Historical Analysis and Projection of Oil Palm Plantation Expansion on Peatland in Southeast Asia

Jukka Miettinen, Al Hooijer, Daniel Tollenaar, Sue Page, Chris Malins, Ronald Vernimmen, Chenghua Shi, and Soo Chin Liew

CRISP
National University of Singapore

Deltares

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

www.theicct.org

For additional information:
1225 I Street NW Suite 900
Washington DC 20005
+1 202 534 1600

communications@theicct.org

www.theicct.org

Funding for this work was generously provided by the ClimateWorks Foundation.

TABLE OF CONTENTS

1 Summary 3

2 Introduction 4

2.1 The ICCT and Land-Use Change 4

2.2 Background 4

2.3 Goal of This Project 6

2.4 Summary of Project Steps and Activities 6

3 Oil Palm Plantation Extent Maps for 1990, 2000, 2007, and 2010 7

4 Determining Trends and Patterns in OP Expansion Over the Past 20 Years 20

5 Projecting Potential OP Expansion in the Coming 10 to 20 Years 23

5.1 Projection of Potential OP Increase 23

5.2 Constraints on OP Expansion 24

5.3 Actual Likely Increase of OP on Peatland in Southeast Asia 38

6 Calculating the Wider Impact Area of OP Plantations on Peatland 40

7 Percentage of Palm Expansion Likely to Occur on Peatland 42

7.1 Percentage of Palm Expansion on Peatland in Malaysia 42

7.2 Percentage of Palm Expansion on Peatland in Indonesia 44

7.3 Percentage of Palm Expansion on Peatland in Indonesia and Malaysia Combined 44

8 Uncertainties and Research Questions 46

9 References 49

1 SUMMARY

This study demonstrates that the area of industrial oil palm (OP) plantations in the peatlands of insular Southeast Asia (Malaysia and Indonesia, except the Papua Provinces) has increased drastically over the past 20 years. From a small area in 1990 to at least 2.15 million hectares in 2010, expansion has affected every region of Malaysia and Indonesia reviewed here. Oil palm development on peat started in Peninsular Malaysia, spread to Sarawak and Sumatra, and is now picking up speed in Kalimantan. Over each time interval included in the analysis (1990⇨2010, 2000⇨2010, and 2007⇨2010), OP expansion accelerated in all the areas considered, except those where peatland was limited.

The 2010 extent of OP plantations on peatland may nearly double to 4.1 Mha by 2020, according to both a linear approach that projects recent trends into the future and a conservative non-linear approach that takes into account long-term trend changes since 1990. Very recent trend changes, such as the rapid acceleration in OP expansion over 2007⇨2010, might bring the OP area by 2020 to 6.2 Mha. The lowest projection of OP area by 2030 is 6 Mha.

Researchers have investigated whether expanding OP plantations on peat in Indonesia would be constrained by local regulations. The constraints tested were a) the total extent of peatland, b) the extent of peat less than 2 m thick, and c) the extent of peat where current land allocation zoning allows conversion to peatland. The investigators also considered whether competing agricultural uses of peatland could limit OP expansion. The findings indicate that none of these factors would limit OP expansion up to 2030 in most areas reviewed, and that a possible slowdown in districts where a “shortage” of peatland may occur could easily be offset by a further acceleration in other regions. We therefore conclude that projected OP expansion may indeed become reality.

This analysis does not take into account developments in global demand for palm oil or possible policy changes in response to concerns regarding the environmental implications of peatland deforestation and drainage.

2 INTRODUCTION

2.1 The ICCT and Land-Use Change

The goal of the International Council on Clean Transportation (ICCT) is to enable and accelerate the transition to cleaner and lower-carbon transport. This objective reflects the opportunities and risks that other fuels such as ethanol and biodiesel present. Since Searchinger et al. (2008) published the first seminal economic analysis on the implications of biofuel for land-use change, one of the most important questions in alternative fuels has been whether carbon emissions from land conversion will reduce or eliminate the carbon benefits of alternative fuel policies, such as the U.S. Renewable Fuel Standard and the European Renewable Fuel Directive.

For biodiesel markets in particular, palm oil is crucial both directly as a feedstock and indirectly as one of the oil crops likely—arguably the oil crop most likely—to expand to meet growing global vegetable oil demand. Because palm oil production has traditionally increased by the conversion of primary or secondary forest, the way that palm oil production will expand to respond to demand growth is widely recognized as a key driver of the net carbon intensity of biodiesel policies (and a source of some of the largest risks to biodiversity). The vast carbon reservoirs in Southeast Asian peatlands raise the vital question of how much peat destruction the biodiesel program expansion is likely to cause.

In this context, and parallel to studies on other issues related to land-use change such as the emissions intensity of peat degradation (Page et al., 2011), the ICCT commissioned Deltares and CRISP to use the most up-to-date satellite mapping data available to increase understanding of the rate of palm expansion on peatlands in Southeast Asia.

We are indebted to the ClimateWorks foundation for support in making this work possible.

2.2 Background

Anaerobic and often acidic conditions in waterlogged areas prevent plant material from decomposing completely. Accumulation of partially decayed vegetation helps to form peat deposits. Around 440,000 km^2, or 11%, of global peatland can be found in tropical regions (Page et al., 2011). The majority of the tropical peatlands are concentrated in insular Southeast Asia, which is estimated to contain around 250,000 km^2 of peat deposits up to 20 m thick in some areas (Page et al., 2011).

Tropical peatlands of insular Southeast Asia perform a range of valuable ecosystem services and societal functions. Because lowland forests on mineral soils have diminished, peat swamp forests have become an increasingly important refuge for endangered animal species like the orangutan and the Sumatran tiger (Morrogh-Bernard et al., 2003;

Giesen, 2004). Moreover, peat deposits in this region are estimated to contain around 70 Gt of carbon (Page et al., 2011), nearly nine times as much carbon as was released globally into the atmosphere by fossil fuel combustion in 2006: 8 Gt, according to the Intergovernmental Panel on Climate Change (IPCC, 2007).

Prior to the large-scale encroachment of plantation forestry, Southeast Asian peatlands had traditionally experienced only minor exploitation by indigenous people (Rieley & Page, 2005). During the past 20 years, however, the clearance of peat swamp forests has escalated at an alarming rate. Scarcity of available mineral soil resources, advancements in land conversion technology, and continuously rising demand for forest and agricultural products have compounded the human impact in peatland areas. Since the 1980s, peat soils have been subjected to widespread logging, drainage, plantation development, and expansion of fragmented landscapes dominated by a mosaic of small-holder parcels (Silvius & Diemont, 2007; Page et al., 2009). Recent widespread conversion of peatlands to oil palm plantations has caused controversy both regionally and globally because of its potentially adverse socio-environmental effects (Hooijer et al., 2006; Stone, 2007; Sheil et al., 2009).

Human activity in tropical peatlands affects the sensitive peat accumulation and storage process, which depends on the delicate balance among hydrology, ecology, and landscape morphology (Page et al., 1999; Hooijer et al., 2010). Agricultural activities on peatlands require regulation of the water table level to prevent inundation. In addition, constructing transportation networks (roads, railways, canals etc.) for peat swamp forest exploitation leads to intentional or unintentional lowering of peatland water table levels. Lowered water table levels create aerobic conditions in the peat profile above the water table, increasing the redox potential that favors microbial activity and nitrogen mineralization (e.g., Hirano et al., 2007; Jauhiainen et al., 2008). This causes enhanced CO_2 loss by peat decomposition and increased carbon emissions to the atmosphere (Couwenberg et al., 2010; Hooijer et al., 2010).

Disturbance in humid tropical forests makes them more vulnerable to fire because of the drying effect of the opened canopy and greater amounts of dead woody debris (Cochrane, 2001; Siegert et al., 2001). Drained peatland areas with degraded vegetation become extremely vulnerable to annual fires that further degrade these ecosystems (Hoscilo et al., 2011). Occasional but catastrophic fires on peatland can release immense quantities of carbon into the atmosphere from peat combustion (Page et al., 2002; Heil et al., 2006).

The major environmental and societal impacts of converting peatlands to oil palm plantations underline the importance of having continuous and accurate updates on the precise rate of conversion and the trends it shows.

2.3 Goal of This Project

The objectives of this project are a) to assess the extent and spatial distribution of industrial plantations in the peatlands of Peninsular Malaysia, Sumatra, and Borneo in 1990, 2000, 2007, and 2010, b) to estimate the species distribution of the mapped plantation areas, c) to analyze the historical development trends of industrial OP plantation agriculture since 1990 in the project area, and d) to provide future projections of OP plantation development in this region.

2.4 Summary of Project Steps and Activities

The analysis was executed in the following main steps:

1. Mapping of the extent of OP and other large-scale industrial plantations on peat in 1990, 2000, 2007, and 2010.
2. Analysis of trends in OP extent and of changes in trends in three periods: 1990⇨2010, 2000⇨2010, and 2007⇨2010.
3. Analysis of possible boundary conditions beyond which OP expansion on peat may not be allowed: the total peat area, the area of peat less than 2 metres in depth, and the peat area where OP expansion is possible under government land allocation maps.
4. Projection of OP expansion on peatland over the coming 10 to 20 years, by province/state, country, and Southeast Asia as a whole.
5. Reporting.

The work was commissioned by ICCT and executed by Deltares and CRISP (NUS) with support of the University of Leicester.

3 OIL PALM PLANTATION EXTENT MAPS FOR 1990, 2000, 2007, AND 2010

Despite the ongoing debate concerning plantation agriculture in Southeast Asian peatlands and its potential regional and global effects, accurate information about the extent of industrial plantations in the region's peatlands is limited. Based on estimates derived from a selection of land cover maps from 1985 to 2000, Hooijer et al. (2006) highlighted the rapid deforestation levels in the peatlands of insular Southeast Asia and conservatively projected industrial plantations to cover around 3 Mha of peatlands in 2010 and to reach nearly 4 Mha by 2020. Peatland deforestation has since continued at a high rate (Miettinen et al., 2011), and projections suggest that the area of peat swamp forest will be considerably reduced over coming decades (Fuller et al., 2011). Moreover, radar-based mapping efforts by SarVision (2011) have suggested that in some parts of the region (e.g., Malaysian Sarawak) industrial plantation development has been closely connected to rapid rates of observed deforestation in recent years.

The majority of the plantations in peatlands are large-scale industrial oil palm and pulpwood (acacia) operations. Large-scale industrial plantations can be reliably delineated using high spatial resolution (<30 m) satellite images. Some specific types of plantations (e.g., closed canopy palm plantations) can also be detected using moderate-resolution (<500 m) optical remote sensing satellite images combined with radar data sets (Miettinen et al., 2012). In addition to large-scale industrial plantations, smaller areas have coconut, pineapple, sago palm, rubber, and other crops, often managed by small-holder farmers. However, the size and heterogeneous structure of small-holder plantations make assessing the extent of these plantation crops cultivated at the regional level practically impossible using currently available remote sensing data sets.

Using manual interpretation of high-resolution satellite data, Miettinen and Liew (2010) estimated that industrial plantations covered a mere 0.3 Mha, or 2%, of peatlands in Peninsular Malaysia and the islands of Sumatra and Borneo in 1990. By 2008, plantation areas covered 2.3 Mha (15%) of peatlands. Of all the industrial plantations in the peatlands of western insular Southeast Asia in 2008, 67% were found on Sumatra. These estimates included all industrial plantation areas regardless of crop (e.g., oil palm, sago, acacia).

Very few species-level estimates of the extent of industrial plantations in Southeast Asian peatlands are currently available. A regional land cover assessment located approximately 0.9 Mha of large-scale palm (predominantly oil palm but likely including some coconut and potentially sago palm) plantations on peat soil in Peninsular Malaysia and on the islands of Sumatra and Borneo by around 2002 (Miettinen et al., 2012). Conversely, Wahid et al., (2010) used a semi-automated classification of high-resolution satellite images to estimate that oil palm plantations covered nearly 0.7 Mha of Malaysian peatland in 2009. These authors also noted that the share of Malaysian oil palm plantations on peatland had increased from 8% in 2003 to 13% in 2009, suggesting that a rapid increase in the area of oil palm cultivation in the region (e.g., Sheil et al., 2009) had fallen disproportionately on peatland areas. By 2009, nearly 30% of all oil palm plantations in Malaysia were located on peat soil (Wahid et al., 2010).

3.1.1 PROJECT AREA

The project area (Figure 1) encompassed the peatlands of Peninsular Malaysia, the island of Sumatra, and most of the Island of Borneo. This assessment did not include Brunei on Borneo because of the lack of information on peatland extent and distribution in the country. Papua Province in Indonesia, which has a considerable peatland area, was also excluded because no reliable maps of peatland extent exist.

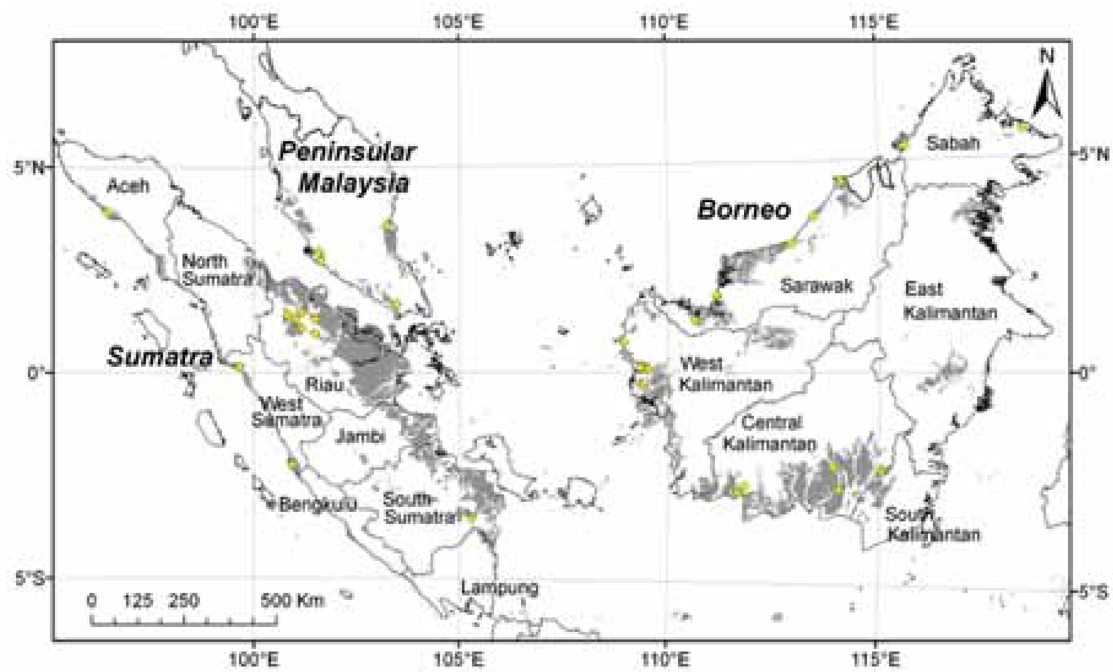

FIGURE 1 Project area with distribution of Google Earth sample sites marked as yellow crosses. Peatlands are shaded.

3.1.2 SATELLITE DATA COVERAGE AND AREA CORRECTIONS

Persistent cloud cover prevented full coverage of peatland areas in this region. For meaningful evaluation of the expansion of industrial plantations on peatland, only areas with valid data in all observed time slices were included in the analysis. The overlapping valid data coverage over all observed time slices was 81% of peatlands across the entire project region, but individual areas showed varying levels of coverage (Table 1). Data coverage was particularly low for Peninsular Malaysia and East Kalimantan Province where valid data were available only for 52% and 36% of peatland areas, respectively. This lack of coverage should be considered in the analysis and interpretation of results. Besides these two areas, all geographic regions included in the analysis had valid data coverage of between 75% and 97%. The results are therefore considered to provide reasonably reliable estimates of the extent of plantation development in the geographical area covered by this analysis.

To derive full OP extent, including plantations on peatland areas that were not mapped, we corrected by assuming the unmapped area had the same relative OP coverage as the mapped area, as demonstrated in Table 1. This was performed for all time steps (1990, 2000, 2007, and 2010), to maintain consistency between periods.

TABLE 1 Proportion of valid data coverage of all peatlands of the administrative areas analyzed in this project. The correction method for OP extent, assuming there would be full data coverage, is also shown for 2010.

GEOGRAPHIC AREA	PEAT AREA HA	DATA COVERAGE %	OIL PALM AREA 2010	
			UNCORRECTED (HA)	CORRECTED (HA)
West Sumatra	211,152	84	84,668	100,327
Aceh	277,296	78	38,344	49,208
North Sumatra	347,560	83	177,923	213,520
Jambi	716,760	81	60,855	74,851
South Sumatra	1,449,689	97	116,377	120,400
Riau	4,014,076	97	462,682	475,764
Other Provinces	217,536	65	12,205	18,679
Total Sumatra	**7,234,069**	**93**	**953,054**	**1,026,922**
West Kalimantan	1,743,224	79	117,953	149,384
South Kalimantan	329,385	80	27,010	33,738
Central Kalimantan	3,008,706	75	23,576	31,614
East Kalimantan	687,721	36	15,622	43,562
Total Kalimantan	**5,769,036**	**71**	**184,161**	**258,299**
Indonesia (–Papua)	**13,003,105**	**88**	**1,137,215**	**1,285,221**
Sarawak	1,442,845	78	417,886	532,931
Sabah	191,330	80	37,206	46,851
Peninsular Malaysia	854,884	52	111,929	264,151
Malaysia	**2,489,059**	**67**	**567,021**	**843,933**
Indonesia + Malaysia	**15,492,164**	**81**	**1,704,236**	**2,129,155**

3.1.3 SATELLITE DATA SETS

Four different high-resolution data sets (1990, 2000, 2007, and 2010) were utilized in the project, and all four were visually interpreted without using automated classification, which has been found to be less reliable in this type of application. The 1990 and 2000 analyses were based on the Landsat GeoCover products (https://zulu.ssc.nasa.gov/mrsid/). The 1990 plantation mapping was performed on the GeoCover 1990 product, which is a mosaic of Landsat 5 TM images acquired between 1987 and 1993. The 1990 GeoCover product has 28.5 m spatial resolution and three wavelength bands: shortwave infrared (band 7: 2.08-2.35 μm), near infrared (band 4: 0.76–0.9 μm), and green (band 2: 0.52–0.6 μm). The 2000 GeoCover utilizes Landsat 7 ETM+ images obtained between 1997 and 2003. The product has been pan-sharpened to a nominal spatial resolution of 14.25 m using the panchromatic band. The spectral band combination is the same as in the GeoCover 1990 product.

The 2007 mapping was based on the Satellite Pour l'Observation de la Terre (SPOT) satellite images used in Miettinen and Liew (2010). A total of 121 high spatial resolution (10–20 m) SPOT scenes were available for the analysis. Persistently cloudy conditions in this region forced data to be acquired over three years (2006-2008) with four additional images captured on January 20, March 14, July 13, and August 7, 2005. The remaining 117 satellite images were acquired between January 28, 2006, and October 17, 2008. with 27 captured in 2006, 58 in 2007, and 32 in 2008.

Twelve of the SPOT images used for the 2007 mapping were acquired by the SPOT 2 HRV sensor, 60 by the SPOT 4 HRVIR sensor, and 49 by the SPOT 5 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 SPOT images were received and pre-processed to level 2A (radiometric and geometric correction) by the Centre for Remote Imaging, Sensing and Processing (CRISP) at the National University of Singapore (NUS). Both the GeoCover mosaic data and the SPOT scenes were spectrally unenhanced. This was considered acceptable for visual image interpretation since human interpretation often accounts for slight variations in the appearance of land cover types because of factors such as haze and viewing angles.

The 2010 mapping was based on individual Landsat 7 ETM+ scenes. Sensor failure left stripes of areas without data in these images. Additionally, because of the persistently cloudy conditions of insular Southeast Asia, most of the images contain a variable amount of cumulus cloud cover.

Nevertheless, after preliminary examination, these images were found to be the most suitable data set for mapping the extent of industrial plantations in 2010. The large scale of these plantations keeps the limitations on data quality from causing significant problems for the reliable mapping of new plantation areas.

A total of 74 Landsat 7 ETM+ images were used for the 2010 plantation mapping, acquired between January 1, 2010, and March 11, 2011. Each image had a spatial resolution of 28.5 m. The three wavelength bands available in the GeoCover products were used in the 2010 mapping: shortwave infrared (band 7: 2.08-2.35 μm), near infrared (band 4: 0.76–0.9 μm), and green (band 2: 0.52–0.6 μm).

3.1.4 PLANTATION MAPPING AND SPECIES IDENTIFICATION

The 1990 and 2007 plantation extent data sets were derived from Miettinen and Liew (2010). In this study, all peatland areas covered by cloud-free satellite data were visually inspected. For on-screen viewing, all three bands were used in the GeoCover (RGB:742) and SPOT 2 HRV images (RGB:321). In the SPOT 4 HRVIR and SPOT 5 HRG images, bands 2, 3, and 4 (RGB:432) provided the best visual separability of land cover types in the classification. The land cover polygons (including industrial plantations) were manually digitized on-screen based on visual interpretation of the images at a scale of 1:100,000.

The same methodology was used to map the 2000 and 2010 plantations as well as those of 1990 and 2007. The same RGB:742 used in interpretation of the 1990 images was used in on-screen viewing of the Landsat 2000 and 2010 data sets. All 2007 plantation areas were checked in the 2000 Landsat GeoCover data set. Plantations that did not exist in 2000 were removed from the data set. All peatland areas were checked simultaneously for the existence of plantations in 2000 that would have disappeared before the 2007 mapping. For the 2010 mapping, all peatland areas were checked on the Landsat 7 ETM+ data, and any new plantations or expansions of plantation areas since 2007 delineated.

The range of wavelengths utilized in the on-screen viewing of the high-resolution satellite images is sensitive to changes in photosynthetic vegetation as well as water/moisture variation. Therefore, different combinations of these bands' reflectance values provide information on the occurrence, quality, and characteristics of vegetation and bare surfaces. Different types of surfaces and vegetation types have different spectral signatures and thus appear in different colors/tones in the images. In addition to the pixel-level reflectance information (i.e., color/tone), visual interpretation of high-resolution satellite images relies heavily on the texture, spatial arrangement, and context of features detected in the image.

In order to obtain consistent classification results throughout the project area and over the different time slices, one person inspected all the final plantation maps. This “final interpreter” had field experience in several peatland sites within the project area (in Riau, Jambi, Central Kalimantan, and Sarawak) and extensive knowledge of visual satellite image interpretation of tropical peatlands using high-resolution imagery.

The high-resolution 2007 SPOT imagery was the most appropriate data set for plantation species identification. Thus, all industrial plantations in the 2007 data set were assigned by visual inspection to one of the five classes listed here: 1) High probability oil palm, 2) Likely oil palm, 3) High probability pulp (i.e., acacia), 4) Likely pulp, and 5) Other/unknown plantation.

Plantations for which species could be confirmed by either clear visual appearance or personal knowledge of the area were assigned to *high probability* classes. Plantations for which no such confirmation could be made, but where other indicators (visual appearance, plantation infrastructure, or location, for example) suggested a particular species, were assigned to *likely* classes. Finally, plantations for which no clear support could be found for any particular plantation species, or which were known to be of other plantation species, were assigned to the *other/unknown* class.

The study operated on the reasonable assumption that the plantation crop species had not changed during the past 20 years because the number of suitable species for industrial plantations on peatlands is limited and the majority of peatland plantations are less than 15 years old. Thus, the 1990 and 2000 plantation areas were assigned the same species detected in the specific locations in 2007.

The 2010 data set did not provide a reliable means to determine the species of new plantations established since 2007. All 2010 plantation areas that existed in 2007 were assigned the same species unless clear evidence justified the correction or change of species. The species for plantation areas established since 2007 was estimated using all available information. First, the appearance in the Landsat ETM+ images was used to evaluate the plantation infrastructure. Second, the location of the plantation area and the interpreters’ personal knowledge were used to estimate the potential plantation species. Finally, available land-use allocation maps were consulted. If none of these methods yielded a justifiable conclusion on the plantation species, the new plantations were assigned to the *other/unknown plantation* class.

3.1.5 PEAT DEPTH MAPS

Information on the location and extent of peatlands, as used in the analyses, was derived from a variety of sources. For Sumatra and Kalimantan (the Indonesian part of Borneo Island), two peatland atlases published by Wetlands International (Wahyunto et al., 2003; Wahyunto et al., 2004) provide reasonably accurate information on the extent and location of peatland areas at a scale of 1:700,000. These maps were subject to minor correction, mainly by somewhat shifting peatland boundaries to be geographically correct: Peatland boundaries in many areas crossed coastlines and rivers, as indicated by both ESRI and Google Earth (which were found to be mutually consistent). These boundary changes did not significantly alter peat extent or thickness.

In detailed peat depth mapping conducted by Deltares in Central and West Kalimantan, Riau, Jambi, and Aceh, the Wetlands International peat maps often underrepresent actual peat thickness (and rarely over-represent thickness). This applies to all peat thickness classes, including the large area of peat in the 0 to 2 m thickness class, which often has significant sections of deeper peat.

For Malaysia, recently published maps of peatland extent could not be found, so maps provided by the European Digital Archive of Soil Maps (Selvaradjou et al., 2005) were considered the best available source of information. For Peninsular Malaysia, we used the 1970 1:800,000 Generalized Soil Map of Peninsular Malaysia, published by the Director General of Agriculture, Peninsular Malaysia. For Sarawak, the 1968 1:500,000 Soil Map of Sarawak by the Sarawak Land and Survey Department was consulted. Finally, for Sabah, we used the 1974 1:250,000 Soils of Sabah map created by the British government’s Overseas Development Administration.

3.1.6 RESULTING PLANTATION EXTENT MAPS

The methodology described here produced four maps presenting the extent and distribution of industrial OP plantations on peatland in 1990, 2000, 2007, and 2010 in Peninsular Malaysia, Sumatra, and Borneo. The maps and derived statistics appear in Figures 2–4 and Table 2.

TABLE 2 Areas of peatland assigned to the various plantation classes, through visual interpretation of the 2007 satellite images.

GEOGRAPHIC AREA	PEAT AREA	HIGH PROBABILITY OIL PALM		LIKELY OIL PALM		HIGH PROBABILITY ACACIA		LIKELY ACACIA		OTHER/ UNKNOWN PLANTATION		OTHER MAPPED PEATLAND		UNMAPPED PEATLAND	
	HA	HA	%	HA	%	HA	%	HA	%	HA	%	HA	%	HA	%
West Sumatra	211,152	30,217	14	41,105	19	0	0	0	0	0	0	106,873	51	32,957	16
Aceh	277,296	0	0	27,076	10	0	0	0	0	0	0	188,999	68	61,221	22
North Sumatra	347,560	135,100	39	19,126	6	0	0	0	0	0	0	135,391	39	57,943	17
Jambi	716,760	44,125	6	7,924	1	42,216	6	1,107	0	0	0	487,361	68	134,027	19
South Sumatra	1,449,689	28,452	2	20,247	1	187,810	13	23,083	2	0	0	1,141,660	79	48,437	3
Riau	4,014,076	79,406	2	317,842	8	294,511	7	74,814	2	7,417	0	3,129,710	78	110,376	3
Other provinces	217,536	12,205	6	0	0	0	0	0	0	4,436	2	125,496	58	75,399	35
Total Sumatra	**7,234,069**	**329,505**	**5**	**433,320**	**6**	**524,537**	**7**	**99,004**	**1**	**11,853**	**0**	**5,315,490**	**73**	**520,360**	**7**
West Kalimantan	1,743,224	49,875	3	8,184	0	0	0	2,587	0	1	0	1,315,793	75	366,784	21
South Kalimantan	329,385	0	0	2,549	1	0	0	0	0	0	0	261,148	79	65,688	20
Central Kalimantan	3,008,706	4,468	0	10,558	0	0	0	0	0	0	0	2,228,681	74	764,999	25
East Kalimantan	687,721	0	0	5,218	1	0	0	4,415	1	1,851	0	235,143	34	441,094	64
Total Kalimantan	**5,769,036**	**54,343**	**1**	**26,509**	**0**	**0**	**0**	**7,002**	**0**	**1,852**	**0**	**4,040,765**	**70**	**1,638,565**	**28**
Indonesia (-Papua)	**13,003,105**	**383,848**	**3**	**459,829**	**4**	**524,537**	**4**	**106,006**	**1**	**13,705**	**0**	**9,356,255**	**72**	**2,158,925**	**17**
Sarawak	1,442,845	205,180	14	53,207	4	0	0	0	0	21,497	1	851,490	59	311,471	22
Sabah	191,330	19,152	10	16,364	9	0	0	0	0	1,958	1	115,591	60	38,265	20
Peninsular Malaysia	854,884	65,166	8	41,685	5	0	0	0	0	5,328	1	350,332	41	392,373	46
Malaysia	**2,489,059**	**289,498**	**12**	**111,256**	**4**	**0**	**0**	**0**	**0**	**28,783**	**1**	**1,317,413**	**53**	**742,109**	**30**
Indonesia + Malaysia	**15,492,164**	**673,346**	**4**	**571,085**	**4**	**524,537**	**3**	**106,006**	**1**	**42,488**	**0**	**10,673,668**	**69**	**2,901,034**	**19**

3.1.7 ACCURACY ASSESSMENT

Suitable data for accuracy assessment are scarce for a project based on visual interpretation of high-resolution satellite images at regional scales. Only ground sampling or very high resolution remote sensing data offer the significantly higher detection reliability needed for such an assessment. Because of the large geographical area of the project, representative ground sampling is not a realistic option. In the past, very high resolution satellite imagery was prohibitively expensive and cloud-free imagery was sparsely available in the humid, tropical insular Southeast Asia. However, Google Earth has gone some way toward overcoming these limitations.

For accuracy assessment, this study utilized very high resolution satellite imagery available in Google Earth. By selecting only images acquired from 2004 through 2010, an adequate set of sampling sites was obtained. The sites covered by the very high resolution satellite data were used to evaluate the accuracy of the 2007 plantation map. The very high resolution data available in Google Earth include satellite images from IKONOS and GeoEye-1 satellites operated by GeoEye, as well as Quickbird, WorldView-1, and WorldView-2 satellites operated by Digital Globe. These satellites all have less than 1 m spatial resolution and enable accurate detection of industrial plantation areas, including species identification.

A total of 30 sites spread around the study area were identified (Figure 1). Within these sites, 600 sample plots were selected using stratified random sampling. Half of the plots were chosen from mapped peatland areas outside industrial plantations to estimate the level of omission errors of the mapping. Half of the sample plots were selected within areas classified as industrial plantations to evaluate the accuracy of the plantation species identification and the level of commission errors in the mapping. The 300 sample plots chosen within plantation areas were distributed among different species based on their proportions in the overall mapping results.

The accuracy assessment results (Table 3) indicate a very high overall accuracy of 96%, with a kappa value of 0.92 for the industrial plantation mapping. The producer's and user's accuracies of 96% to 97% reinforce the high reliability of the map.

TABLE 3 Accuracy assessment results of industrial plantations mapping.

		REFERENCE			
		INDUSTRIAL PLANTATION	OTHER MAPPED	TOTAL	USER'S ACCURACY
LC map	**Industrial plantation**	287	13	300	95.7
	Other mapped	10	290	300	96.7
	Total	297	303	600	
	Producer's accuracy	96.6	95.7		

Analysis of the separation accuracy among industrial plantation species (Table 4) revealed high usability of the results. Overall accuracy of the classification, including the industrial plantation species, was 94% with a kappa value of 0.91. Both oil palm and pulpwood plantations had user and producer accuracies of 90% or better. Table 4 also shows that around half of the plantations classified as *unknown* were in fact shown to be oil palm plantations. In theory, this could lead to an underestimation of the extent of oil palm plantations in this study. Owing to the very small proportion of *other/unknown* plantations (~3%), however, any potential underestimation due to this cause can be expected to be on the order of only 1% to 2%.

TABLE 4 Accuracy assessment results including industrial plantation (IP) species.

		REFERENCE					
		OIL PALM IP	PULP IP	OTHER/ UNKNOWN IP	OTHER MAPPED	TOTAL	USER'S ACCURACY
LC map	**Oil palm IP**	185	0	4	6	195	94.9
	Pulp IP	4	89	0	6	99	89.9
	Other/ Unknown IP	4	0	1	1	6	16.7
	Other mapped	6	0	4	290	300	96.7
	Total	199	89	9	303	600	
	Producer's accuracy	93.0	100.0	11.1	95.7		

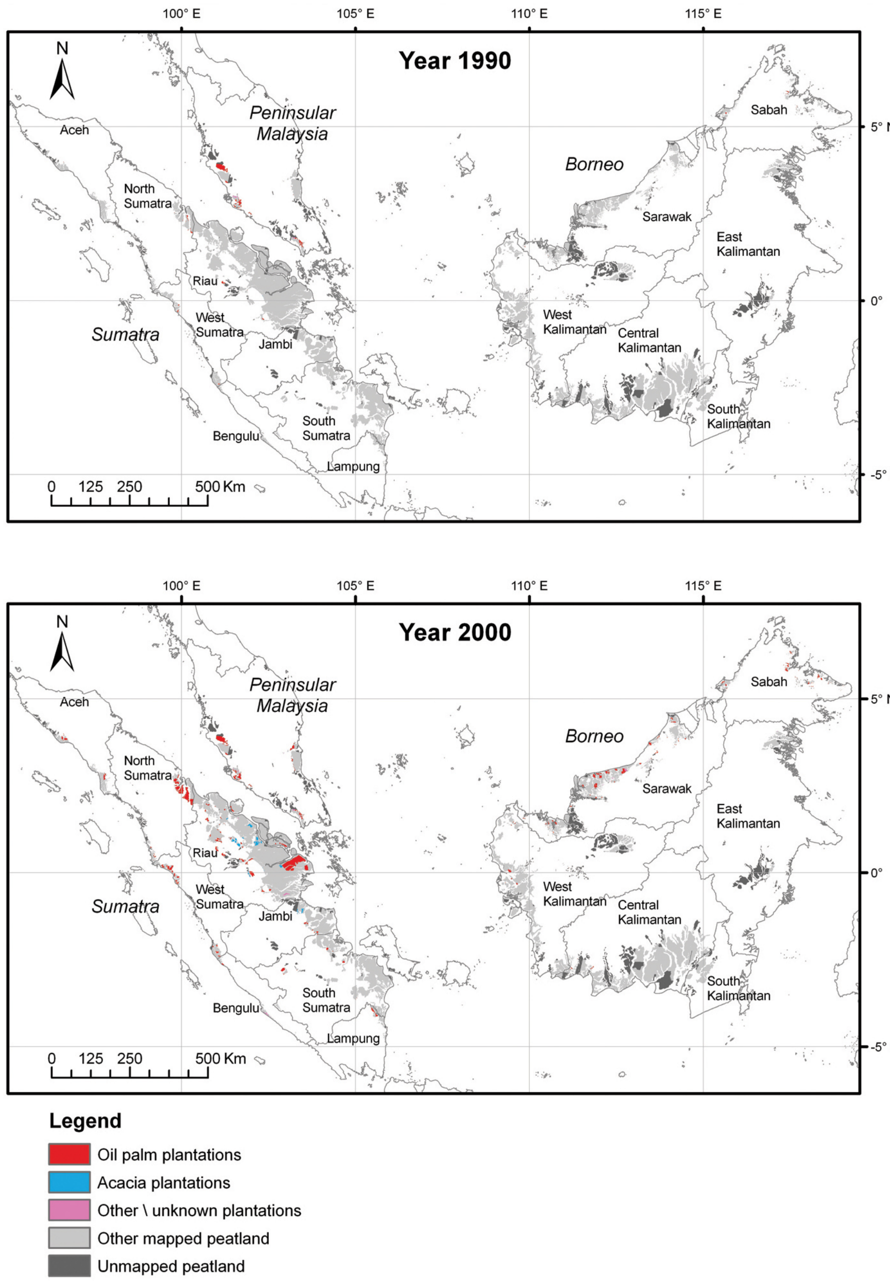

FIGURE 2 Extent of OP plantations on peatland, 1990 and 2000.

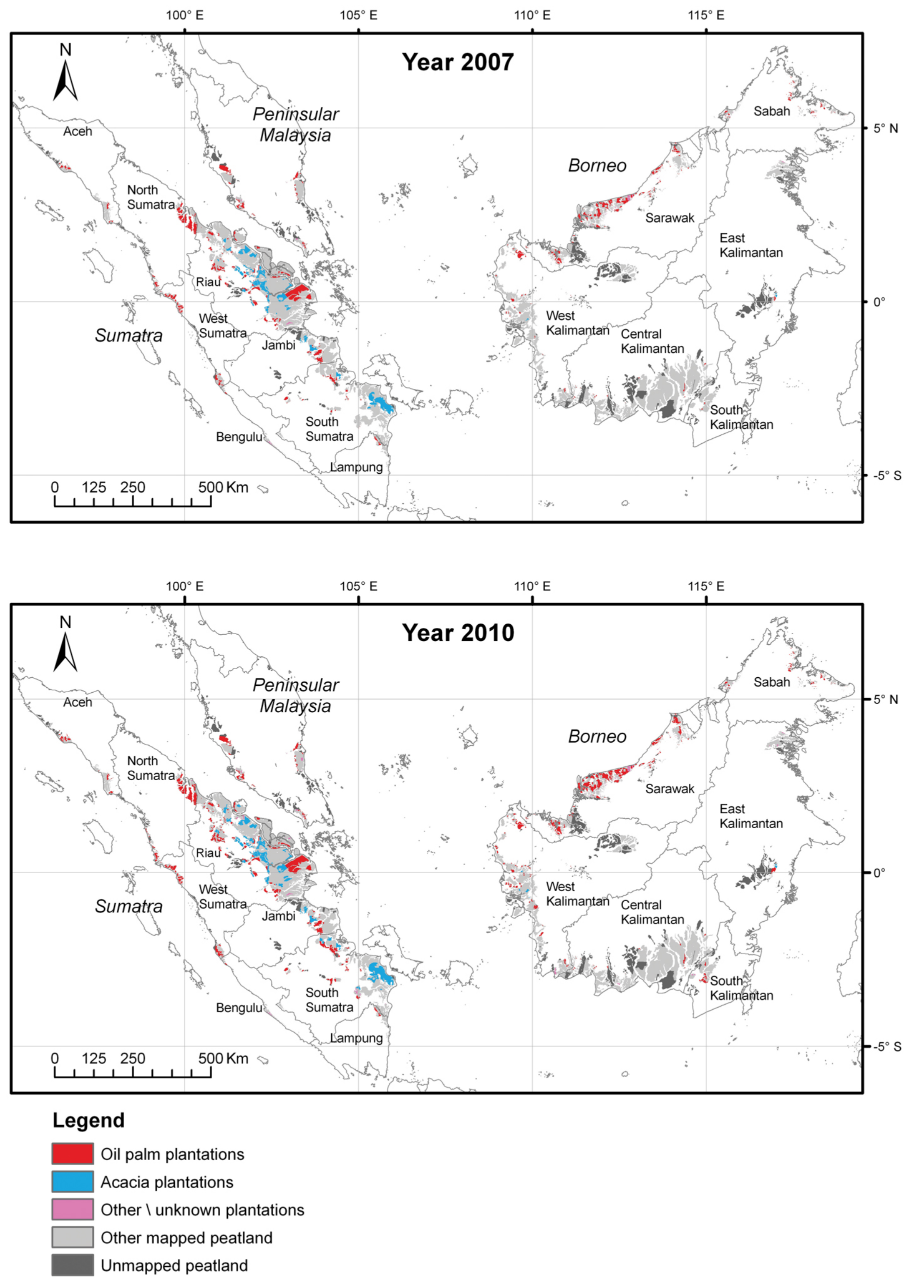

FIGURE 3 Extent of OP plantations on peatland, 2007 and 2010.

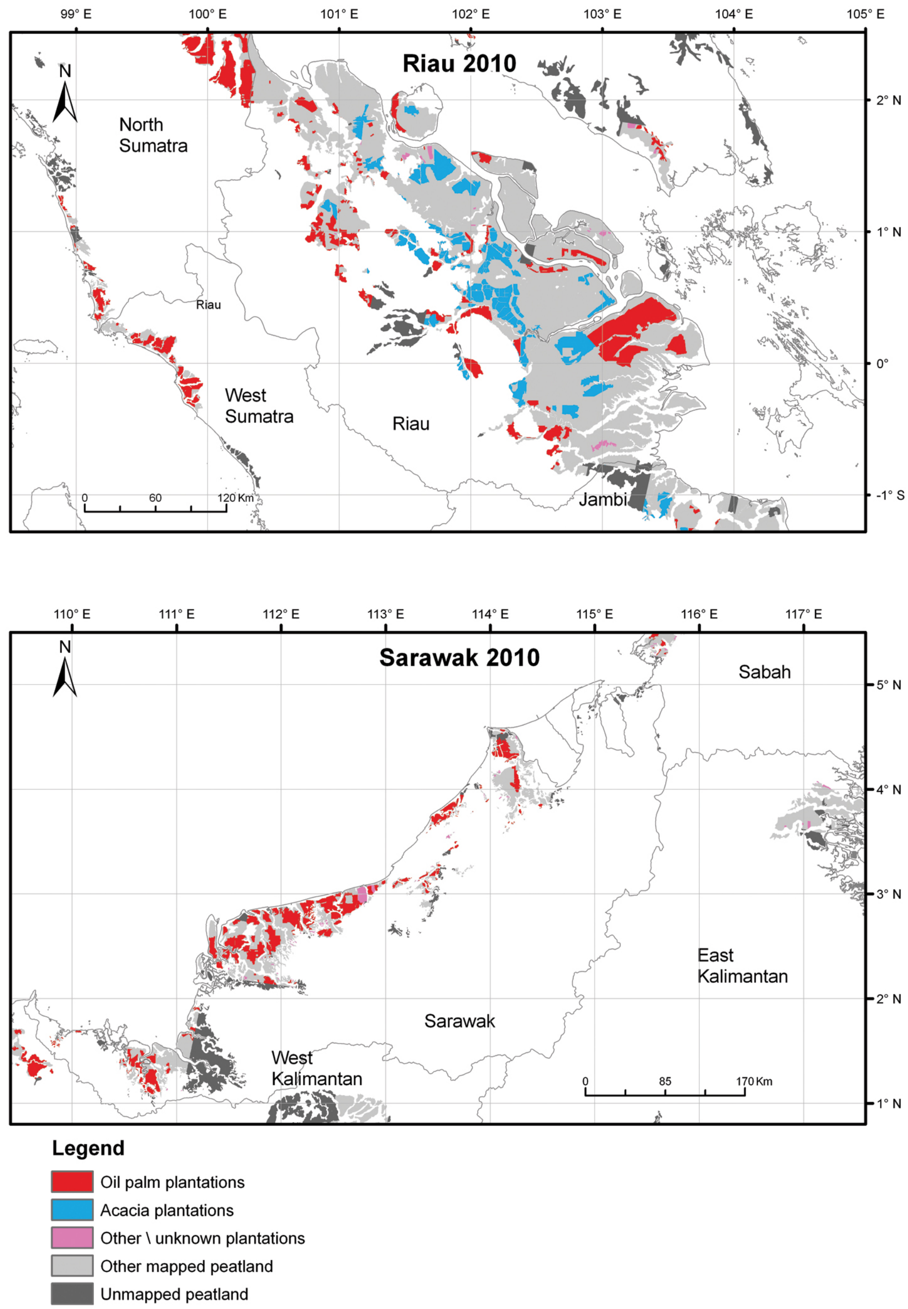

FIGURE 4 Extent of oil palm plantations on peatland in Riau and Sarawak, 2010.

4 DETERMINING TRENDS AND PATTERNS IN OP EXPANSION OVER THE PAST 20 YEARS

In nearly all geographic units included in this study, the extent of industrial-scale oil palm plantations has grown continuously from a low starting point 20 years ago (Table 5, Figure 5). This expansion has accelerated considerably over each time interval (1990⇨2000, 2000⇨2007, and 2007⇨2010), but the rate of acceleration (in both absolute and relative terms) was greatest in 2007⇨2010.

In 1990, only Malaysia had a significant area of OP on peat, while Sumatra had just a negligible area and Kalimantan had none. At that time, the total extent of OP on peatland in Indonesia and Malaysia combined was 250,000 ha. By 2000, the total area of industrial OP plantations on peatland had increased to over 900,000 ha. By 2010, Sarawak and Riau, both of which had negligible OP area in 1990, each contained a quarter of the 2.15 Mha. Including the province of Riau, Sumatra's more than 1 Mha is nearly half the total OP area, exceeding the 840,000 ha in Malaysia. The remaining area of 260,000 ha is in Kalimantan, the Indonesian part of Borneo Island, where OP development on peat had barely started by 2000 and has only really taken off since 2007.

Between 2007 and 2010, the total area of industrial OP on peatland increased sharply by well over half a million hectares, from 1.6 to 2.15 Mha, at a rate of 190,000 ha/year. Some 200,000 ha of this most recent expansion was in Malaysia—nearly all of it in Sarawak—and the remainder is divided more or less evenly between Sumatra and Kalimantan.

TABLE 5 Historical trend and (linear) future projection of industrial OP plantations in Indonesia and Malaysia.

	PEAT AREA	1990		2000		2007		2010		2020		2030	
GEOGRAPHIC AREA	HA	HA	%	HA	%	HA	%	HA	%	HA	%	HA	%
West Sumatra	211,152	4,982	2	50,685	24	84,513	40	100,327	48	153,042	72	205,756	97
Aceh	277,296	199	0	22,793	8	34,748	13	49,208	18	97,410	35	145,612	53
North Sumatra	347,560	7,641	2	142,878	41	185,082	53	213,520	61	308,313	89	403,106	116
Jambi	716,760	0	0	9,877	1	64,020	9	74,851	10	110,956	15	147,061	21
South Sumatra	1,449,689	0	0	18,922	1	50,382	3	120,400	8	353,791	24	587,183	41
Riau	4,014,076	6,134	0	264,656	7	408,480	10	475,764	12	700,045	17	924,325	23
Other provinces	217,536	0	0	18,664	9	18,679	9	18,679	9	18,679	9	18,679	9
Total Sumatra	**7,234,069**	**18,955**	**0**	**528,475**	**7**	**845,904**	**12**	**1,052,750**	**15**	**1,742,236**	**24**	**2,431,722**	**34**
West Kalimantan	1,743,224	0	0	12,190	1	73,530	4	149,384	9	402,231	23	655,078	38
South Kalimantan	329,385	0	0	0	0	3,184	1	33,738	10	135,586	41	237,434	72
Central Kalimantan	3,008,706	0	0	3,792	0	20,149	1	31,614	1	69,831	2	108,049	4
East Kalimantan	687,721	0	0	0	0	14,550	2	43,562	6	140,267	20	236,973	34
Total Kalimantan	**5,769,036**	**0**	**0**	**15,982**	**0**	**111,414**	**2**	**258,299**	**4**	**747,916**	**13**	**1,237,534**	**21**
Indonesia (-Papua)	**13,003,105**	**18,955**	**0**	**544,457**	**4**	**957,318**	**7**	**1,311,049**	**10**	**2,490,152**	**19**	**3,669,256**	**28**
Sarawak	1,442,845	727	0	110,374	8	329,522	23	532,931	37	1,210,963	84	1,888,995	131
Sabah	191,330	4,950	3	34,097	18	44,723	23	46,851	24	53,944	28	61,038	32
Peninsular Malaysia	854,884	227,763	27	240,230	28	250,163	29	264,151	31	310,780	36	357,409	42
Malaysia	**2,489,059**	**233,440**	**9**	**384,701**	**15**	**624,407**	**25**	**843,933**	**34**	**1,575,688**	**63**	**2,307,442**	**93**
Indonesia + Malaysia	**15,492,164**	**252,395**	**2**	**929,158**	**6**	**1,581,725**	**10**	**2,154,982**	**14**	**4,065,840**	**26**	**5,976,698**	**39**

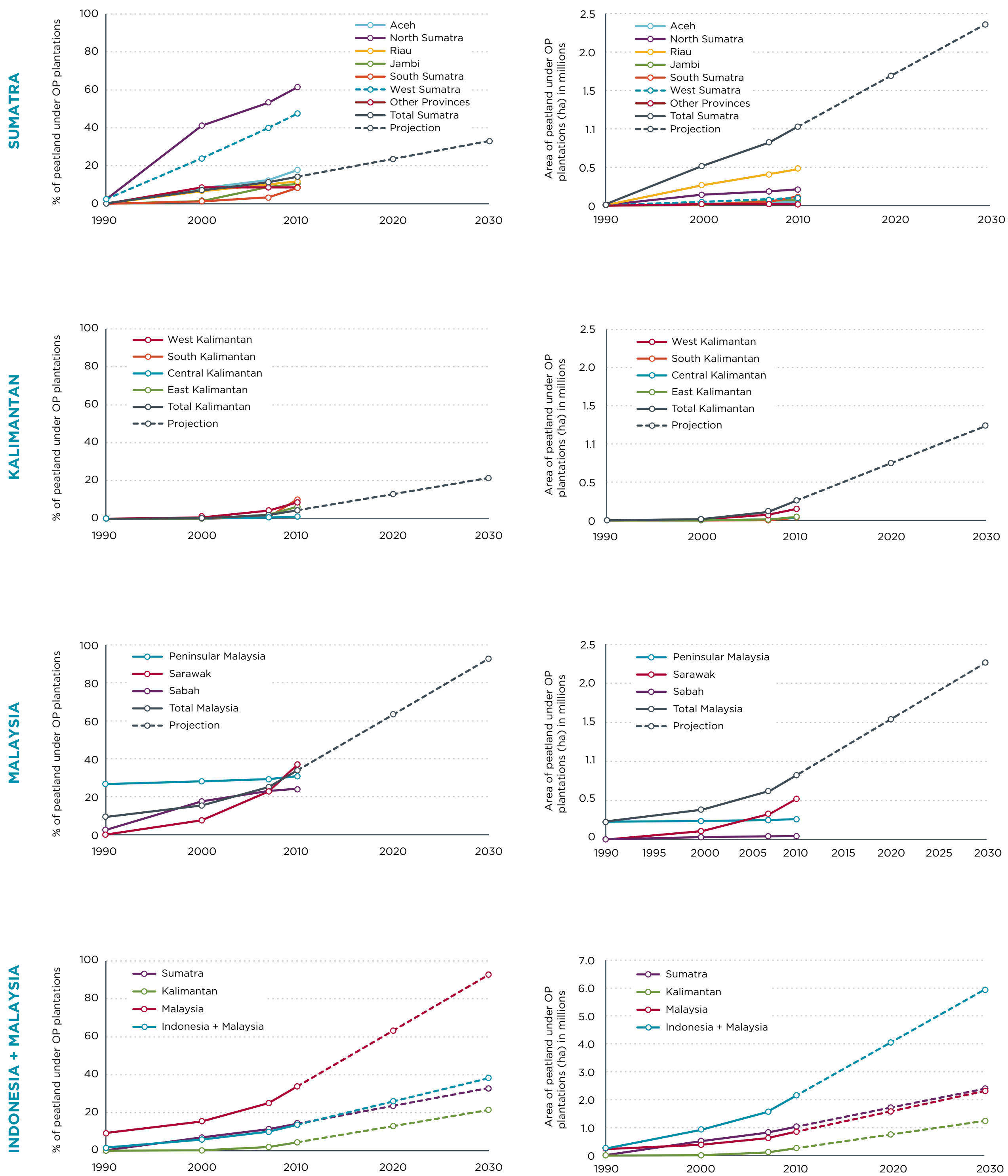

FIGURE 5 Historical trend and (linear) future projection of industrial OP plantations in Indonesia and Malaysia.

5 PROJECTING POTENTIAL OP EXPANSION IN THE COMING 10 TO 20 YEARS

5.1 Projection of Potential OP Increase

The potential increase in the area of industrial OP plantations in Southeast Asia was estimated by projecting recent OP area expansion trends, and changes therein, into the near future. This approach does not consider the actual drivers of OP plantation expansion: developments in global vegetable oil markets. While such a demand driver analysis would be helpful, it would need to be based on a projection of wider economic developments that is beyond the scope of the current study. Also, it is doubtful that a driver analysis would significantly reduce uncertainty in the analysis, as economic developments are in themselves highly tentative and cannot fully account for the possible market distortion effects of international regulation on palm oil use for biofuels.

5.1.1 LINEAR PROJECTION OF RECENT INCREASE

The simplest projection assumes that OP extent will grow in coming decades at the same rate as in the most recent period of 2007-2010. This is a very conservative approach since the increase has actually accelerated continuously over the past 20 years and there is no reason to assume this acceleration will not continue apace, at least in the near future. Nevertheless, we have adopted this approach in Table 5 and Figure 5, because making assumptions on the degree of acceleration adds a level of uncertainty to the analysis.

A linear projection results in an OP extent on peatland of 4.1 Mha in 2020, up from 2.1 Mha at present. In 2030, there would be 6 Mha of OP on peatland if the rate of increase neither accelerates nor diminishes.

5.1.2 PROJECTION OF ACCELERATING INCREASE

The outcome of a continued acceleration of increasing OP area has been tentatively explored in two ways. First, an annual increase model was fitted over the 1990-2010 data and yielded realistic results over this period (R^2=0.99; Figure 6), when applying an increase value of 11.28% per year. The long-term projection to 2030 is, however, clearly unrealistic at a value of 18 Mha, an area that is greater than the available peatland. Nevertheless, the resulting value of 6.2 Mha in 2020, close to the value that is achieved in 2030 applying a linear projection, might be taken as a tentative maximum value for how fast OP area could increase if expansion is allowed to continue unchecked.

The second approach is to determine how much greater the rate of increase was in the 2000⇨2010 period than in the previous decade, 1990⇨2000. This method yields a projection that is more similar to the linear approach. However, since it does not take into account the sharp acceleration from 2007 to 2010, this approach will most likely result in an underestimate of plantation area if the recent trend continues. Nevertheless, the projected figure of 7.2 Mha in 2030 may be as realistic as the 6 Mha that the linear approach produces. The results of the two approaches for 2020 are identical.

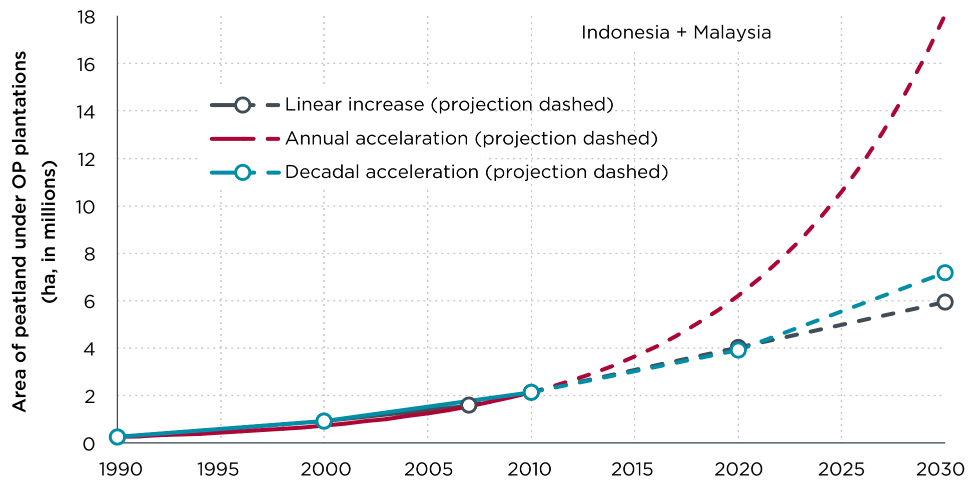

FIGURE 6 Comparison of projection methods for increase in OP area for the period 1990-2030.

5.2 Constraints on OP Expansion

The opportunity for OP to expand on peatland was assessed on the basis of three different sets of constraints (Tables 6–8; Figure 7): a) the total extent of peatlands; b) the extent of peat less than 2 m thick; c) the extent of peat in areas where land allocation zoning allows conversion to plantation. Maps were produced with boundaries around peatland areas where OP is allowed within those constraints. In each case, the area available for OP expansion was determined as the area within those boundaries minus the area within those boundaries that was already covered by OP plantations in 2010. We also investigated the possible limiting effect that an increase in other agricultural uses could have on OP expansion on peatland.

5.2.1 TOTAL PEAT EXTENT

Obviously, the area of OP on peatland cannot be larger than the total extent of the peatland itself. We have therefore checked whether the available area of peatland would be exceeded in our linear projection.

It is clear from Table 5 that projected OP expansion would not exceed the total peatland area in any of the examined regions by 2020. By 2030, the available peatland area would be exceeded only in North Sumatra and Sarawak. Of these two areas, the peatland “shortage” would be greatest in

Sarawak at 450,000 ha. By 2020, 84% of Sarawak peatlands could already be developed at current rates of conversion, as opposed to 37% at present. In the entirety of Malaysia, the 34% of the total 2.5 Mha of peatland area under OP could potentially rise to 93% by 2030 assuming there are no constraints to expansion. While it should be noted that it may not indeed be possible for such high percentages of peatland to be converted to OP, it remains unknown in the public domain how much of this peatland area is currently available for conversion or logging. The implications of a peatland shortage in Malaysia for regional OP expansion are discussed in a later section.

Indonesia has much more space for expansion on peatland, as OP would occupy only 28% of the total 13 Mha by 2030, assuming a linear projection (Table 5). By 2010, industrial OP plantations covered 10% of the peatland area in Sumatra and Kalimantan, leaving 11.7 Mha undeveloped.

TABLE 6 Area of existing industrial oil palm plantations in 2010, on different peat depth ranges.

GEOGRAPHIC AREA	ALL PEATLAND			PEAT DEPTH 0-2 M			PEAT DEPTH 2-4 M			PEAT DEPTH > 4 M		
	TOTAL	OP PLANTATIONS		TOTAL	OP PLANTATIONS		TOTAL	OP PLANTATIONS		TOTAL	OP PLANTATIONS	
	HA	HA	%	HA	HA	%	HA	HA	%	HA	HA	%
West Sumatra	211,152	100,327	48	144,462	86,994	60	18,509	4,630	25	48,181	8,703	18
Aceh	277,296	49,208	18	207,293	37,299	18	70,003	11,909	17	0	0	0
North Sumatra	347,560	213,520	61	324,154	200,066	62	23,406	13,454	57	0	0	0
Jambi	716,760	74,851	10	387,540	44,936	12	278,458	21,839	8	50,762	8,076	16
South Sumatra	1,449,689	120,400	8	1,427,386	119,756	8	22,303	644	3	0	0	0
Riau	4,014,076	475,764	12	1,586,333	404,850	26	821,747	36,186	4	1,605,996	34,729	2
Other provinces	217,536	12,646	6	210,009	12,646	6	6,848	0	0	679	0	0
Total Sumatra	**7,234,069**	**1,046,716**	**14**	**4,287,177**	**906,546**	**21**	**1,241,274**	**88,661**	**7**	**1,705,618**	**51,508**	**3**
West Kalimantan	1,743,224	149,384	9	1,237,979	125,629	10	208,708	0	0	296,537	23,755	8
South Kalimantan	329,385	33,738	10	234,512	24,775	11	94,873	8,963	9	0	0	0
Central Kalimantan	3,008,706	31,614	1	1,515,184	17,035	1	562,725	8,170	1	930,797	6,409	1
East Kalimantan	687,721	43,562	6	388,883	32,242	8	204,560	9,417	5	94,278	1,903	2
Total Kalimantan	**5,769,036**	**258,299**	**4**	**3,376,558**	**199,681**	**6**	**1,070,866**	**26,550**	**2**	**1,321,612**	**32,068**	**2**
Indonesia (-Papua)	**13,003,105**	**1,305,015**	**10**	**7,663,735**	**1,106,228**	**14**	**2,312,140**	**115,212**	**5**	**3,027,230**	**83,576**	**3**

TABLE 7 Area of land allocated for conversion to oil palm plantations, on different peat depth ranges.

GEOGRAPHIC AREA	ALL PEATLAND			PEAT DEPTH 0-2 M			PEAT DEPTH 2-4 M			PEAT DEPTH > 4 M		
	TOTAL	CONVERSION		TOTAL	CONVERSION		TOTAL	CONVERSION		TOTAL	CONVERSION	
	HA	HA	%	HA	HA	%	HA	HA	%	HA	HA	%
West Sumatra	211,152	192,203	91	144,462	128,355	89	18,509	18,508	100	48,181	45,340	94
Aceh	277,296	211	0	207,293	211	0	70,003	0	0	0	0	0
North Sumatra	347,560	4,635	1	324,154	4,635	1	23,406	0	0	0	0	0
Jambi	716,760	375,327	52	387,540	314,431	81	278,458	38,684	14	50,762	22,212	44
South Sumatra	1,449,689	603,912	42	1,427,386	589,833	41	22,303	14,079	63	0	0	0
Riau	4,014,076	1,788,589	45	1,586,333	1,134,475	72	821,747	403,316	49	1,605,996	250,798	16
Other provinces	217,536	149,968	69	210,009	145,757	69	6,848	4,211	61	679	0	0
Total Sumatra	**7,234,069**	**3,114,845**	**43**	**4,287,177**	**2,317,697**	**54**	**1,241,274**	**478,798**	**39**	**1,705,618**	**318,350**	**19**
West Kalimantan	1,743,186	883,404	51	1,237,941	634,077	51	208,708	78,913	38	296,537	170,414	57
South Kalimantan	328,870	327,938	100	233,997	233,065	100	94,873	94,873	100	0	0	0
Central Kalimantan	3,007,890	807,550	27	1,514,474	600,274	40	562,619	169,229	30	930,797	38,047	4
East Kalimantan	684,699	447,621	65	385,861	248,045	64	204,560	142,986	70	94,278	56,590	60
Total Kalimantan	**5,764,645**	**2,466,513**	**43**	**3,372,273**	**1,715,461**	**51**	**1,070,760**	**486,001**	**45**	**1,321,612**	**265,051**	**20**
Indonesia (-Papua)	**12,998,714**	**5,581,358**	**43**	**7,659,450**	**4,033,158**	**53**	**2,312,034**	**964,799**	**42**	**3,027,230**	**583,401**	**19**

TABLE 8 Area of land allocated to production forest/logging, on different peat depth ranges.

	ALL PEATLAND			PEAT DEPTH 0-2 M			PEAT DEPTH 2-4 M			PEAT DEPTH > 4 M		
	TOTAL	LOGGING		TOTAL	LOGGING		TOTAL	LOGGING		TOTAL	LOGGING	
GEOGRAPHIC AREA	HA	HA	%	HA	HA	%	HA	HA	%	HA	HA	%
West Sumatra	211,152	12,487	6	144,462	12,487	9	18,509	0	0	48,181	0	0
Aceh	277,296	849	0	207,293	849	0	70,003	0	0	0	0	0
North Sumatra	347,560	74,871	22	324,154	70,758	22	23,406	4,113	18	0	0	0
Jambi	716,760	173,102	24	387,540	55,410	14	278,458	102,266	37	50,762	15,426	30
South Sumatra	1,449,689	723,301	50	1,427,386	719,497	50	22,303	3,804	17	0	0	0
Riau	4,014,076	1,983,938	49	1,586,333	430,082	27	821,747	404,178	49	1,605,996	1,149,678	72
Other provinces	217,536	40,384	19	210,009	37,747	18	6,848	2,637	39	679	0	0
Total Sumatra	**7,234,069**	**3,008,932**	**42**	**4,287,177**	**1,326,830**	**31**	**1,241,274**	**516,998**	**42**	**1,705,618**	**1,165,104**	**68**
West Kalimantan	1,743,186	641,696	37	1,237,941	465,616	38	208,708	91,183	44	296,537	84,897	29
South Kalimantan	328,870	0	0	233,997	0	0	94,873	0	0	0	0	0
Central Kalimantan	3,007,890	814,331	27	1,514,474	425,803	28	562,619	275,714	49	930,797	112,814	12
East Kalimantan	684,699	190,411	28	385,861	91,174	24	204,560	61,573	30	94,278	37,664	40
Total Kalimantan	**5,764,645**	**1,646,438**	**29**	**3,372,273**	**982,593**	**29**	**1,070,760**	**428,470**	**40**	**1,321,612**	**235,375**	**18**
Indonesia (-Papua)	**12,998,714**	**4,655,370**	**36**	**7,659,450**	**2,309,423**	**30**	**2,312,034**	**945,468**	**41**	**3,027,230**	**1,400,479**	**46**

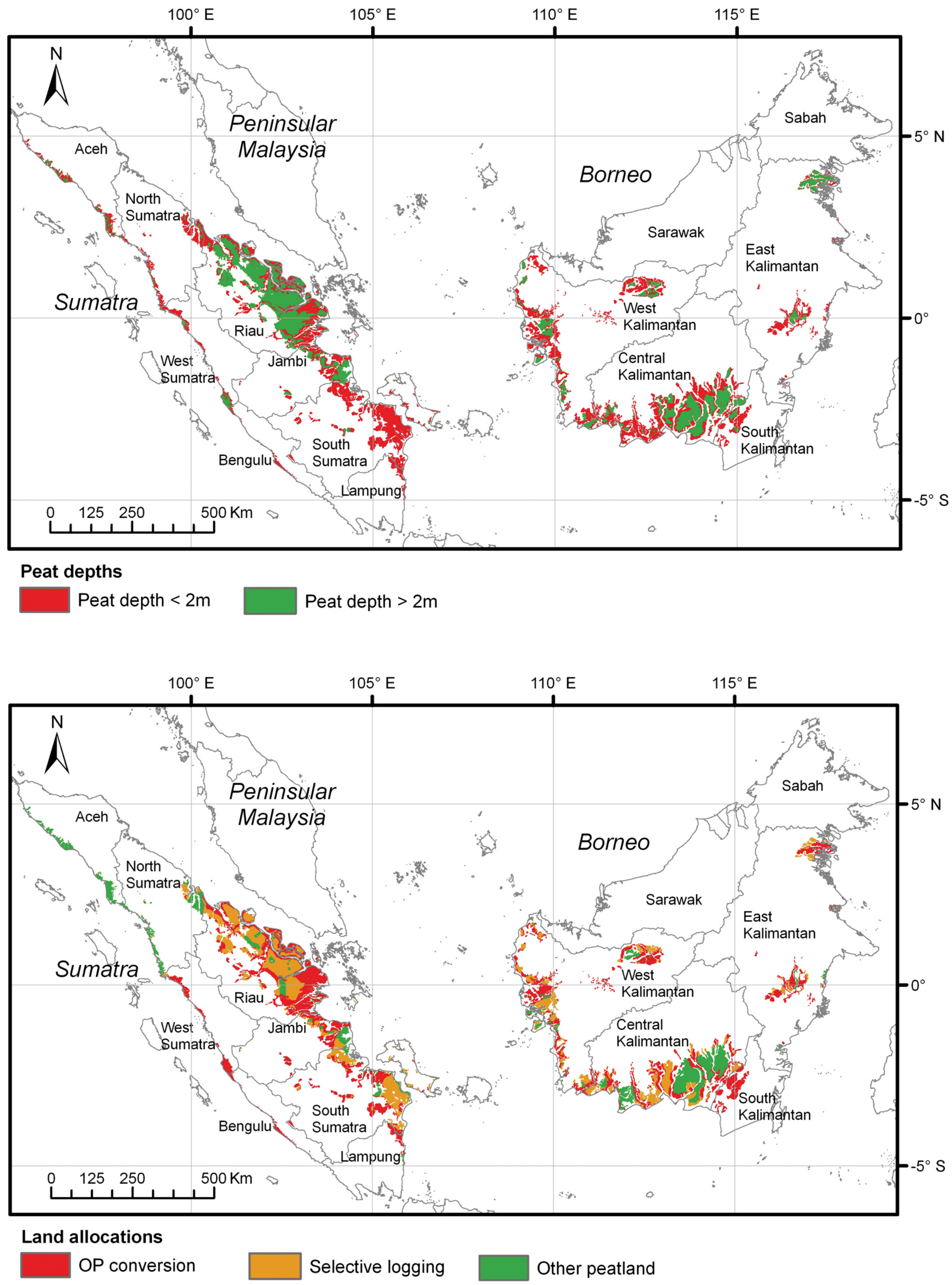

FIGURE 7 Different OP plantation expansion constraints in Indonesia. Top: peat that is less than 2 m thick according to the Wetlands International peat maps. Bottom: peatland area allocated for conversion and logging by the Ministry of Forestry.

5.2.2 EXTENT OF PEAT < 2 M THICKNESS IN INDONESIA

While shallow peat of limited thickness may in some cases be suitable for agriculture, including OP plantations, thicker peat deposits are generally considered unsuitable in the long term. The problems associated with such lands include poor rooting stability, poor nutrient status, poor temperature conductance, and high fire risk. The most significant problem is that the loss of peat through oxidation results in land subsidence by as much as 2.5 m in the first 25 years after drainage and potentially up to 6 m over 100 years (Hooijer et al., 2011). As the natural peat surface is generally located between 2 and 10 meters above mean sea level, this subsidence will cause major drainage problems in most peatlands. In many areas, semi-permanent inundation will be inevitable in the long term. These limitations to peatland conversion for agricultural use are known globally and are well described in literature on Southeast Asian peatlands (e.g., Andriesse, 1988; DID Sarawak, 2001). The conclusion in Southeast Asia, as in other parts of the world, has long been that in principle, peatlands are unsuitable for agriculture, with the possible exception of certain areas of shallow peat, and that selective logging is the only sustainable use of such lands. The "problem depth" boundary cited most often is 2 m peat thickness. In Malaysia, land capability maps declare nearly all peatland in Sarawak to be "organic soils with such severe limitations in their original state that agriculture is not feasible," and the remaining peat of limited depth to be "land marginally suitable for agriculture" (Figure 8; Department of Agriculture, Sarawak, 1982). These "unsuitable" and "marginally suitable" peatlands include all peat areas that have been converted to OP since 2000, which the Sarawak DID (2001) declares can be "returned to nature" should land subsidence render them undrainable in the future.

For the reasons described above, Indonesian law stipulates that peat thicker than 3 m should not be drained or clear-felled. However, implementing this law proves problematic because no accurate peat depth map exists that provides a 3 m peat depth line. In practice, the Indonesian ban on developing peatlands deeper than 3 m is not strictly enforced, as is clear from the fact that the share of peatland allocated to conversion to OP plantation on peat of 2 to 4 meters deep is as high as 42%, only slightly lower than the allocated area on peat of up to 2 m thick (Table 7). Even on peat exceeding a depth of 4 m, 19% is allocated for conversion to OP.

No peat thickness data for Malaysia are available in the public domain. For Indonesia, the Wetlands International map presents peat thickness boundaries of 2 and 4 meters. We have attempted to interpolate the 3 m depth line from this map, but we have not produced credible results. In any case, it appears that the 2 m and 3 m contours are usually very close together as they are located on the relatively steep "slope" part of the peat dome profile (unpublished data). Furthermore, the WI maps tend to underestimate peat depth, as discussed above. We have therefore tentatively used the 2 m peat thickness boundary as a proxy for the 3 m depth boundary.

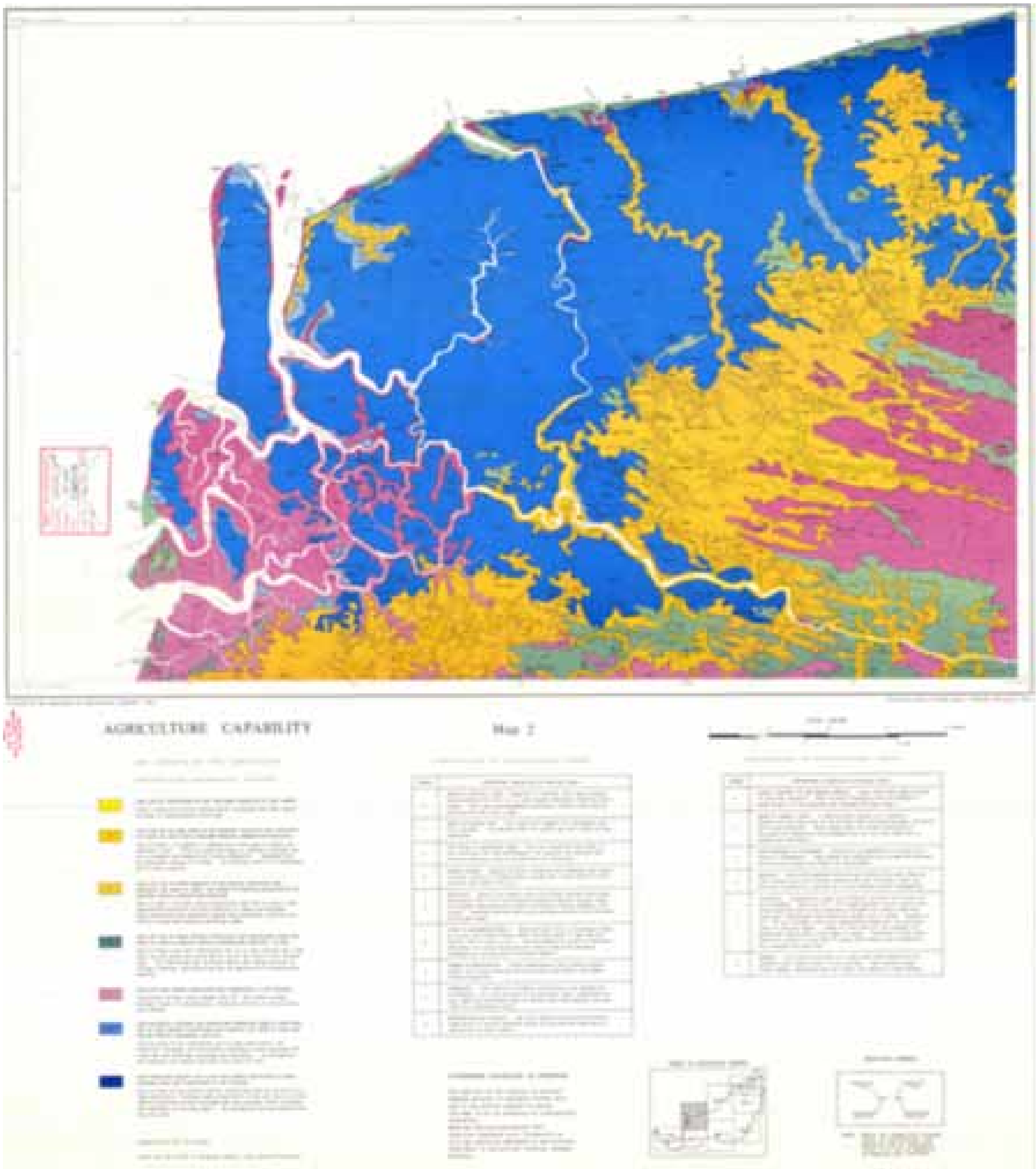

FIGURE 8 Land Capability map for the Rajang Delta in Sarawak, declaring nearly all peatland (blue areas) to be "organic soils with such severe limitations in their original state that agriculture is not feasible" (source: Department of Agriculture, Sarawak, 1982). Note that nearly this entire peatland area has since 2000 been converted to OP plantations.

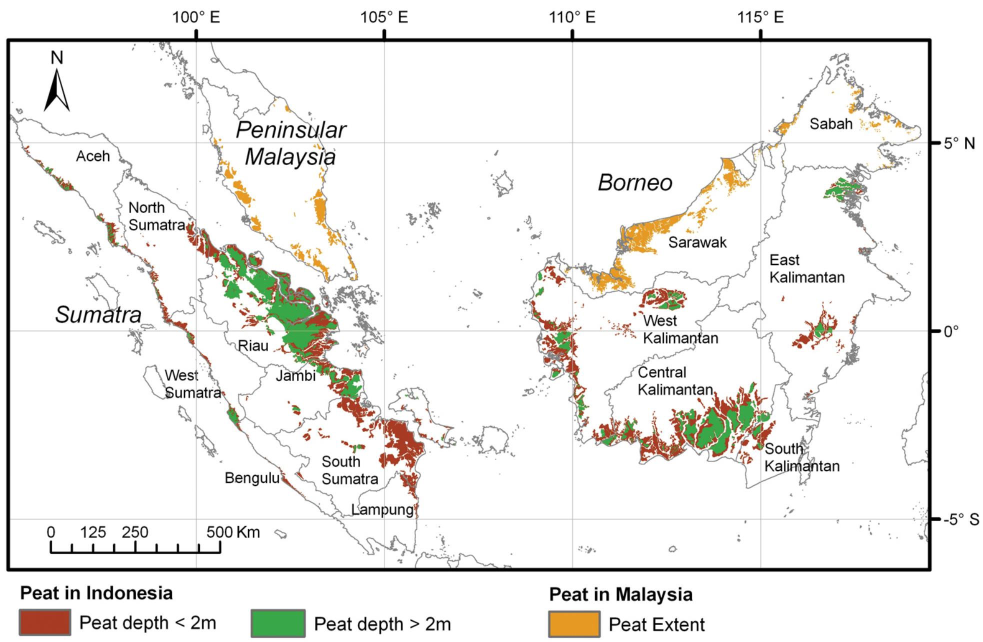

FIGURE 9 Map of peat extent in Indonesia and Malaysia. For Indonesia, the 2 m peat depth boundary is shown, as presented in the Wetlands International atlas.

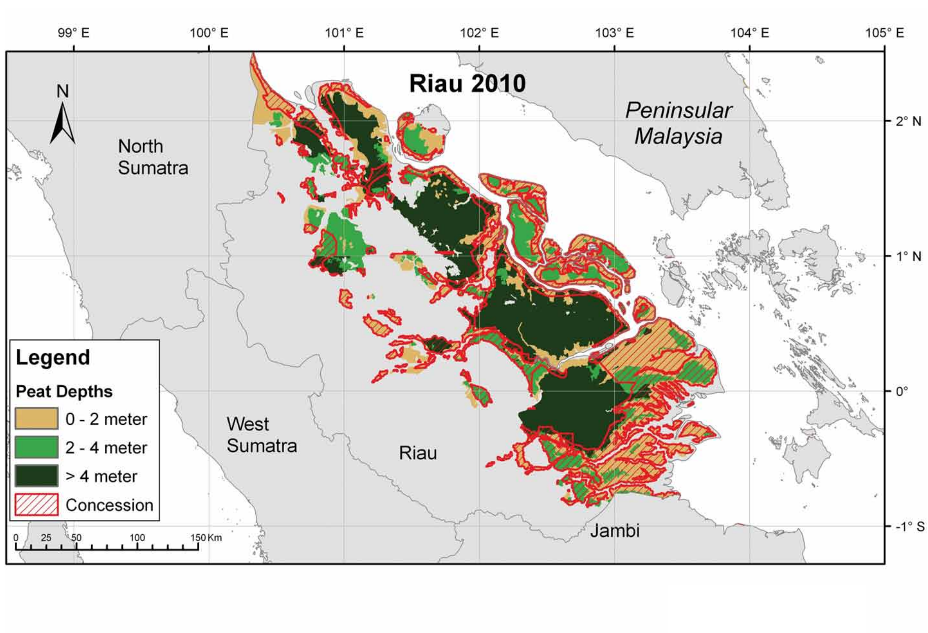

FIGURE 10 Peat depth boundaries (Wetlands International) and existing OP plantations (2010) in Riau.

Because Indonesia may start enforcing the ban on development on peat over 3 m in depth, thereby encouraging more OP expansion on shallow peat or mineral soils, we have explored what this would mean for the expansion of OP on peat. Table 9 shows that if OP, as projected linearly, continued to expand only on peat less than 2 m thick, merely 36% of shallow peat that is not already planted with OP in 2010 would be in 2030. Only in two provinces that have relatively limited peat extent, West Sumatra and North Sumatra, would expansion of OP at current rates exceed the available area of peat less than 2 m thick. The availability of shallow peat is therefore not a limitation to the expansion of OP on peat.

TABLE 9 Potential area of OP on peatland by 2030, as determined through linear projection, compared with the area available for expansion in 2010, considering different possible constraints.

GEOGRAPHIC AREA	Total OP corrected	Total peat area	Shallow peat area (< 2 m)	Peat area allocated for conversion	Peat area allocated for conversion or logging	Total peat area minus area already under OP plantation in 2010	Shallow peat area (< 2 m) minus area already under OP plantation in 2010	Peat area allocated for conversion minus area already under OP plantation in 2010	Peat area allocated for conversion or logging minus area already under plantation in 2010	Potential OP expansion as a fraction of total peat that was not yet planted in 2010	Potential OP expansion as a fraction of total peat < 2 m that was not yet planted in 2010	Potential OP expansion as a fraction of total peat allocated for conversion that was not yet planted in 2010	Potential OP expansion as a fraction of total peat allocated for conversion or logging that was not yet planted in 2010
	HA	HA	HA	HA	HA	HA	HA	HA	HA	%	%	%	%
West Sumatra	205,756	211,152	144,462	192,203	204,690	110,825	92,187	108,892	120,954	95	114	97	87
Aceh	145,612	277,296	207,293	211	1,060	228,088	175,825	211	1,060	42	55	45,689	9,095
North Sumatra	403,106	347,560	324,154	4635	79,506	134,040	154,904	1,101	41,985	141	122	17,219	452
Jambi	147,061	716,760	387,540	375,327	548,429	641,909	318,723	317,566	442,350	11	23	23	16
South Sumatra	587,183	1,449,689	1,427,386	603912	1,327,213	1,329,289	1,001,593	486,611	901,991	35	47	96	52
Riau	924,325	4,014,076	1,586,333	1,788,589	3,772,527	3,538,312	1,332,966	1,344,440	2,835,192	13	34	33	16
Other provinces	18,679	217,536	210,009	150,647	191,031	198,857	193,368	134,072	174,456	0	0	0	0
Total Sumatra	**2,393,410**	**7,234,069**	**4,287,177**	**3,115,524**	**6,124,456**	**6,207,147**	**3,269,566**	**2,392,893**	**4,517,988**	**22**	**42**	**57**	**30**
West Kalimantan	655,078	1,743,224	1,237,979	883,404	1,525,100	1,593,840	1,118,552	799,076	1,391,478	32	45	63	36
South Kalimantan	237,434	329,385	234,512	327,938	327,938	295,647	214,308	297,368	297,368	69	95	68	68
Central Kalimantan	108,049	3,008,706	1,515,184	807,550	1,621,881	2,977,092	1,499,792	795,596	1,606,659	3	5	10	5
East Kalimantan	236,973	687,721	388,883	447,621	638,032	644,159	371,630	430,886	611,747	30	52	45	32
Total Kalimantan	**1,237,534**	**5,769,036**	**3,376,558**	**2,466,513**	**4,112,951**	**5,510,737**	**3,204,282**	**2,322,926**	**3,907,252**	**18**	**31**	**42**	**25**
Indonesia (-Papua)	**3,630,944**	**13,003,105**	**7,663,735**	**5,582,037**	**10,237,407**	**11,717,884**	**6,473,848**	**4,715,819**	**8,425,240**	**20**	**36**	**50**	**28**

5.2.3 LAND ALLOCATION ZONING IN INDONESIA

Maps of 2010 Indonesian land allocation to specific uses, including peatland areas, can be found on the Ministry of Forestry's website (http://www.dephut.go.id/index.php?q=id/node/6981). The maps used in this study were updated for 2011 to include 19 land allocation classes (Table 10), some national and others only in specific provinces. These classes have been simplified to three: *conservation/protection, production/logging,* and *production and conversion.* It should be noted that the *logging* class is sometimes referred to as *selective logging,* while in practice these lands are fully cleared.

We have explored the space for OP expansion on peat within the constraints of these land allocation zones. The first assumption was that areas with an official conservation/protection status cannot be converted to OP; conversion in national parks is rare, although logging and forest degradation is common in such areas. The second assumption was that no conversion to OP will take place in areas allocated for production/logging only, although numerous examples to the contrary bring this assumption into question (see below).

On the basis of a strict interpretation of the land allocation maps, a total peatland area of 5.5 Mha, nearly half the total peatland in the area, is formally allocated to conversion to industrial oil palm plantations in Indonesia (Sumatra and Kalimantan). Table 9 shows that if OP continued to expand on peat, as projected linearly, only in areas allocated for conversion, just 50% of such peat that is not already planted with OP in 2010 would be in 2030 (assuming that part of the OP expansion continues to take place in Malaysia in proportion to developments to date). Allocated peatland would become limited only in the provinces of Aceh and North Sumatra that do not have large peatland area. Clearly, these formal land allocation classes do not limit OP expansion on Indonesian peatland.

Table 9 predictably shows that if OP conversion occurs in areas where only logging without conversion is allowed in addition to areas where it is legally permitted, the area available for OP conversion would be even larger. Considering that many areas now allocated for OP were allocated only for logging in past decades, changes in land allocation class are common practice and may not present an obstacle to future OP expansion. If we assume that land allocated for production/logging will indeed be available for OP conversion, the total available area for OP is 10.2 Mha, and only 28% of the area not already planted with OP in 2010 would have OP by 2030.

TABLE 10 Reclassification table for Indonesian land allocation classes as determined by the Ministry of Forestry.

ALLOCATION	CLASSID	RECLASSIFICATION	RECLASS ID
Hutan Lindung (HL)	1001	conservation/protection	1
Cagar Alam (CA)	1002	conservation/protection	1
Cagar Alam Darat	1002	conservation/protection	1
Hutan Konservasi (HK)	1002	conservation/protection	1
Hutan Suaka Alam dan Wisata (HSAW)	1002	conservation/protection	1
Kawasan Suaka Alam (KSA)	1002	conservation/protection	1
Suaka Alam Laut (KSA-SAL)	1002	conservation/protection	1
Taman Hutan Rakyat	1002	conservation/protection	1
Taman Hutan Raya (KPA-THR)	1002	conservation/protection	1
Taman Nasional (KPA-TN)	1002	conservation/protection	1
Taman Nasional Darat	1002	conservation/protection	1
Taman Wisata Alam (KPA-TWA)	1002	conservation/protection	1
HP-HPH	1003	production/logging	2
Hutan Produksi (HP)	1003	production/logging	2
HP-HTI	1004	production/logging	2
Hutan Produksi Terbatas (HPT)	1004	production/logging	2
Hutan Rakyat	1004	production/logging	2
Hutan Produksi Konversi (HPK)	1005	production and conversion	3
Areal Penggunaan Lain (APL)	1007	production and conversion	3
Air	5001	Water	10

5.2.4 COMPETING INDUSTRIAL-SCALE USES OF PEATLAND: ACACIA, PINEAPPLE, AND SAGO PLANTATIONS

Oil palm plantations are the main industrial-scale plantation type on peatlands in Southeast Asia, but not the only one. In Malaysia, some 6% of industrial plantations on peatland grow sago and pineapple crops, with the remaining 94% OP; these percentages have remained stable since 1990 (Table 11). These crops are also grown on peatland in Indonesia, on similarly relatively small areas. In Sumatra, however, acacia for pulp and paper production occupies almost as much peatland area as OP, at 12% and 14%, respectively. Acacia is grown only in Riau, South Sumatra, and Jambi, where two companies (SinarMas/APP and APRIL/RAPP) have built large pulp mills. The area of acacia plantations on peatland in these three provinces has increased very rapidly between 2000 and 2010, from 80,000 ha (1% of Sumatra's peatland area) to 875,000 ha (12%).

The stable area of pineapple and sago plantations over the past 20 years, a fraction of the total area of industrial plantations on peat, suggests that no major increase should be expected in the future. Thus, these crops hardly compete for peatland space with OP.

The rapid expansion of acacia plantations in parts of Sumatra over the past 10 years suggests that this crop may compete with OP for space. However, acacia is grown only to supply locally owned pulp mills, which represent huge industrial complexes that cost billions of dollars to build. There are only a few such mills at present, concentrated in a small area in Riau around the Kampar Peninsula. The possible expansion of acacia grown on peatland is largely controlled by distance to mills. As existing pulp mills are currently running below capacity, it appears unlikely that more will be built in the near future. In addition, local communities and non-governmental organizations appear more resistant to this crop than to OP, as the latter creates some relatively stable local industry and employment, while acacia requires less manpower and often follows a boom-and-bust cycle linked to the paper market and other external factors. Overall, the expansion of acacia plantations on peatland over the next 10 years will be at a lower rate than was observed over the previous 10 years that followed the initial pulp mill construction.

In summary, it appears very likely that industrial plantations will expand on Malaysian and Indonesian peatland for OP, rather than other plantation crops.

TABLE 11 Expansion of industrial crops other than OP on peatland.

		PEAT AREA	1990		2000		2007		2010	
		HA	HA	%*	HA	%*	HA	%*	HA	%*
Oil palm plantations	Sumatra	7,234,069	17,985	0.2	512,341	7.1	821,949	11	1,026,922	14
	Kalimantan	5,769,036	0	0	15,982	0.3	111,414	1.9	258,299	4.5
	Malaysia	2,489,059	233,440	9.4	384,701	15	624,407	25	843,933	34
	Indonesia + Malaysia	**15,492,164**	**251,424**	**1.6**	**913,024**	**5.9**	**1,557,770**	**10**	**2,129,155**	**14**
Acacia plantations	Sumatra	7,234,069	306	0	80,176	1.1	671,919	9.3	874,921	12
	Kalimantan	5,769,036	0	0	250	0	9,780	0.2	22,797	0.4
	Malaysia	2,489,059	0	0	0	0	0	0	0	0
	Indonesia + Malaysia	**15,492,164**	**306**	**0**	**80,426**	**0.5**	**681,699**	**4.4**	**897,718**	**5.8**
Other & unknown plantations**	Sumatra	7,234,069	0	0	12,478	0.2	12,773	0.2	34,593	0.5
	Kalimantan	5,769,036	0	0	335	0	2,587	0	25,873	0.4
	Malaysia	2,489,059	14,715	0.6	20,675	0.8	40,285	1.6	58,457	2.3
	Indonesia + Malaysia	**15,492,164**	**14,715**	**0.1**	**33,488**	**0.2**	**55,644**	**0.4**	**118,923**	**0.8**
All plantations other than OP	Sumatra	7,234,069	306	0	92,654	1.3	684,692	9.5	909,514	13
	Kalimantan	5,769,036	0	0	585	0	12,366	0.2	48,669	0.8
	Malaysia	2,489,059	14,715	0.6	20,675	0.8	40,285	1.6	58,457	2.3
	Indonesia + Malaysia	**15,492,164**	**15,021**	**0.1**	**113,914**	**0.7**	**737,343**	**4.8**	**1,016,641**	**6.6**
All plantations including OP	Sumatra	7,234,069	18,291	0.3	604,995	8.4	1,506,641	21	1,936,436	27
	Kalimantan	5,769,036	0	0	16,567	0.3	123,780	2.1	306,968	5.3
	Malaysia	2,489,059	248,154	10	405,375	16	664,692	27	902,391	36
	Indonesia + Malaysia	**15,492,164**	**266,445**	**1.7**	**1,026,937**	**6.6**	**2,295,113**	**15**	**3,145,796**	**20**
			%		%		%		%	
OP plantations as % of industrial plantations	Sumatra		98		85		55		53	
	Kalimantan		—		96		90		84	
	Malaysia		94		95		94		94	
	Indonesia + Malaysia		**94**		**89**		**68**		**68**	

*As a percentage of likely peatland area

**Including unidentified OP plantations

5.3 Actual Likely Increase of OP on Peatland in Southeast Asia as a Whole

It appears that expansion of OP on peatland in Indonesia and in the general region will not be limited by any of the constraints investigated: total peatland extent, area of shallow peatland, land allocation zoning, or competing industrial-scale land uses. However, there is likely to be local-level variation within the region in the extent to which various factors start limiting the expansion of peatland OP plantations. The situation in Malaysia is especially unclear. The remaining area for OP expansion on peatland, which is mostly concentrated in Sarawak, will decrease rapidly at current expansion rates, leading to a shortage of peatland at some point within the next 20 years. Moreover, Sarawak mineral soils have limited lowland available for agricultural development, with much of the inland area either under some other form of cultivation or topographically unsuitable for plantation development. This may further build the pressure on plantation expansion in the peatlands of Sarawak in the near future. Shortage of peatland in Malaysia may become an issue even sooner if land allocation laws begin to limit availability of the remaining peatlands, but the status of such laws remains unknown to us. These questions introduce great uncertainty in the estimation of how long OP plantations can continue to expand at current rates in the peatlands of Sarawak and in Malaysia overall.

The similar trends in OP expansion in most geographic units analyzed here, with the rate of OP expansion accelerating almost everywhere at every time step over the past 20 years, suggest that these developments are planned regionally in response to global demand for palm oil. This is not surprising because most palm oil companies active in the region are part of international conglomerates, like Sime Darby, Sinar Mas, Wilmar, or APRIL. These companies think beyond national borders and will expand OP activities wherever conditions are most advantageous. It is therefore concluded that regional OP expansion would not be limited because Indonesian availability would easily compensate for a shortage of peatland in Malaysia.

Furthermore, it should be noted that our analysis has not fully captured recent and rapid rates of OP expansion in Kalimantan. For instance, the 2010 OP area in Central Kalimantan is mapped at only 32,000 ha (Table 1), about 1% of the provincial peatland area of 3 Mha, though field observations suggest that the actual area may be at least double this estimate; the difference attributed to the *no data* mask applied to some areas in this study. Moreover, the extensive peatlands in Indonesian Papua and Papua New Guinea (Page et al., 2011) have not been included in this analysis and could provide additional spillover area should conditions for expansion on peatland elsewhere become restrictive.

In summary, we conclude that at the regional level, the room for OP expansion on peatland in a “business as usual” scenario is unlimited over at least the next 20 years. While some areas (particularly in Malaysia) may already face shortages of expansion area on peatland within the near future, this is not expected to affect the overall rate of OP plantation expansion in Southeast Asian peatlands. Unless existing or new laws for protection of peatlands and forests are enforced in the near future, OP plantations can expand freely on peatland in Southeast Asia if the global demand for palm oil increases further.

6 CALCULATING THE WIDER IMPACT AREA OF OP PLANTATIONS ON PEATLAND

In the analyses here, we have considered only the area planted with OP. It should be noted that the area affected by drainage extends well beyond actual plantation boundaries. Drainage effects along access roads and canals cannot be quantified because the location of this infrastructure is largely unknown. However, we can, quantify the effect of plantation drainage on adjoining peatlands, where water tables were lowered over long distances. In a study by Hooijer et al. (2011), this impact zone, where water tables were lowered by 0.33 m on average, was found to extend 2 km after less than 10 years of drainage on deep peat. An ongoing hydrological modelling study (Van der Vat and Hooijer, to be published) demonstrates how, over decades, land surface subsidence will progressively increase the surface gradient in surrounding peatlands toward drained plantations and may eventually create an impact zone of up to 5 km on deep peat.

To explore the additional area affected by drainage outside OP plantations, we added drainage impact zones of 2 km and 5 km around all OP plantations mapped in 2010. These zones were only counted as affected area where they were on peat and did not cover other plantations. The resulting numbers (Figure 11 and Table 12) indicate that a 2 km impact zone almost doubles the overall area affected by OP plantation drainage, from 14% to 25% of total peatland area in insular Southeast Asia. Assuming a 5 km drainage impact zone, the overall area increases to 36%. While it is probably an overestimate of the actual hydrological impact area, as the affected drainage area will be smaller on shallower peat, this estimate demonstrates that impact assessments for OP plantations in peatland should take into account a considerably larger area than the plantation alone.

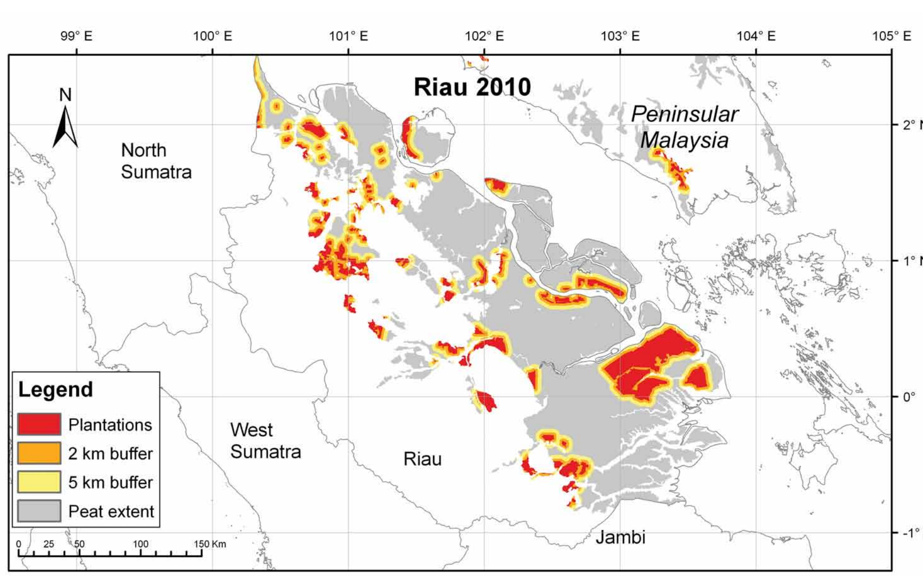

FIGURE 11 Oil palm plantations in Riau, with impact zones *(buffers)* of 2 km (short term) and 5 km (long term).

TABLE 12 The area affected by OP plantation drainage, assuming hydrological impact zones *(buffers)* of 2 km and 5 km away from plantations. Hydrological impact zones were considered only where they were on peat and where they did not overlap with other OP plantations.

GEOGRAPHIC AREA	NO BUFFER		2 KM BUFFER INCLUDED		5 KM BUFFER INCLUDED	
	HA	%	HA	%	HA	%
West Sumatra	100,327	48	160,601	76	202,751	96
Aceh	49,208	18	101,799	37	149,349	54
North Sumatra	213,520	61	288,119	83	326,801	94
Jambi	74,851	10	145,054	20	231,584	32
South Sumatra	120,400	8	197,643	14	280,250	19
Riau	475,764	12	875,375	22	1,354,110	34
Other Provinces	18,679	9	40,814	19	68,452	31
Total Sumatra	**1,052,750**	**15**	**1,809,405**	**25**	**2,613,297**	**36**
West Kalimantan	149,384	9	319,427	18	515,927	30
South Kalimantan	33,738	10	69,260	21	103,766	32
Central Kalimantan	31,614	1	99,603	3	200,409	7
East Kalimantan	43,562	6	63,132	9	92,690	13
Total Kalimantan	**258,299**	**4**	**551,423**	**10**	**912,792**	**16**
Indonesia (-Papua)	**1,311,049**	**10**	**2,360,828**	**18**	**3,526,088**	**27**
Sarawak	532,931	37	894,400	62	1,190,455	83
Sabah	46,851	24	96,034	50	144,971	76
Peninsular Malaysia	264,151	31	484,309	57	696,312	81
Malaysia	**843,933**	**34**	**1,474,743**	**59**	**2,031,737**	**82**
Indonesia + Malaysia	**2,154,982**	**14**	**3,835,571**	**25**	**5,557,826**	**36**

7 PERCENTAGE OF PALM EXPANSION LIKELY TO OCCUR ON PEATLAND

In this report we have concentrated on oil palm plantation expansion on peatland areas. It must be remembered that the majority of oil palm plantations are located outside peatland areas. The recent acceleration of oil palm establishment on peatland areas may increase the proportion of oil palm cultivation on peat soil in comparison to mineral soils. A review was undertaken in order to evaluate how the peatland oil palm expansion projections presented in this report compare to general oil palm expansion projection for the region and how this would affect the proportion of oil palm plantations in and outside of peatland areas. This will allow us to estimate what percentage of future oil palm plantations may be built on peat.

7.1 Percentage of Palm Expansion on Peatland in Malaysia

In Malaysia, government figures for planted palm oil area show that in recent years most expansion occurred in Sarawak. This finding is consistent with the Sarawak government's stated intention to continue substantial palm oil expansion in the next decade, and with well-documented limitations on the availability of additional land for palm expansion in Peninsular Malaysia.

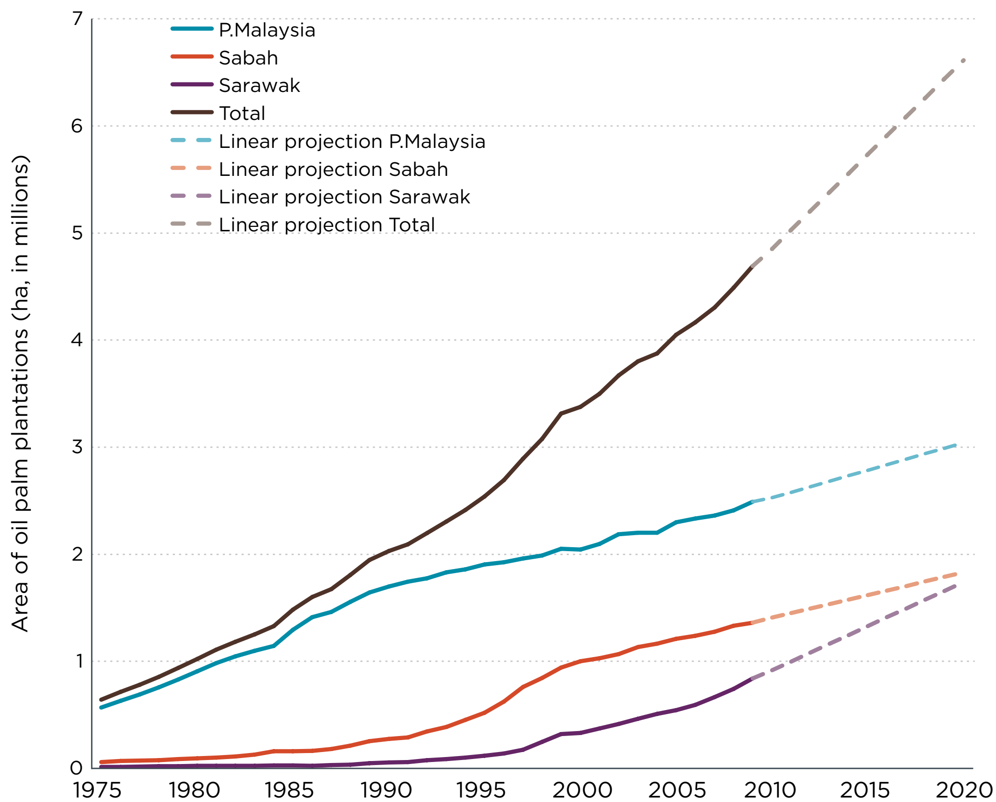

FIGURE 12 Planted palm oil area in Malaysia 1975-2009, with linear projection out to 2030.

Figure 12 shows historical planted areas in Malaysia, divided into Peninsular Malaysia and the Bornean states of Sabah and Sarawak. If both overall palm area and the amount of palm expansion on peat followed the linear trend based on the last three years of data, we expect to see about 42% of palm expansion in Malaysia occurring on peat, the encroachment driven largely by peatland conversion in Sarawak (Table 13).

TABLE 13 Comparing total area expansion to expansion on peat (linear projections).

OIL PALM EXPANSION 2010-2020	PENINSULAR MALAYSIA	SABAH	SARAWAK	TOTAL
Total	515,000	422,000	825,000	1,761,000
On peatland	47,000	7,000	678,000	732,000
% on peat	9%	2%	82%	42%

These results assume that the area of oil palm in Sarawak expands to 1.7 Mha by 2020, with 82% of that expansion occurring on peatland. This projected overall area expansion is below the stated intention of the Sarawak government to expand the area of palm concessions to 2 Mha (http://www.oxfordbusinessgroup.com/content/sarawak-palm-oil-industry-earmarked-major-expansion), an expansion that, if realized by 2020, would be consistent with a quadratic fit to the trend for overall palm expansion in Sarawak since 2000. If overall oil palm area in Sarawak expanded to 2 Mha by 2020 in line with government intentions, with 82% on peat, the overall expansion onto peat would rise to 46% in Malaysia.

Owing to constraints on available area, it seems likely that less than the 0.5 Mha of palm oil expansion suggested by linear projection will occur in Peninsular Malaysia over the next decade. The same is likely true of Sabah. This would suggest that 42% may be a conservative estimate for the overall percentage of Malaysian palm expansion that would occur on peatland in this time frame, with the 82% suggested for Sarawak as an upper limit.

7.2 Percentage of Palm Expansion on Peatland in Indonesia

Indonesia is likely to be the dominant player in Southeast Asian palm oil expansion, with a substantially larger area of available land than Malaysia. Again, we have taken Indonesian government figures for palm oil area and applied a linear projection based on the last three years of data (Figure 13). If palm expansion overall and palm expansion on peat both follow a linear trend, we would expect to see 28%, 1.2 Mha, of Indonesian palm oil expansion occur on peatland, with 4.2 Mha of expansion overall.

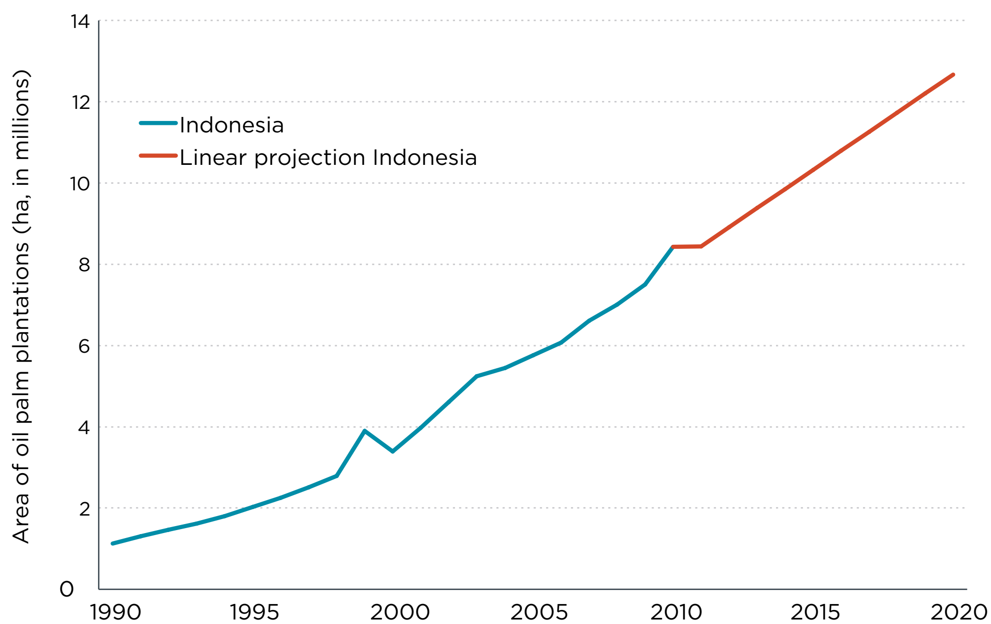

FIGURE 13 Indonesian oil palm area planted, 1990-2010.

7.3 Percentage of Palm Expansion on Peatland in Indonesia and Malaysia Combined

Taking Indonesia and Malaysia together, the linear projections imply a 32% rate of palm expansion onto peat soils, close to the 33% minimum value suggested by the EU Joint Research Centre (JRC, 2010). If total area in Sarawak rises to 2 Mha with 82% of expansion on peat, the overall rate of peatland conversion would rise to 34%. If Malaysian expansion occurred only in Sarawak with 82% on peat, the rate would still rise just to 36%. This negligible difference demonstrates that because future expansion is likely to be focused in Indonesia, the results are more sensitive to what happens in Indonesia.

We can explore the sensitivity of these results using alternative data. The Food and Agriculture Organization publishes data reported by Indonesia and Malaysia regarding the area harvested for palm oil. If we again undertake linear projection based on the last three years of area expansion using these data, and compare with the linear projection for expansion on peat, we get higher values for the percentage of expansion occurring on peat: 65% and 38% respectively for Malaysia and Indonesia, with an overall rate of 45%. Because these values depict harvested rather than planted area, they do not capture the apparent acceleration in overall palm area growth between 2007 and 2011 (as newly planted plantations will not have matured yet), making the overall area projections low and the percentage on peat projections high.

A better estimate of the percentage of oil palm expansion occurring on peat requires a more detailed socio-economic and legal assessment of which areas in Indonesia are most likely to be developed for palm preferentially in the next decade. As we have noted, peatland areas are abundant in Indonesia because of limited planning and legal constraints. The nation also has potential administrative reasons for palm companies to favor peat areas for expansion, which could support the suggestion by JRC (2010) of 33% as an appropriate minimum value for palm expansion onto peat for modelers to use, and perhaps with 45% (see above) as a maximum. On the other hand, in the context of international talks on REDD+ and deforestation, it is conceivable that Indonesia could impose tighter limitations on peat degradation in this time frame. If such controls were effectively implemented, it would be appropriate to redo the assessment of whether legal barriers represent a constraint on development of peat for oil palm.

8 UNCERTAINTIES AND RESEARCH QUESTIONS

In this project, we have assessed the extent and spatial distribution of industrial plantations in the peatlands of Peninsular Malaysia, Sumatra, and Borneo in 1990, 2000, 2007, and 2010 using visual interpretation of high-resolution satellite imagery. In general, the results obtained in this assessment agree with previous studies. Hooijer et al. (2006) estimated that in 2010 approximately 3 Mha of Southeast Asian peatlands would be covered by industrial plantations. This study found the total industrial plantation extent in 2010 to be 3.1 Mha (Table 11). However, it must be noted that Hooijer et al. (2006) included all of Indonesia and the countries of Brunei and Papua New Guinea in their analysis. Although peatlands in these parts of Southeast Asia are not expected to include extensive industrial plantations, the addition of these areas to our 2010 figures would nevertheless make the original estimate by Hooijer et al. rather conservative.

Based on a recent regional land cover map, large-scale palm plantations made up approximately 0.9 Mha of the peatlands of Peninsular Malaysia and the islands of Sumatra and Borneo around 2002 (Miettinen et al., 2012). According to the present assessment, oil palm plantations covered about 0.9 Mha already in 2000, indicating that the Miettinen at al. (2012) map slightly underestimated the extent of large-scale palm plantations. However, significant differences in the mapping approaches make these two figures not fully comparable.

In a recent study performed with high-resolution satellite data, Wahid et al. (2010) estimated that less than 0.7 Mha of peatland was covered by oil palm plantations in Malaysia in 2009. This is significantly less than the more than 0.8 Mha estimated in this study for 2010. Visual comparison of the two data sets revealed high similarity of the mapping results, with the difference in the estimated extent in part due to variations in the peat extent maps used in the two studies. In addition, oil palm expansion is currently occurring faster in some parts of Malaysia, as documented by both SarVision (2011) and this present study. In their analysis, Wahid et al. (2010) used satellite data acquired in 2008-2009, as opposed to some images in our study, which were acquired as late as March 2011. This indicates that the difference in acquisition dates of satellite data was nearly two years in some areas.

The comparisons to other recent studies reveal that the oil palm estimates presented in this report agree with other recent studies. They also expose some differences, thereby emphasizing common problems related to implementation of such studies in insular Southeast Asia. A number of points remain unresolved in the current study. First of all, some existing areas of OP plantation on peatland in insular Southeast Asia could not be included in the analysis:

A. Some small-holder plantations could not be detected as they lack the typical drainage pattern that identifies large-scale plantations. For instance, OP is increasingly planted in what are meant to be rice-producing lowland schemes in Indonesia, often in numerous small pockets.

B. Industrial plantations in the very early stages of development, before a recognizable drainage system is implemented, were not detected.

C. Plantations in the Indonesian provinces of Papua and West Papua, as well as in the countries of Papua New Guinea, Brunei, and Thailand, were excluded from the analysis, but the latter two countries do not have extensive plantations on peat.

There are also uncertainties in the precise area of plantations:

D. Peatland areas in the unmapped *no data* mask area applied in the study cannot be known exactly (a correction was made for that area, but this can of course not be 100% accurate).

E. Plantations on peatland areas that do not appear on the peat distribution maps used in this study are not included in the analysis. Up-to-date peatland maps of the region are lacking.

As a result, the total area of OP plantations is likely to be somewhat under-estimated. We estimate that the underreporting resulting from combined Points B, C, D, and E will make up less than 10% of the total OP plantation area. However, the underreporting resulting from Point A may be significant. For further refinement, higher-resolution images must be analyzed manually, and higher-resolution automatic classification methods could also be explored. More detailed and accurate peat maps (extent and thickness) based on field reconnaissance surveys are also required. But such approaches may exceed current technical capabilities and would take time and resources to develop, apply, and validate.

Projecting future expansion of OP on peatland, of course, presents the greatest uncertainty. The applied projection methods simply assume that recent trends will continue, but the accuracy of this approach may be limited for several reasons:

- Assessment of demand drivers, under different scenarios for economic development and biofuel market regulation, would help to reduce this uncertainty.
- As the longer-term risks and costs of draining peatlands, namely land subsidence and reduced drainability in time, become clearer, companies may focus plantation development on mineral dryland soils where tens of millions of hectares of deforested land (most particularly in Indonesia) are currently unproductive.
- It is unknown how local governments will respond to national and international pressures to reduce greenhouse gas emissions from peatlands and to conserve remaining wetland forests. Enforcement of existing rules banning drainage and deforestation of peatlands is still possible.
- Finally, it is unknown when and where the presence of drained OP plantations on peat will cause the peat to be fully oxidized and lost to

carbon emission to the atmosphere. The key problem here is the absence of highly accurate and recent peat depth maps, which would require extensive field surveys to complete.

9 REFERENCES

Andriesse, J. P. (1988). Nature and management of tropical peat soils, *FAO Soils Bulletin, 59,* 248 pp.

Cochrane, M. A. (2001). Synergistic interactions between habitat fragmentation and fire in evergreen tropical forests. *Conservation Biology 15,* 1515-1521.

Couwenberg, J., Dommain, R., & Joosten, H. (2010). Greenhouse gas fluxes from tropical peatlands in South-East Asia. *Global Change Biology 16*: 1715–1732.

Department of Agriculture, Sarawak. (1982). Maps of Land Agriculture Capability.

DID Sarawak. (2001). *Water management guidelines for agricultural development in lowland peat swamps of Sarawak,* Report of the Drainage and Irrigation Department, Sarawak, Malaysia, 78 pp.

European Commission Joint Research Center (2010). *Indirect Lland Uuse Cchange from increased biofuels demand* (EUR 24485 EN). Italy: Publications Office of the European Union.

Fuller, D. O., Hardiano, M., & Meijaard, E. (2011). Deforestation projections for carbon-rich peat swamp forests of Central Kalimantan, Indonesia. *Environmental Management 48,* 436–447.

Giesen, W. (2004). *Causes of peat swamp forest degradation in Berbak National Park and recommendations for restoration.* Water for food & ecosystems programme, International Agricultural Centre (IAC), Wageningen, The Netherlands.

Heil, A., Langmann, B., & Aldrian, E. (2006). Indonesian peat and vegetation fire emissions: study on factors influencing large-scale smoke haze pollution using a regional atmospheric chemistry model. *Mitigation and adaptation strategies for global change 12,* 113-133.

Hirano, T., Segah, H., Harada, T., Limin, S., June, T., Hirata, R., & Osaki, M. (2007). Carbon dioxide balance of a tropical peat swamp forest in Kalimantan, Indonesia. *Global Change Biology 13,* 412–425.

Hooijer, A., Silvius, M., Wösten, H., & Page, S. (2006). PEAT-CO2, Assessment of CO2 emissions from drained peatlands in SE Asia. *Delft Hydraulics Report Q3943* (http://peat-co2.deltares.nl).

Hooijer, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk J., Wösten, H., & Jauhiainen, J. (2010). Current and future CO2 emissions from drained peatlands in Southeast Asia. *Biogeosciences, 7,* 1–10.

Hooijer, A., Page, S., Jauhiainen, J., Lee, W.A., Lu, X., Idris, A., & Anshari, G. (2011). Peatland subsidence and carbon loss in pulp tree and oil palm plantations in Sumatra, SE Asia: reducing uncertainty and implications for emission reduction options. *Biogeosciences Discussions.* http://www.biogeosciences-discuss.net/8/9311/2011/

Hoscilo, A., Page, S. E., Tansey, K. J., & Rieley, J. O. (2011). Effect of repeated fires on land-cover changes on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. *International Journal of Wildland Fire 20*, 578-588.

IPCC (2007). *Climate change 2007: The AR4 synthesis report.* Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC). http://www.ipcc.ch, viewed 21 April 2009.

Jauhiainen, J., Limin, S., Silvennoinen, H., & Vasander, H. (2008). Carbon dioxide and methane fluxes in drained tropical peat before and after hydrological restoration. *Ecology 89,* 3503–3514.

Miettinen, J., & Liew, S. C. (2010). Degradation and development of peatlands in Peninsular Malaysia and in the islands of Sumatra and Borneo since 1990. *Land Degradation & Development 21,* 285–296.

Miettinen, J., Shi, C., & Liew, S. C. (2011). Two decades of destruction in Southeast Asia's peat swamp forests. *Frontiers in Ecology and in the Environment* (e-view first).

Miettinen, J., Shi, C., Tan, W. J., & Liew, S. C. (2012). 2010 land cover map of insular Southeast Asia in 250m spatial resolution. *Remote Sensing Letters 3:* 11-20.

Morrogh-Bernard, H., Husson, S., Page, S. E., & Rieley, J. O. (2003). Population status of the Bornean orang utan (Pongo pygmaeus) in the Sebangau peat swamp forest, Central Kalimantan, Indonesia. *Biological Conservation 110,* 141-152.

Page, S. E., Morrison, R., Malins, C., Hooijer, A., Rieley, J. O. & Jauhiainen, J. (2011). *Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia* (ICCT White Paper 15). Washington: International Council on Clean Transportation.

Page, S. E., Rieley, J. O., Shotyk, O. W., & Weiss, D. (1999). Interdependence of peat and vegetation in a tropical peat swamp forest. *Philosophical Transactions of the Royal Society B: Biological Sciences, 345,* 1885–1897.

Page, S. E., Siegert, F., Rieley, J., Boehm, H.-D. V., Jaya, A., & Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature 420,* 61-65.

Page, S. E., Hoscilo, A., Wösten, H., Jauhiainen, J., Silvius, M., Rieley, J., Ritzema, H., Tansey, K., Graham, L., Vasander, H., & Suwido, L. (2009). Restoration ecology of lowland tropical peatlands in Southeast Asia: current knowledge and future research directions. *Ecosystems 12,* 888-905.

Page, S. E., Rieley, J. O., & Banks, C. J. (2011). Global and regional importance of the tropical peatland carbon pool. *Global Change Biology 17,* 798–818.

Rieley, J. O., & Page, S. E. (eds). (2005). *Wise use of tropical peatlands: focus of Southeast Asia.* ALTERRA – Wageningen University and Research Centre and the EU INCO – STRAPEAT and RESTORPEAT Partnership, Wageningen, The Netherlands.

SarVision (2011). *Impact of oil palm plantations on peatland conversion in Sarawak 2005-2010.* Summary report. Version 1.6. SarVision, Wageningen, The Netherlands. Available at: http://www.wetlands.org/Portals/0/publications/Report/Malaysia%20Sarvision.pdf

Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F .X., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., & Yu, T. J. (2008). Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science,* 319, 1238-1240.

Selvaradjou, S.-K., Montanarella, L., Spaargaren, O., Dent, D., Filippi, N., & Dominik, S. (2005). European Digital Archive of Soil Maps (EuDASM) – Metadata of the Soil Maps of Asia. Office of the Official Publications of the European Communities, Luxembourg. Available online at: http://eusoils.jrc.ec.europa.eu/esdb_archive/EuDAsm/Asia/indexes/map.htm, accessed 5th May 2011.

Sheil, D., Casson, A., Meijaard, E., van Nordwijk, M. Gaskell, J., Sunderland-Groves, J., Wertz, K., & Kanninen, M., (2009). *The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know?* Occasional paper no. 51. (Bogor: CIFOR).

Siegert, F., Ruecker, G., Hinrichs, A., & Hoffmann, A. A. (2001). Increased damage from fires in logged forests during droughts caused by El Nino. *Nature 414,* 437-440.

Silvius, M., & Diemont, H. (2007). Deforestation and degradation of peatlands. *Peatlands International 2/2007:* 32-34.

Stone, R. (2007). Can palm oil plantations come clean? *Science 317,* 1491.

Wahid, O., Nordiana, A. A., Tarmizi, A. M., Haniff, M. H., & Kushairi, A. D. (2010). *Mapping of oil palm cultivation in peatland in Malaysia.* MPOB information series. MPOB TT no. 473.

Wahyunto, Ritung, S., & Subagjo, H. (2003). *Maps of area of peatland distribution and carbon content in Sumatera, 1990–2002.* Wetlands International-Indonesia Programme & Wildlife Habitat Canada (WHC), Bogor, Indonesia.

Wahyunto, Ritung, S., Suparto, & Subagjo, H. (2004). *Map of peatland distribution area and carbon content in Kalimantan, 2000–2002.* Wetlands International-Indonesia Programme & Wildlife Habitat Canada (WHC), Bogor, Indonesia.

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

The International Council on Clean Transportation is an independent nonprofit organization founded to provide first-rate objective research and technical and scientific analysis to environmental policy makers in the transportation sector. Our mission is to improve the environmental performance and energy efficiency of road, marine, and air transport systems and technologies worldwide, in order to benefit public health and mitigate climate change.

BEIJING BERLIN BRUSSELS SAN FRANCISCO WASHINGTON

www.theicct.org