REPORT

# Status of Peatland Degradation and Development in Sumatra and Kalimantan

Jukka Miettinen, Soo Chin Liew

**Abstract** Peatlands cover around 13 Mha in Sumatra and Kalimantan, Indonesia. Human activities have rapidly increased in the peatland ecosystems during the last two decades, invariably degrading them and making them vulnerable to fires. This causes high carbon emissions that contribute to global climate change. For this article, we used 94 high resolution (10–20 m) satellite images to map the status of peatland degradation and development in Sumatra and Kalimantan using visual image interpretation. The results reveal that less than 4% of the peatland areas remain covered by pristine peatswamp forests (PSFs), while 37% are covered by PSFs with varying degree of degradation. Furthermore, over 20% is considered to be unmanaged degraded landscape, occupied by ferns, shrubs and secondary growth. This alarming extent of degradation makes peatlands vulnerable to accelerated peat decomposition and catastrophic fire episodes that will have global consequences. With on-going degradation and development the existence of the entire tropical peatland ecosystem in this region is in great danger.

**Keywords** Tropical peatland · Peatland degradation · Southeast Asia · Indonesia

## INTRODUCTION

The Southeast Asian region contains nearly 70% (20–30 Mha) of the global tropical peatland area (Page and Banks 2007). In Sumatra and Kalimantan, Indonesia, peatlands cover around 15 and 11% of the total land area, respectively, resulting in approximately 13 Mha of peatland (Wahyunto et al. 2003, 2004). These peatlands are estimated to contain at least 30 Gt of carbon (Wahyunto et al. 2003, 2004; Jaenicke et al. 2008), which makes them globally considerable carbon deposits. In addition, the tropical peatland ecosystems in Sumatra and Kalimantan sustain unique biodiversity and ecosystem values (Rieley and Page 2005).

Logging activities, drainage, fires, conversion to plantations and expansion of small-holder dominated mosaic landscape have rapidly increased in peatland areas since the 1980s (Silvius and Diemont 2007). These destructive activities not only disturb the ecosystem functions, but affect gas fluxes between peatland areas and atmosphere. In addition to reducing the amount of biomass contained by living vegetation, activities in peatland areas cause changes in water table level, which affect peat decomposition and carbon fluxes from peat (Jauhiainen et al. 2005). Indirectly, degradation of peatland ecosystems makes them more vulnerable to yearly fire activity (Cochrane 2001; Siegert et al. 2001) and increases the risk of periodical severe fire episodes that release high quantities of carbon into the atmosphere (Page et al. 2002; Heil et al. 2006).

Nevertheless, the peatlands of Sumatra and Kalimantan continue to have numerous ecological, hydrological and biochemical functions and societal values (Rieley and Page 2005) as much at local as at regional level. In recent years, the remaining peatland forests have also become an increasingly important refuge for endangered animal species (see e.g. Morrogh-Bernard et al. 2003), due to shrinking area of lowland forests on mineral soils.

As a result of a wide range of multi-disciplinary research, the dynamics of the tropical peatland ecosystems in insular Southeast Asia are increasingly well understood on the small scale. It is essential to understand the local level effects of peatland degradation and development (e.g. Kool et al. 2006; Wösten et al. 2006) to be able to estimate the regional consequences. Furthermore, information on gas fluxes in both undisturbed (e.g. Jauhiainen et al. 2005)

and disturbed (e.g. Hirano et al. 2007; Jauhiainen et al. 2008) conditions are needed for estimation of gas emissions with potentially global consequences. However, the results of small-scale studies cannot be reliably propagated to the regional level without large-scale high spatial resolution assessments of the overall status of degradation and development in the peatland areas.

Owing largely to persistently cloudy weather conditions in humid tropical Southeast Asian region, acquisition of high resolution (<30 m) satellite image coverage for large-scale studies is extremely difficult. To date, no large scale land cover classification based on high resolution data with classification scheme designed for peatland areas has been published in insular Southeast Asia. Published high resolution land cover classifications on peatland areas in Sumatra and Kalimantan have in most cases been part of small-scale studies (e.g. King 2002; Page et al. 2002; Miettinen and Liew 2005; Wösten et al. 2006) and in one case part of a general Sumatra land cover classification (Laumonier 1997).

In this article, we will report the results of a high resolution assessment of the status of peatland degradation and development in Sumatra and Kalimantan. This information is derived from visual interpretation of 94 high resolution (10–20 m) Satellite Pour l'Observation de la Terre (SPOT) images using a classification scheme with 12 classes specifically designed for peatland areas in insular Southeast Asia.

## MATERIALS AND METHODS

### Satellite Data

Altogether, 94 high spatial resolution (10–20 m) SPOT satellite images were used in this study. Owing to extremely cloudy conditions, the acquisition dates needed to be spread over several years. Four of the images were acquired in 2005 (20th January, 14th March, 13th July and 7th August). The acquisition date for the remaining 90 images ranged between the 28th January 2006 and 17th October 2008. Of these, 24 images were captured in 2006, 43 in 2007 and 23 in 2008. With this data set, we were able to cover 83% (10.804 Mha) of the total 12.974 Mha of peatland in Sumatra and Kalimantan, including all the major peatland areas. Cloud-free images for the rest of the areas were not available.

Twelve of the satellite images used in this study were acquired by SPOT 2 High Resolution Visible (HRV) sensor, 43 by SPOT 4 High Resolution Visible and Infrared (HRVIR) sensor and 39 by SPOT 5 High Resolution Geometric (HRG) sensor. The 20-m resolution SPOT 2 HRV sensor has three wavelength bands: green (band 1:

0.50–0.59 μm), red (band 2: 0.61–0.68 μm) and near infrared (band 3: 0.79–0.89 μm). In addition to these three bands, the 20-m resolution SPOT 4 HRVIR and 10-m resolution SPOT 5 HRG sensors have a fourth band in the shortwave infrared range of the electromagnetic spectrum (band 4: 1.53–1.75 μm). The satellite images were received and preprocessed to level 2A (radiometric and geometric correction) by the Centre for Remote Imaging, Sensing and Processing (CRISP) at the National University of Singapore (NUS).

## Classification of Land Cover and Degradation Levels

Peatland areas outlined by Wahyunto et al. (2003, 2004) and covered by cloud-free satellite data were visually inspected, and land cover polygons were manually digitized on screen. Although it has been suggested that the abovementioned peatland distribution maps may underestimate the extent of peatlands for as much as 10% (Jaenicke et al. 2008), no corrections or modifications to these maps were attempted in this study. This was considered to be the best approach to maintain the consistency of the data, repeatability of the study and comparability to other studies based on the same maps. This decision was, however, taken into account in the interpretation of the results of this study.

The range of wavelengths available in the SPOT images is sensitive to changes in photosynthetic vegetation (bands 2 and 3) as well as water/moisture (band 4). Therefore, different combinations of these bands provide information on the occurrence, quality and characteristics of vegetation and bare surfaces. Different types of surfaces and vegetation types have different spectral signatures. This means that they appear in different colours/tones in the images. In addition to the pixel level reflectance information (i.e. colour/tone), visual interpretation of high resolution satellite images is heavily based on the texture, spatial arrangement and context of features detected in the image.

For on screen viewing, all the three bands were used for the SPOT 2 HRV images (RGB: 321) and bands two, three and four for the SPOT 4 HRVIR and SPOT 5 HRG images (RGB: 432). These combinations were considered to provide the best separability for different land cover types. The delineation of land cover and degradation level polygons was done in 1:100,000 scale. In order to obtain consistent classification results throughout the study area, all of the classification work was performed by one person. The interpreter had worked on the field in several sites within the study area (in Riau, Jambi and Central Kalimantan provinces) and had extensive experience on visual satellite image interpretation of tropical peatlands with high resolution images.

The classification scheme was designed based on literature review (e.g. Page et al. 2002; Rieley and Page 2005;

**Table 1** Description of land cover types used in this study

| Land cover type | Description |
| --- | --- |
| Water | Permanent water bodies. Owing to single date interpretation with varying wetness levels, the permanence of the water bodies was in some cases difficult to determine. Therefore, confusion may exist between water and seasonal water classes |
| Seasonal water | Areas that are inundated part of the year. Most typically flood zones of rivers. This class was used conservatively. Please read also the description of water class |
| Pristine PSF | PSF with no signs of human intervention |
| Slightly degraded PSF | PSF with minor signs of human intervention, typically in the form of weak pathways criss-crossing the area but no clear signs of opened canopy |
| Moderately degraded PSF | PSF with clear signs of systematic logging, typically in the form of logging tracks and canals and/or opened canopy |
| Heavily degraded PSF | PSF with only remnants of original forest cover visible |
| Tall shrub/secondary forest | Shrub land or secondary forest with average height above 2 m |
| Ferns/low shrub | Ferns and grass or shrub land with average height less than 2 m |
| Small-holder dominated area | Mosaic area of farms, small plantations, agricultural fields, gardens, shrub etc., used by small-holder farmers for their livelihood |
| Industrial plantations | Large-scale industrial plantations. Mainly oil palm and pulp wood |
| Built-up area | Towns, industrial areas etc. |
| Cleared/burnt area | Open area with no vegetation, including recently burnt areas |

Wösten et al. 2006; Corlett 2009) and personal experience of the authors. It was further defined by several field visits to a wide range of land cover types. The final classification scheme included 12 classes (Table 1; Fig. 1). The study was done in two steps. In the first step, all remaining forest areas were delineated, and the non-forest areas were classified into eight classes that describe land cover types of the non-forest areas. In the second step, all the forest areas were classified into four different levels of degradation based on the amount of visible signs of human intervention. Figure 2 illustrates the style of the final classification.

The aim was to include the main phases of tropical peatland degradation and development process into the classification scheme while keeping it simple enough to maintain reliability of the results. The simplicity and reliability of the classification were considered very important since field data suitable for accuracy assessment for a large scale but high resolution study like this could not be obtained due to the vast study area and low accessibility of the tropical peatlands. The largest source of error in the visual/manual classification approach used in this study was considered to be the unintentional generalization of border lines between land cover types (see Fig. 2). However, this source of error is not expected to cause significant bias into the land cover statistics since these types of errors tend to balance out in large datasets. However, due to the issues mentioned above and due to the long data acquisition period, the figures presented in this article should not be taken as absolute values of the extent or proportion of land cover classes, but more as indicators of the general land cover distribution in the peatlands of Sumatra and Kalimantan.

## RESULTS

Of all peatland areas mapped, approximately 41% are occupied by peatswamp forest (PSF) (Table 2). Thereby, at least 4.4 Mha of peatland is still covered by PSF in Sumatra and Kalimantan. However, the great majority of the PSF is considered to be either moderately degraded PSF showing clear signs of systematic logging in the form of logging tracks or canals and/or opened canopy (Fig. 1c), or heavily degraded PSF with only remnants of the original forest ecosystem left (Fig. 1d). Less than 11% of the peatland areas remain covered with PSF showing only minor (Fig. 1b) or no (Fig. 1a) signs of human activities.

The proportion of the remaining forest areas varies considerably between Sumatra and Kalimantan. While approximately half of the mapped peatland areas in Kalimantan are covered by forests, only one-third remains as PSF in Sumatra (Table 2). It must be pointed out in this context, however, that some of the most intact and undisturbed PSFs in the study area are found in Sumatra, most notably in Riau and Jambi provinces. However, Kalimantan has overall larger forest areas with at least 2.2 Mha of slightly or moderately degraded PSF left (as opposed to 1.5 Mha in Sumatra).

As far as the whole study area is concerned, most of the non-forested areas are covered by managed land cover

Fig. 1 Examples of forest degradation levels and land cover types used in the classification. a Pristine PSF, b slightly degraded PSF, c moderately degraded PSF, d heavily degraded PSF, e tall shrub/secondary forest, f ferns/low shrub, g industrial plantations, h small-holder dominated area, i permanent water body, j seasonal water, k cleared/burnt area, l built-up area. All panels cover the area of 2 km × 2 km, North upwards. i and l are from SPOT 4 HRVIR images (RGB: bands 4, 3 and 2). All other panels are from SPOT 5 HRG images (RGB: bands 4, 3 and 2). Note the minor human intervention in b, visible in the form of light pathways running predominantly diagonally through the image. (SPOT images© 2007 CNES)
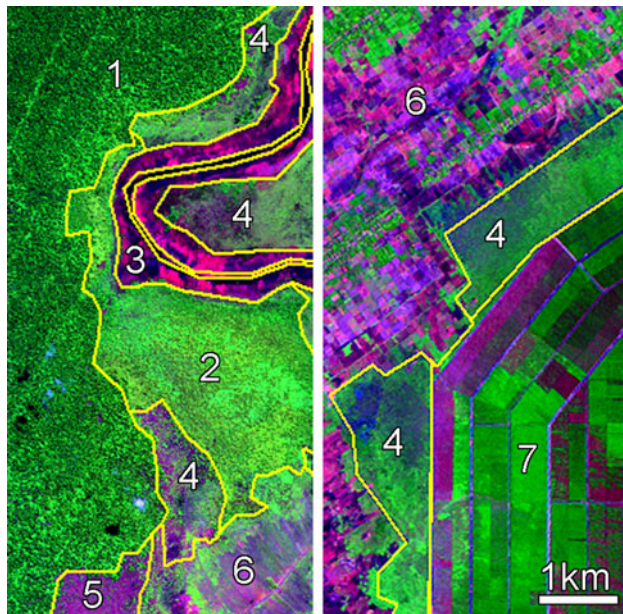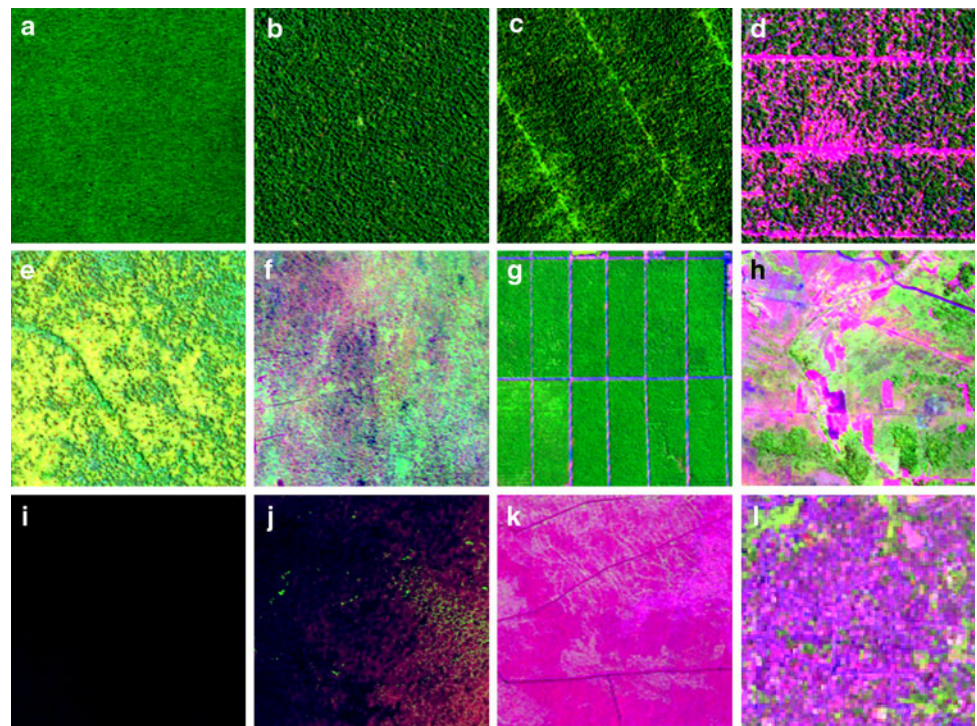


Fig. 2 Examples of the final classification overlaid on SPOT satellite images. Yellow lines present land cover polygon borders. Land cover types visible in the West Kalimantan (left) and South Sumatra (right) images include: moderately degraded PSF (1), tall shrub/secondary forest (2), seasonal water (3) in the form of flood zones on both sides along the permanent water body (river), ferns/low shrub (4), clearance (5), small-holder agriculture (6), and large-scale industrial plantation (7). Satellite images: West Kalimantan SPOT 5 HRG (RGB: bands 4, 3 and 2) and South Sumatra SPOT 4 HRV (RGB: bands 4, 3 and 2). (SPOT images© 2007 CNES)

types, predominantly by either small-holder agriculture or industrial plantations (Table 2). Industrial plantations cover at least 1.4 Mha in the peatlands of Sumatra and Kalimantan. However, the distribution of managed land cover types between Sumatra and Kalimantan highlight a general difference in the level of peatland development in these two areas. In Sumatra, nearly half of the peatland areas are managed and covered by either small-holder agriculture (24%) or industrial plantations (21%). Whereas in Kalimantan, only 14% of areas are occupied by these managed land cover types, plantation area barely exceeding 2% (Table 2). Instead, non-forested peatland areas are dominated by unmanaged degraded landscape, which covers nearly a quarter of all peatlands in Kalimantan.

Finally, it is important to point out that the results also reveal great variation between provinces. In order to highlight this issue, we can compare South Sumatra and West Kalimantan provinces (Table 3; Fig. 3). Both of these provinces have extensive peatland areas (1.5–1.7 Mha) but the status of degradation and development is extremely different. West Kalimantan still has 64% of the peatland areas covered by PSF (although just 11% is considered to show only minor or no signs of human intervention). There are very few industrial plantations (4%) and most of the managed areas are occupied by small-holder farmers (11%).

South Sumatra, on the other hand, has less than 10% of its PSF left, with less than 2% showing only slight or no degradation (Table 3). Instead, more than half of the

**Table 2** Land cover distribution in the peatlands of Sumatra and Kalimantan

| | Sumatra | | Kalimantan | | Total | |
|---|---|---|---|---|---|---|
| | Area (1000 ha) | % | Area (1000 ha) | % | Area (1000 ha) | % |
| Water | 38 | 0.6 | 9 | 0.2 | 47 | 0.4 |
| Seasonal water | 44 | 0.7 | 201 | 4.4 | 246 | 2.3 |
| Pristine PSF | 287 | 4.6 | 97 | 2.1 | 384 | 3.6 |
| Slightly degraded PSF | 373 | 6.0 | 457 | 9.9 | 830 | 7.7 |
| Moderately degraded PSF | 1165 | 18.9 | 1701 | 37.0 | 2866 | 26.6 |
| Heavily degraded PSF | 217 | 3.5 | 108 | 2.3 | 325 | 3.0 |
| Tall shrub/secondary forest | 434 | 7.0 | 458 | 9.9 | 892 | 8.3 |
| Ferns/low shrub | 651 | 10.5 | 654 | 14.2 | 1305 | 12.1 |
| Small-holder dominated area | 1486 | 24.1 | 549 | 11.9 | 2035 | 18.9 |
| Industrial plantations | 1308 | 21.2 | 99 | 2.2 | 1408 | 13.1 |
| Built-up area | 6 | 0.1 | 2 | 0.0 | 8 | 0.1 |
| Cleared/burnt area | 160 | 2.6 | 263 | 5.7 | 423 | 3.9 |
| Total mapped | 6170 | 100.0 | 4598 | 100.0 | 10767 | 100.0 |
| % Mapped of total peatland | | 85.6 | | 79.7 | | 83.0 |

**Table 3** Land cover distribution in the peatlands of South Sumatra and West Kalimantan provinces

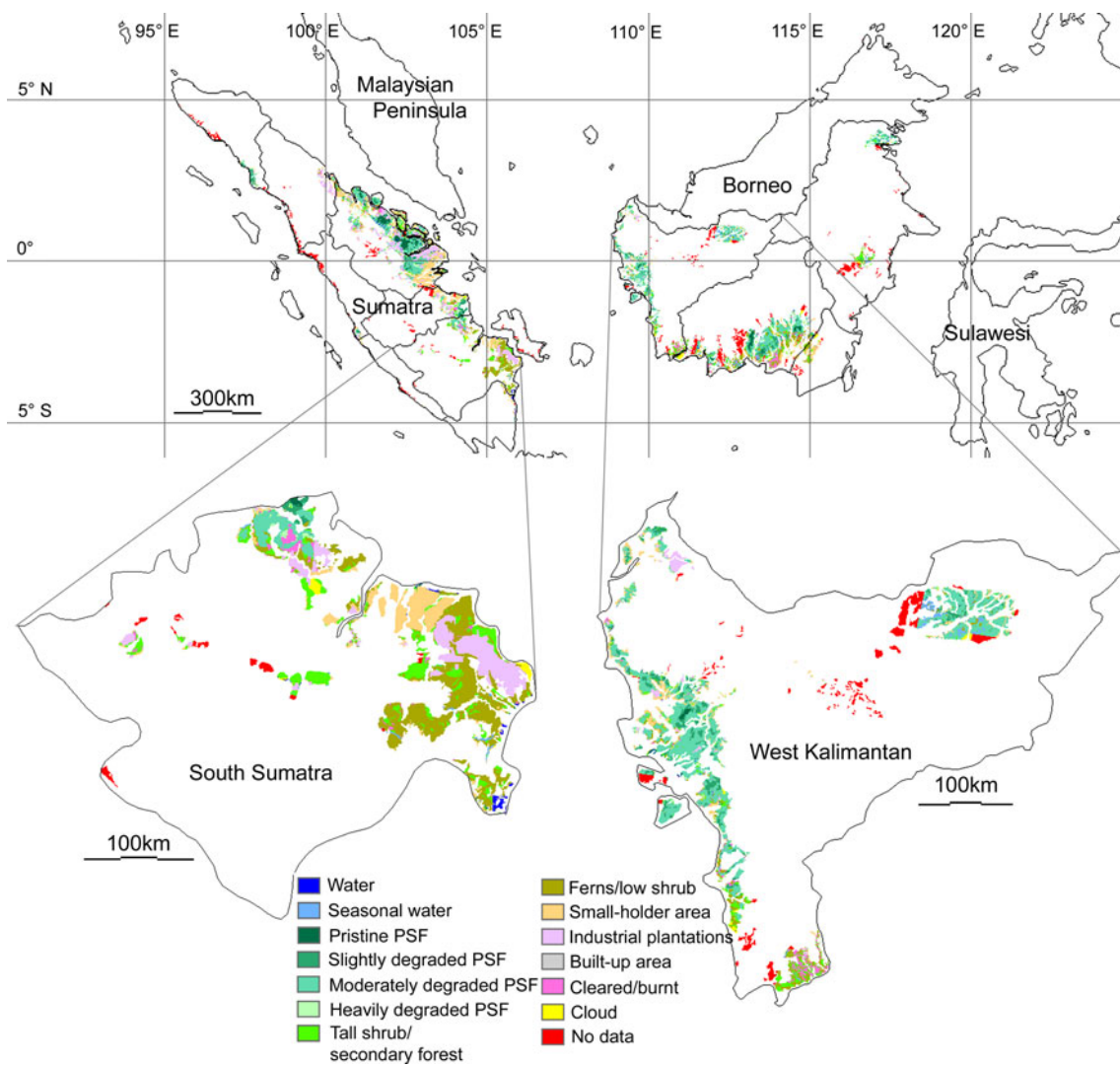| | South Sumatra | | West Kalimantan | |
|---|---|---|---|---|
| | Area (1000 ha) | % | Area (1000 ha) | % |
| Water | 13 | 1.0 | 2 | 0.2 |
| Seasonal water | 13 | 0.9 | 38 | 2.5 |
| Pristine PSF | 6 | 0.4 | 6 | 0.4 |
| Slightly degraded PSF | 17 | 1.3 | 153 | 10.4 |
| Moderately degraded PSF | 97 | 7.2 | 765 | 51.9 |
| Heavily degraded PSF | 11 | 0.8 | 16 | 1.1 |
| Tall shrub/secondary forest | 221 | 16.3 | 109 | 7.4 |
| Ferns/low shrub | 483 | 35.8 | 108 | 7.3 |
| Small-holder dominated area | 199 | 14.7 | 161 | 10.9 |
| Industrial plantations | 251 | 18.6 | 59 | 4.0 |
| Built-up area | 4 | 0.3 | 0 | 0.0 |
| Cleared/burnt area | 35 | 2.6 | 58 | 3.9 |
| Total mapped | 1349 | 100.0 | 1473 | 100.0 |
| % Mapped of total peatland | | 90.9 | | 85.1 |

peatlands in South Sumatra have been reduced to landscape covered by ferns, shrub and secondary growth. Thereby, South Sumatra alone constitutes 65% of the whole extent of these land cover types in the peatlands of Sumatra. Currently, industrial plantations cover nearly 20% of the peatlands in South Sumatra, while small-holder farmers control around 15%.

## DISCUSSION

The results presented in this article highlight (1) the alarming overall status of peatland ecosystems in Sumatra and Kalimantan and (2) the great variability of the degradation and development levels within this region. While 41% (4.4 Mha) of the peatland areas in Sumatra and Kalimantan are still covered by PSFs, only 11% (1.2 Mha) is estimated to be covered by relatively intact forests. Owing to increased fire vulnerability of degraded forests (Goldammer 1999; Siegert et al. 2001; Page et al. 2009), this puts the majority of the remaining PSFs at high risk of fire and further degradation during dry spells.

The remaining forest areas are concentrated in Kalimantan, while the Sumatran peatlands have been converted into cultivation more extensively. Of all the 1.4 Mha of industrial plantations mapped, only 0.1 Mha was located in

**Fig. 3** Extent of peatlands in Sumatra and Kalimantan and distribution of land cover types on the peatlands of South Sumatra and West Kalimantan provinces

Kalimantan. Similarly, small-holder dominated areas cover nearly three times more peatland in Sumatra than in Kalimantan. These differences in development level can be explained largely by population distribution and accessibility of peatland areas. Regardless of the origin of the pronounced differences, the current development levels put Sumatra and Kalimantan into very different positions from a peatland management perspective.

With sustainable peatland management, it would still be possible to maintain nearly half of all peatland areas in Kalimantan as PSF and thereby try to maintain the ecosystem functions and values, as well as prevent carbon emissions into the atmosphere. The most alarming feature of Kalimantan peatlands is the amount of unmanaged degraded peatland areas that have replaced forests typically destroyed by recurrent fires (Langner and Siegert 2009; Page et al. 2009). In the majority of these areas, the original

vegetation has been replaced by regrowth ranging from ferns to secondary forest. In addition, water table balance is often disturbed by drainage. This type of landscape is highly susceptible for further degradation and very difficult to regenerate into forest (Page et al. 2009). Recurrent burning not only prohibits regeneration of forest but further combusts top layers of peat, lowering the surface level. In the worst case, repeated fires reduce these areas into seasonal lakes of over one meter deep, nullifying any restoration efforts (Wösten et al. 2006).

In Sumatra, apart from a few remaining PSF areas, the future management planning will most likely concentrate on efforts to maintain the productivity and usability of peatland areas under cultivation. The cultivated areas include small-scale farming of oil palm, sago, coconut, pineapple etc. as well as large-scale industrial plantations of mainly oil palm and pulp wood. As a whole, the

**Fig. 4** Peatland area in Sumatra undergoing changes. PSF has been cleared and burnt for potential further development, but ferns have invaded the area (at least temporarily). The edge of the remaining PSF can be seen in the horizon in a distance of around 8 km (Photo by Jukka Miettinen)



variations in degradation and development levels noticed within the region highlight the wide range of problems and alternative courses of action that peatland management planners have to face in different parts of Sumatra and Kalimantan nowadays.

The delineation of peatland areas in this study was based on existing peatland maps (Wahyunto et al. 2003, 2004). Although these maps are the newest and most reliable maps that are currently available, it has been suggested that they may underestimate the extent of peatland areas for as much as 10% (Jaenicke et al. 2008). In addition, 17% of the peatland areas could not be mapped due to the lack of cloud-free data. Therefore, the area values presented in this article should be treated as underestimates. However, the land cover distribution percentages can be considered to represent the entire peatland area in Sumatra and Kalimantan. There are no specific reasons to believe that the peatland land cover distribution in the unmapped areas (17%) would differ from the areas covered with the cloud-free satellite data (83%). Thereby, the percentages are expected to reliably describe the general land cover distribution in the peatlands of Sumatra and Kalimantan at the time of the survey as long as the issues discussed in the "Materials and Methods" section are kept in mind.

It is very important to understand, however, that the development and degradation of peatlands have continued during the study and publication process. Therefore, the results presented in this article are very likely to give an overly positive impression of the situation. Latest indication of continuing degradation was the regionwide fire episode in 2009. Early results show that the degraded peatland landscape of Kalimantan was particularly severely affected (Chan et al. 2010). These recurring fire episodes not only accelerate the degradation of ecosystems but also lead to increasing fragmentation of the remaining PSFs which further diminish the value of the remaining forest areas from biodiversity conservation perspective.

This article has presented the status of degradation and development in the peatlands of Sumatra and Kalimantan, Indonesia. The results have shown large variability in the directions of degradation and development within the region. Thereby, the results emphasize the importance of detailed information on the distribution of land cover types (a) in estimation of regional and global consequences of the activities taking place in the peatland areas of Sumatra and Kalimantan as well as (b) in planning and implementation of future peatland management strategies in this region. However, most importantly, this article has revealed the alarming state of peatland ecosystems in Sumatra and Kalimantan. If the degradation and development (Fig. 4) continues on the same track which has led the situation to this point, then the existence of the entire tropical peatland ecosystem in this region is in great danger.

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