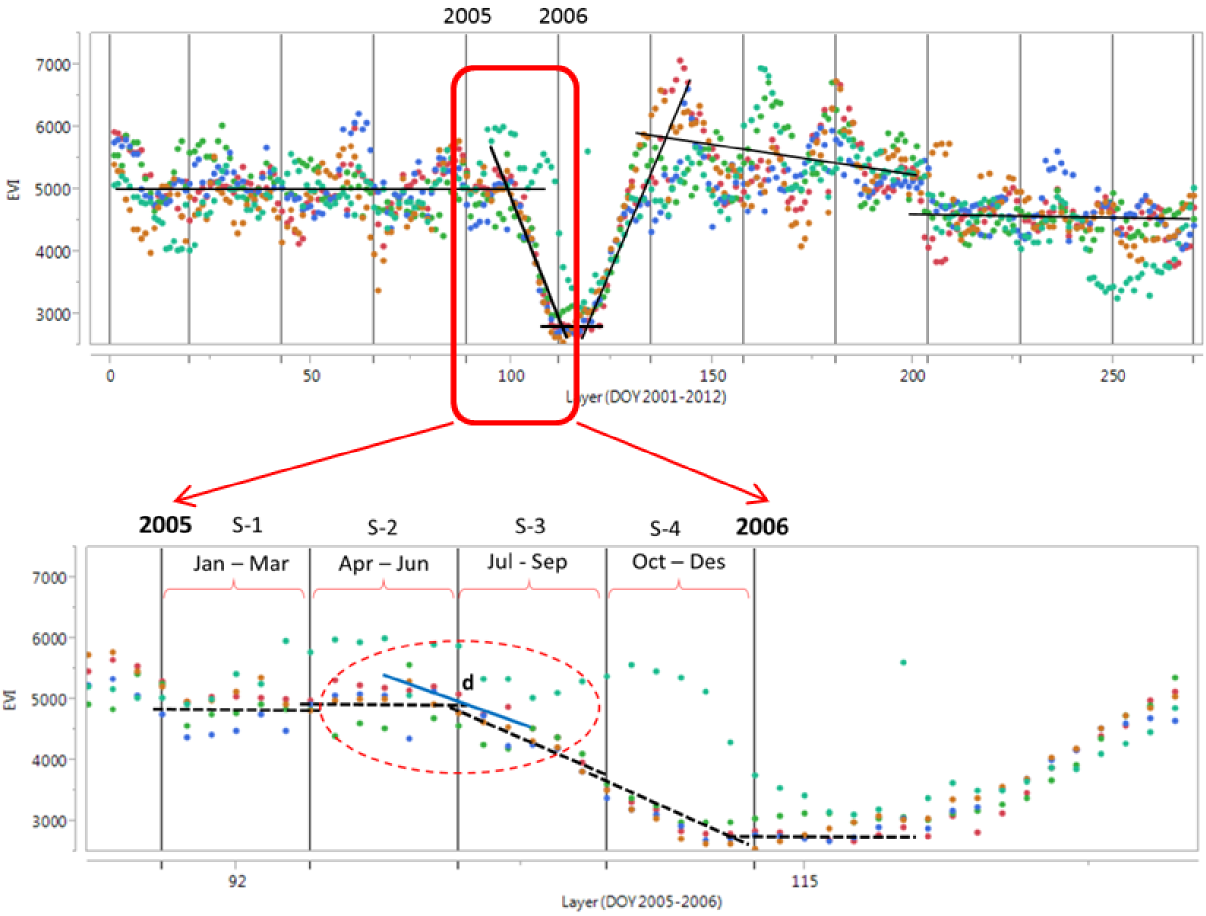
$$d_{k,l} = \frac{N_k}{N_{new}} |\mu_k - \mu_{new}|^2 + \frac{N_l}{N_{new}} |\mu_l - \mu_{new}|^2 \quad [1]$$

where $k$ and $l$ are two successive 3 months, and $d_{k,l}$ is the distance between EVI values of the two successive patterns of $k$ and $l$ three months data, $N_k$,$N_l$ is the number of observations in $k$ and $l$ three months data, $N_{new}$ is the number of observation of the two pattern of $k$ and $l$ three months data ($N_{new} = N_k + N_l$) and $\mu_k$, $\mu_l$ is the mean of EVI values in $k$ and $l$ three months data, $\mu_{new}$ is the mean of EVI values of the two pattern of $k$ and $l$ three months with following equation:

$$(\mu_{new} = \frac{N_k \mu_k + N_l \mu_l}{N_{new}}) \quad [2]$$

**Figure 3** illustrates the change detection based on vegetation pattern change thorugh a change of the distance of index value in two successive time series data. A complete image processing analysis for this change detection method was applied in the previous work (Setiawan & Yoshino, 2014).

**Figure 3.** Illustration of the forest cover change detection system example change pattern at period July – September 2005 (Setiawan & Yoshino, 2014)



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### 2.6. Change Pattern Thresholds

We assumed that the difference in distance for those four periods in every year shown an approximately normal distribution. Therefore, we identified the pixels that had the greatest change in distance of EVI for each period. The three change thresholds (TH) of 2.0, 3.0, and 4.0 were selected corresponding to a range of z-value probabilities which was the limit to define a change or no-change in the temporal pattern. Based on the previous study (Setiawan et al., 2013; Setiawan et al., 2014), these value ranges were selected because they produced appropriate estimates of annual change values based on a previous change rate for the Java area. Some pixels of the change and no-change events were randomly selected to determine the threshold of change pattern probability.

### 2.7. Accuracy Assessment

In this study, accuracy assessment is performed using a finer spatial resolution Landsat TM and ETM+ as well as ground checking at some selected areas. The hotspot datasets derived from NOAA 8 were collected in the period of 2000 – 2015 from the ASEAN Specialised Meteorological Centre (ASMC) (http://asmc.asean.org). The ASMC was established in January 1993 as a regional collaboration programme among the National Meteorological Services (NMSs) of ASEAN member countries.

## 3. RESULTS AND DISCUSSION

Characterizing the time series vegetation dynamics will provide information about the temporal vegetation pattern in the peatlands. The distribution map of the change patterns of peat swamp ecosystem in Sumatra will be also provided.

**Figure 4.** Temporal vegetation change in peatland areas detected by two successive 3 months (Analysis, 2016)

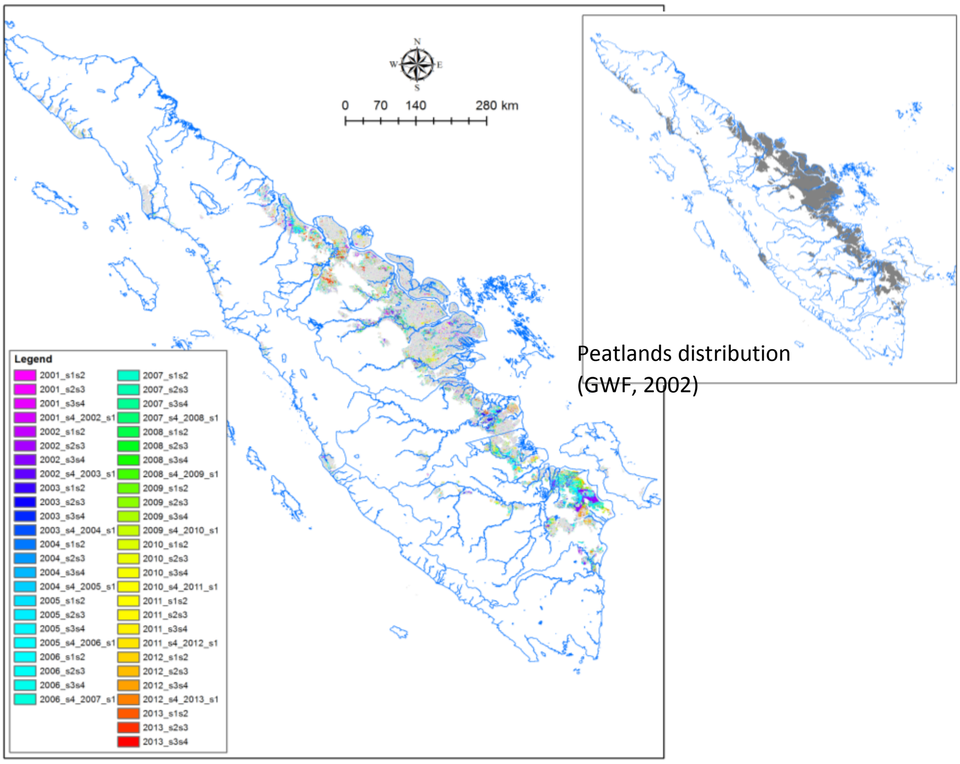
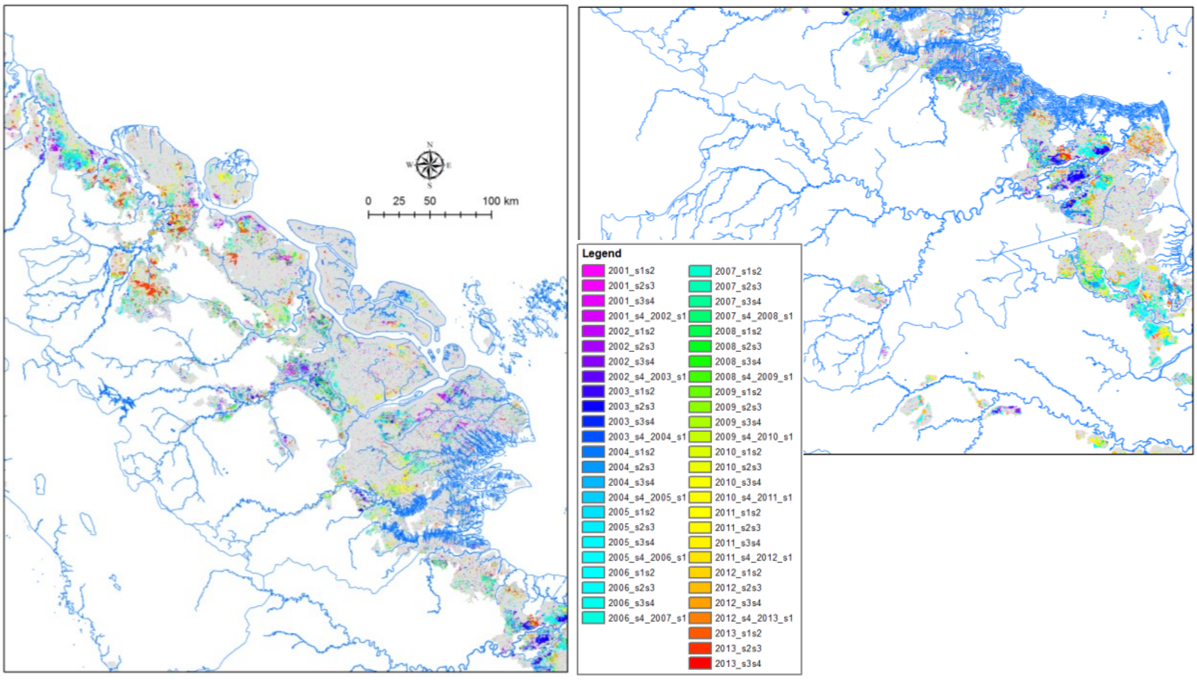



**Figure 4** shows the distribution of vegetation pattern change in the peatland areas which was detected by the approach. Detail changed area in Jambi and Riau is given in **Figure 5**. Some significant causes of the change pattern in the peatlands can be identified systematically, either caused by natural forest fire or

human activities factor. Based on the identification of the pattern change, we found many significant patterns that indicated a change pattern in the peatland areas.

**Figure 5.** Detail change distribution in Riau (left) and Jambi (right) detected detected by the change of temporal pattern two successive 3 months (Analysis, 2016)




The EVI pattern was used to measure reliable spatial and temporal characteristics of vegetation dynamics of land cover, as a means for better understanding of land characterization (Setiawan et al., 2013; Verburg et al., 2009). The previous study (Setiawan et al., 2016) explained that some typical EVI patterns of the Sumatran peat swamp indicates different type of ecosystem and/or different response of ecosystems to the changing environment.

**Figure 6.** Significant change patterns of EVI on selected sites as forest change detected by TH-1 (Analysis, 2016)

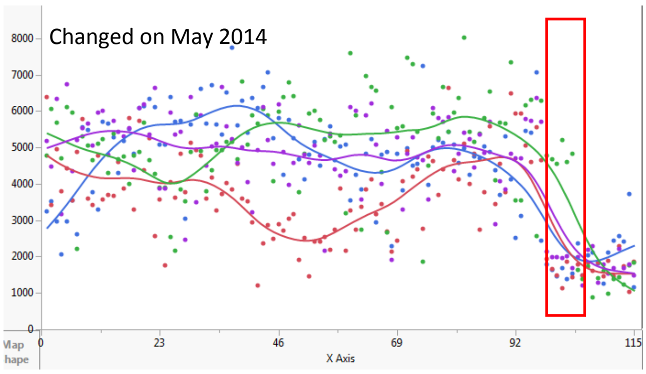
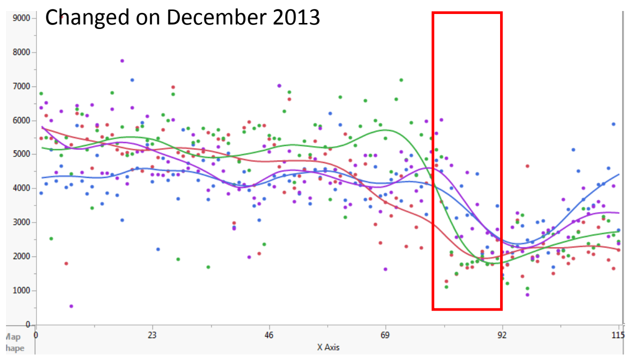



**Figure 7.** Dynamics change patterns of EVI on selected sites as forest change detected by TH-3 (Analysis, 2016)




Monitoring temporal vegetation patterns allowed the change in peatlands to be detected including some properties of that change such as the location, area, time and mechanism of the change. For instance, **Figure 6** shows several patterns of forest cover change detected in peatland areas; (1) forest conversion into barren land through burning (at the end of March, 2014), (2) forest area was converted into plantation with was firstly converted to barren land. Meanwhile, **Figure 7** shows several patterns of forest cover changes affected by anthropogenic activities (timber forest management), where forest changed to open land because of the threes harvesting and the later replanting process. Regarding to the change pattern of

EVI, the selection of thresholds (TH-1 and TH-3) was significantly affected to the accuracy of change patterns detection system.

We compared the result with the hotspot occurrences with up to 90 percent of confidence, there was a relationship between the pattern changes in peatlands and the land fires. The highest number of hotspots was happened in 2006. However, the majority of hotspots was relatively constant every year during the dry season (July - September). It seems that the pattern changes was mainly occured in dry season when it was high in hotspot occurrences. This could be the case that fire is still being used both small-holders and large holders as the only tool for land clearing (Stolle et al., 2003).

Moreover, the majority of pattern changes occurred in production forest zone, where forest and palm oil industrial estates established. In addition, the amount of changes was relatively constant every year, means that there have been activities in the production forest areas related to clearing for new plantation. However, based on limited ground checking activities, the changes of vegetation index did not wholly related to forest clearing; some of them were cleared from old and non-productive plantations to new plantations especially in oil palm companies. Meanwhile, it also happened in the several big timber companies, the vegetation index were drop when they harvested the trees and planted new ones after that. Compared to hotspot occurrences with up to 90 percent of confidence level, it was very unlikely that these big companies used fires for replanting their new plantations. It could be the case that logging companies control fire during their exploitation of concessions, logged-over forest and forest allocated to production.

Conservation areas (nature preserves, protected forest, national parks, and protected peat forest) have also experienced changes. This is due to several conservation areas such as Berbak National Park are located in peatland area which is vulnerable to forest fires especially in the border with other non-protected areas. Miettinen et al. (2012) studied peatland conversion and degradation processes in Jambi between 1970 and 2009. They found that nearly-pristine forest cover have declined from 95 to 73 percent inside the Berbak National Park and outside the National Park from 86 to 25 percent. Outside the protected area, 66 percent of former nearly‐pristine forests turned into degraded forests or unmanaged deforested areas. Large‐scale oil palm plantations accounted for 21 percent of the formerly nearly‐pristine areas and small‐holder agriculture for 8 percent.

The production forest which is mainly occupied by logging companies, oil palm plantation, and industrial timber concessions is the most dynamic land use in Sumatra. The peatland ecosystem in this area is constantly changing either by opening new cultivation area or from re-planting activities by the owners. However, based on this study which looks the changing based on vegetation activities, it is not clear that the land cover and land use changes from one type to another or within the same type but different age of vegetation. It needs more study by combining different satellite imageries with different resolutions in combination with more ground checking activities.

The performance of our change detection approach was evaluated by 100 reference points, and the result revealed an overall accuracy of 80.10%. Comparison of the accuracy in change detection among many land use types in peatlands reveals a variation. Plantation area had the greatest overall accuracy (94.02%), followed by agricultural land (86.62%), and natural forest (81.97%). In the natural forest, 44.61% of the errors is due to omission errors, meaning that the change area in those classes was assigned incorrectly. The result also indicates that the change in plantations could be detected more accurately relative to other classes.

Overlaid the deforestation detected area of MODIS with the two different dates of LANDSAT images in selected locations in Sumatra are presented below. By the **Figure 8**, the results indicate that the approach developed in this study offer great promise to detect deforestation events quickly (monthly) at large scale.

Furthermore, through these results, the understanding of environmental changes will be improved including carbon storage change and sequestration by terrestrial plants. Characterization of typical peat ecosystem based on temporal pattern analysis would provide useful information regarding the change dynamics in the peatland ecosystems; consequently it should be possible to provide information of the inter-annual ecosystem change in Sumatran peatlands.

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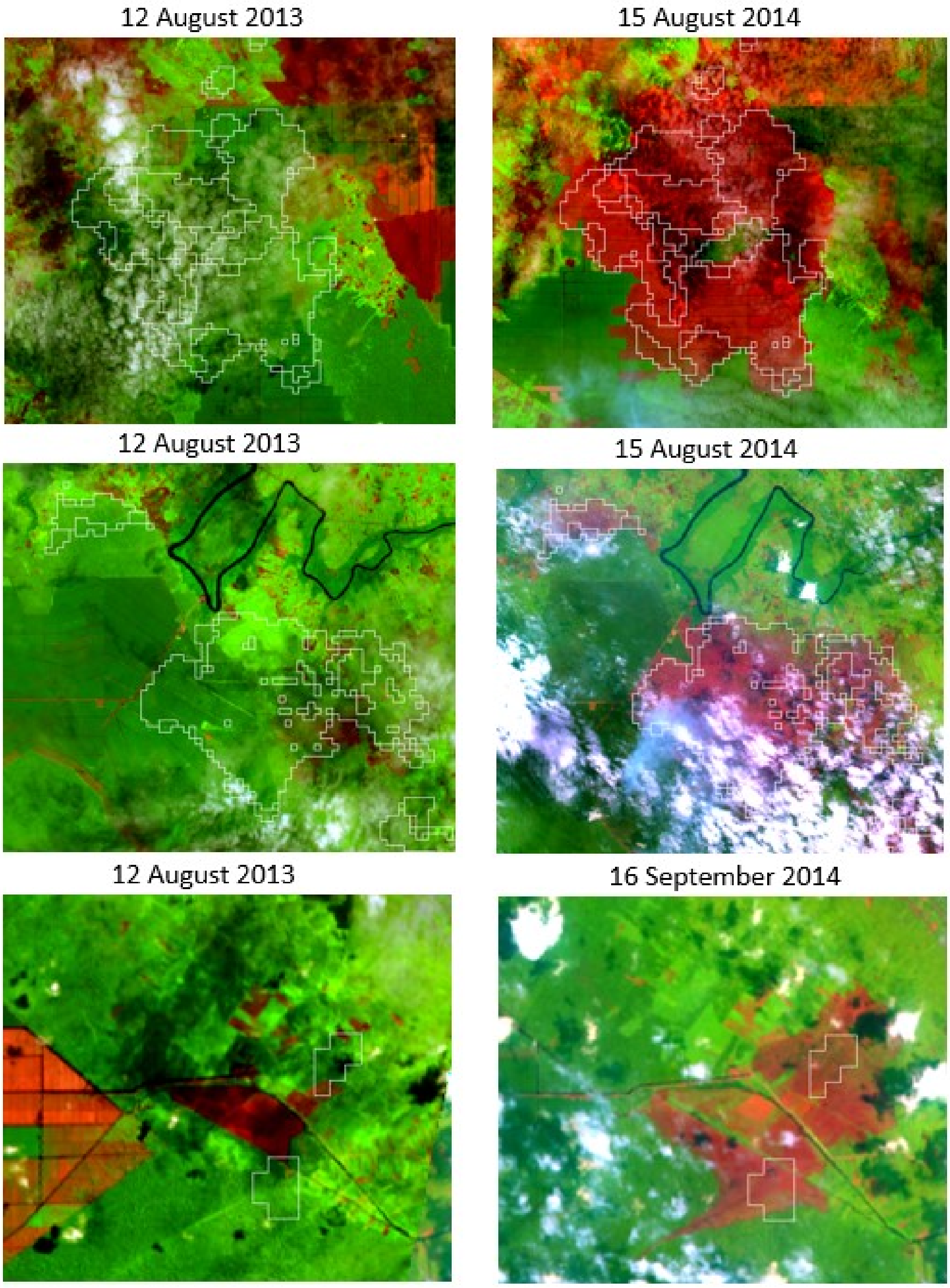
**Figure 8.** Comparison between the result of our approach with the two different dates of Landsat images in selected locations in Sumatran peatlands (Analysis, 2016)




## 4. CONCLUSION

Due to characterizing the long-term vegetation dynamics, the main types of change in peatlands were recognized. The first is the change in forest lands, either by forest fire or human factors which forest is converted into oil palm plantation as well as an open area. The second is the temporary change in oil palm plantation (replanting) as well as timber forest plantation (harvesting and replanting). The third is agricultural development, including some trajectories such as non-agricultural lands converted into intensive agricultural lands. Each change category has specific change mechanisms or processes, which then reveals the specific spatial model for each type.

Additionally, the results indicate that on a regional scale, many of the change patterns are affected by temporary changes in land cover. A change in the temporal vegetation pattern is detected as a land use change even if that land use type had not really changed. It is highly inter-related with climate variability, for example, the ENSO (El Nino Southern Oscillation) that has significantly affected the water availability due to the low-intensity rainfall. Also, some agricultural lands became barren in those periods because there was insufficient water for plant growth. Distinguishing the actual type of change from temporary change by land cover dynamics provide sufficient, significant and useful information to understand the pattern of dynamic pattern change of peatlands in Sumatra and their future roles.

Regional shifts in temporal vegetation dynamics, including the actual changes of land use and temporary changes of land cover in peat swamp areas, have numerous consequences relevant to the environment as well as changes in carbon and nitrogen storage, land degradation and loss of biodiversity. An understanding of temporal vegetation dynamics to explain the mechanisms and pathways of vegetation change pattern is important because of its relationship to ecosystem characteristics and socio-economic attributes of the peatland, and it will be discussed separately in further studies.

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