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Assessment of impacts of plantation drainage on the Kampar Peninsula peatland, Riau

Wetlands International

Assessment of impacts of plantation drainage on the Kampar Peninsula peatland, Riau

Report 1207384

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Preface

Peat swamp forests in SE Asia have been subject to rapid conversion to drained land-uses, especially oil palm and *Acacia* plantations. Over the last decade increasing concerns have been raised about environmental issues linked to this development. These include loss of biodiversity and the very high CO_2 emissions related to the oxidation of the carbon stored in the peat as well as the increased occurrence of fires in the desiccated peatlands. Fires occur every year but in very dry years - related to the El Niño - the number and duration of fires can take on disastrous proportions, with the resulting haze and smog blanketing substantial areas of SE Asia causing huge economic losses and impacting public health. However another environmental impact, soil subsidence, has received little attention so far in SE Asia, even though it has been well known from other peatland regions in the world since the 19th Century. This is especially of concern in lowland regions where land subsidence can bring the soil surface down to levels at which drainability and flooding become an issue. Eventually it can result in extensive loss of productive land.

Wetlands International has been advocating against unsustainable land-use developments in peatlands worldwide and for alternative sustainable peatland management, including the conservation and restoration of peatlands. We are particularly concerned about the degradation of the peatlands in SE Asia, in view of their high biodiversity as well as the disproportionately high GHG emissions. Our advocacy has contributed to increased awareness on these issues and over the last years resulted in significant steps by key players in the plantations industry and by the Indonesian government. These include commitments to halt expansion on peat and the adoption of more stringent policies for improved peatland management. However, peatland drainage is unsustainable, even under best management practice, and results in continued peat loss and thus carbon emissions and soil subsidence.

Wetlands International believes that the issue of peatland subsidence and related flood risks will only be taken serious if policy makers and land-use planners have access to appropriate science-based information. We have therefore commissioned Deltares to carry out a case study in the Kampar Peninsula, which in terms of its peat swamp qualities can stand as a prime example for many lowland peat swamps in Sumatra and elsewhere in SE Asia. It has been subject to forest clearing and plantation development by pulp-for-paper and palm oil companies. Over the last decades, substantial areas of the peninsula's natural peat swamp forests have been clear-felled for these drainage-based land-uses. The question this study addresses is for how long this land-use can be continued given the inevitability of the subsidence of the peat soil under drainage.

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Summary and Key Findings

It has long been known that drainage of peatlands inevitably causes peat loss resulting in CO_2 emissions and land subsidence. In turn, subsidence results in increased flood risk as the land surface falls below river and sea flood levels. These impacts have been well described and understood for many decades (Figure 1, Figure 4; Figure 5), and, for this reason, most countries have long ago stopped peatland conversion to agriculture and are now actively restoring some areas to nature in attempts to reduce emissions and flood risk. Indonesia and Malaysia are now the only countries attempting to convert peatlands to agriculture and silviculture at a large scale. The rate of carbon loss, and of associated CO_2 emissions and land subsidence, is highly temperature dependent (Figure 2), and therefore proceeds at a faster rate in the tropics than in other climate zones (Table 1).

We demonstrate the rate of peat surface subsidence, increased flood risk and carbon emission for the Kampar Peninsula (KP) in Riau, Indonesia. An elevation model (DTM) was constructed from LiDAR data (Figure 7), and land use was determined from Landsat analyses and plantation concession data from the government (Figure 14). The elevation model was used to create a map of minimum peat thickness and carbon stock for the KP (Figure 9), assuming the base of the peat (i.e. where the underlying mineral soil layer starts) to be at 2 m above Mean Sea Level (MSL). This measure of minimum peat thickness can underestimate actual peat thickness by several metres, as the peat base is actually often around or even below MSL, as explained in this report (Figure 10).

The total KP study area of 674,200 ha is almost entirely covered by peat that has an average minimum thickness of 4.9 m (Table 4) and a more likely average thickness of ~7 m. By 2014, 294,227 ha (43.6 %) was converted to plantations (Table 4; Table 5), with the remainder still covered by peat swamp forest of reasonable to good quality. Three types of plantations are distinguished in this analysis: *Acacia* plantations (AP) for the pulp and paper industry (31.3 % of the KP area and 71.7 % of the total plantation area), industrial oil palm plantations (IOPP; 5.2 and 11.9 %) and smallholder oil palm plantations (SOPP; 7.2 and 16.4 %). These plantation types tend to be in very different settings in the landscape, with AP being on the highest elevations and the deepest peat (6.4 m +MSL and 4.5 m, respectively); SOPP closest to rivers at the lowest elevation that tend to have shallow peat (3.7 m +MSL and 2.8 m), and IOPP in intermediate positions (4.3 m +MSL and 3.2 m).

Current peat oxidation CO_2 emissions from the KP, applying the average IPCC (2013) emission factor of 15 t C ha^{-1} yr^{-1} for plantations (Table 1), amount to 4.4 Mt C yr^{-1} for the KP as a whole. Separate emissions from AP, SOPP and IOPP plantation types are 3.2, 0.7 and 0.5 Mt C yr^{-1} respectively. The minimum carbon stock of the KP is 1.6 Gt C, 364 times annual total emission, indicating that major emissions can be expected to continue for decades to come if drainage continues. This emission number excludes the initial peat emission spike following drainage, as well as emissions outside of plantation areas that are caused by the lateral drainage effects of plantations as well as drainage by logging canals in remaining forest. The number also excludes fire emissions; a substantial omission considering that fires on the KP occur almost exclusively within plantation areas (Figure 21). Overall, the assessment of carbon emission can therefore be considered to be very conservative.

Current and future (with continued subsidence) flood risk was calculated using a High Water Level (HWL; Figure 15) that was determined from the level of river banks (RBL) along main tidal rivers (excluding blackwater rivers on the peat dome), and validated against tidal data for the area. The subsidence rate applied to the DTM is 3.5 cm yr^{-1}, which corresponds with the IPCC (2013) emission factor of 15 t C ha^{-1} yr^{-1} for plantations assuming subsidence is caused by peat loss alone (if peat compaction also contributes, subsidence rate would be higher). The difference in elevation between plantation types is expressed in very different flooding regimes. SOPP are often already so low-lying (by 2014) that 39.2% (Table 6) are below HWL i.e. prone to flooding by river water. For AP this is only 5.1 %, whereas for IOPP an intermediate figure of 28.7 % is at risk of flooding. Extending the analysis into the future reveals that in 50 years, the difference between plantation types is still considerable at 74.1, 54.8 and 36.9 % for SOPP, IOPP and AP respectively, whereas after 100 years, 68.1 % of AP, 86.6 of SOPP and 86.9 % of IOPP are at risk of flooding. In the longer term the differences are further reduced as all plantations are expected to flood at some point in the future given the low average position of the peat bottom (around MSL). For *Acacia* plantations, the projection of future flood risk is considered conservative because the actual subsidence rates measured in such areas is found to be around 5 cm yr^{-1}, even at water table depths of 0.7 m on average, which is considered close to ‘best management practice’. For smallholder oil palm plantations, on the other hand, it is possible that subsidence rates in shallow peat with frequent high water levels could drop towards 2 cm yr^{-1}, which would mean that flood risk could increase at a somewhat lower rate than predicted. However this reduction would typically only happen after the flood risk was already high.

The precise flood regime to which areas at risk of flooding are exposed cannot be quantified for lack of local river water level data. But typical river level regimes in the region suggest that these areas may be assumed to be flooded at least every few years, for periods of months in the wet season. This will have an impact on plantation production that will decrease as floods intensify. It is expected that most plantations on the Kampar Peninsula peatland will be economically unviable at some point, but the timing of plantation abandonment is hard to predict as it depends on the mitigation measures taken and also on the tolerance of plantation managers to reduced productivity.

We recommend thorough site investigations and water level data collection to further quantify the current and future risks involved. Nevertheless, based on the current evidence we can conclude that - depending on the location in the terrain – most drainage-based land-use on peatland in the Kampar Peninsula will sooner or later become impossible, as the subsiding land will inevitably become subject to more frequent and prolonged flooding. We suggest that policy makers, businesses and small-holder farmers in Indonesia would be wise to consider peatland subsidence and increased flooding in their economic and land use decisions, as their counterparts do in other parts of the world.

Key Points

- Peatland drainage for agriculture inevitably leads to rapid land surface subsidence and carbon loss, anywhere in the world, often followed by flooding.
- Rates of subsidence and carbon loss in drained peatlands are temperature dependent and are highest in the tropics. Flood risk therefore also increases much faster in tropical drained peatlands that in other parts of the world.
- Water management improvements can somehow, but not greatly, reduce rates of subsidence and carbon loss.
- The peatland of the Kampar Peninsula (KP) is representative of peatlands elsewhere in Southeast Asia; it is dome shaped with a peat base located at or below river and sea flood levels.
- Land surface subsidence caused by plantation drainage on the KP will cause a steady decline in drainability, and eventually in the surface being below river flood levels, resulting in increased flooding.
- Already, 31 % of the plantation area on the KP is probably subject to drainability problems and/or flooding.
- Within 25, 50 and 100 years, 71%, 83% and 98% of the existing plantation area is projected to experience drainability problems and/or flooding.
- This will affect plantation productivity and may result in land abandonment.
- Smallholder OP plantations are first affected by flooding as they are situated at lower elevations closer to the river, whereas *Acacia* pulp plantations tend to be situated at higher elevations where flooding problems will take longer to develop. However the end result for all these plantations will be the same regardless of crop or management type.
- We recommend that land managers and policy makers should consider this increased risk of flooding in their economic and land use decisions.

1 Introduction

Peatlands are wetland ecosystems formed by the accumulation of organic matter from partially decomposed vegetation over thousands of years in waterlogged conditions. As peat is not really a ‘soil’ in the normal sense but an unstable mix of water (90%) and partially decomposed vegetation remains (mostly carbon), it will inevitably disappear through decomposition when the water is drained and the peat exposed to air. Under such conditions, peat will rapidly oxidize and be lost as carbon emissions. These processes have been documented and studied scientifically in peatlands in all regions of the world including Indonesia, with peat oxidation through decomposition recognized as the major contributor to peatland subsidence following drainage (Stephens *et al.*, 1984; Hooijer *et al.*, 2012). Peatland subsidence has created challenges for continued agriculture in all peatland regions because it inevitably leads to a lowering of the land surface that results in a loss of drainability and often increased flood risk. These impacts threaten production and increase the risk that such peatland will be abandoned at some point in the future in an unmanaged degraded state.

These impacts are now of major relevance for Indonesia in terms of determining the most appropriate policies to manage its peatlands. Despite legislation introduced in 1990 to protect much of the country’s peatland with a peat depth deeper than 3m from drainage and development, most peatland in Sumatra and Kalimantan has since been cleared of forest and drained, irrespective of the peat depth, with millions of hectares developed for oil palm and *Acacia* pulp fibre plantations. In association with the expansion of canals and roads that have come with these developments, people have migrated into these sensitive areas, which previously were hardly populated. The earlier use of these peatlands - selective logging using light railway systems that involved no drainage - has been abandoned despite being considered relatively sustainable. The forest loss, fires and flooding that have accompanied these recent developments have had significant environmental and social impacts: on local communities, on businesses, and internationally as a result of haze episodes and globally significant emissions of greenhouse gases. However, the focus of discussion on peatland management has remained on haze and carbon emissions, perhaps in view of the immediate noticeable impacts of the haze and the major policy attention to climate change. The consequences of peatland drainage in terms of land subsidence and increased flood risk have been given very little attention, but will also give rise to considerable societal, economic and environmental impacts.

1.1 This report

This report explores the question: for how long can the drainage-based land-use on the Kampar Peninsula peatlands be continued given the inevitability of the subsidence of peat soil under drainage? It considers the case of the Kampar Peninsula in Riau, Sumatra, a major area of peatland that is the largest and thickest single peat deposit in Indonesia, but which has seen rapid expansion of plantations in recent years.

These findings have implications not just for the Kampar Peninsula but also for national peatland policy with a focus on raised (ombrogenous, rain-fed) peatlands, which are the dominant peatland formation in Indonesia.

Findings are presented as follows:

- **Chapter 2** discusses the historical and global experience with peatland drainage and considers how the problems of peatland drainage – most notably land subsidence - have been studied and the key scientific lessons from this research.
- **Chapters 3 and 4** present a new assessment of the Kampar Peninsula landscape, its peat characteristics and current land use.
- **Chapters 5 and 6** present a projection of the impacts of peatland drainage and subsidence on the peatland morphology of the Kampar Peninsula and future drainability problems and flood risks, as well as carbon emissions.
- In **ANNEXES** we provide detailed descriptions of technical analyses supporting this study.

2 Peat loss, carbon emissions and subsidence rates in drained peatlands

Peatlands in Europe and the USA have been drained for centuries in order to transform these wetlands into drier lands that can be used for agriculture. However, experience globally has shown that peatland drainage creates substantial long-term problems. Most significant are the high rates of land subsidence and subsequent flooding that accompany peatland drainage and that have long been widely accepted in mainstream science (Armentano, 1980; Fowler, 1933; Galloway *et al.*, 1999; Hutchinson, 1980; Lindsay *et al.*, 2014; Prokopovich, 1985; Stephens *et al.*, 1984). Recognition of these problems has broadly led to the end of large-scale peatland conversion to agriculture during the mid to late 20th century in Europe and USA, in some cases followed by costly initiatives to return peatlands to wetlands and reduce emissions and other problems (e.g. Turrini, 1991; Cris *et al.*, 2014).

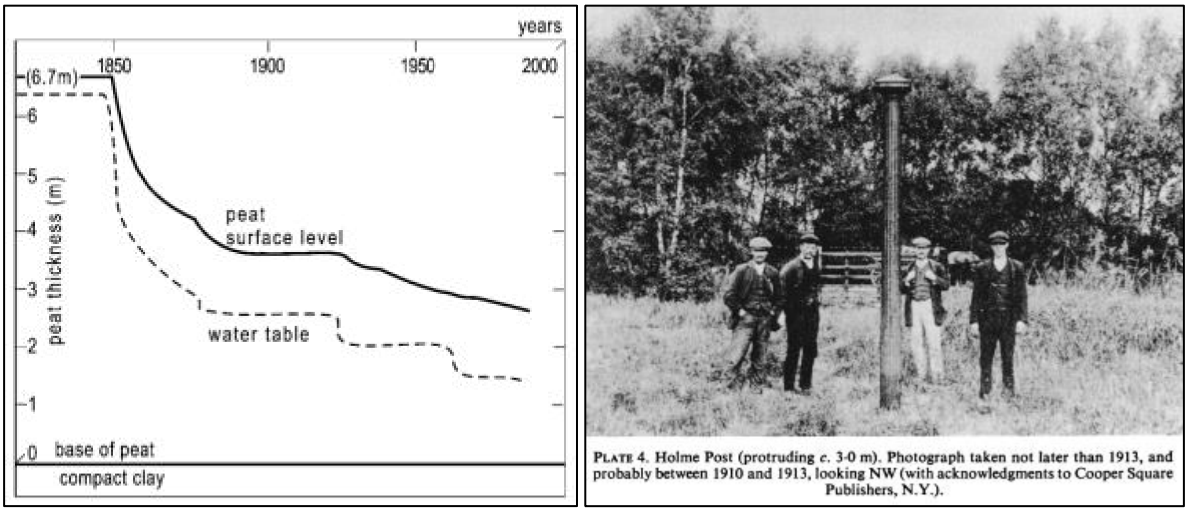

Figure 1 Historical peat subsidence in the UK Fenlands.
Left: Periods of rapid subsidence coincide with periods of major drainage. In recent decades subsidence has slowed down substantially because the land effectively became undrainable and was therefore returned to a state of near-natural water table depths, as pasture (for non-intensive summer grazing) and nature area. **Right:** The subsidence pole at Holme post photographed in 1913; the top of the pole coincides with the original peat surface level. Source: Hutchinson (1980).

2.1 Causes of subsidence after peatland drainage

Subsidence during the initial period following drainage of peatland is mainly due to physical compression but over the longer-term, subsidence is dominated by the biochemical process of peat decomposition through oxidation that causes peat loss and also results in carbon emission to the atmosphere (Stephens and Speir, 1969; Schothorst, 1977; Gambolati *et al*,. 2003; Page and Hooijer, 2014). In fact, the peat loss process is so dominant after the first years beyond drainage that in carbon emission monitoring in Western Europe it is assumed to cause 100 % of subsidence beyond the first few years following drainage (van den Akker *et al.*, 2008), and the same approach has been demonstrated for SE Asia (Couwenberg and Hooijer, 2013). Peat loss through oxidation occurs in drained peatland because the lowering of the water table introduces oxygen into the peat soil, creating oxygen-rich aerobic conditions that stimulate increased microbial activity that breaks down the peat.

2.2 Impacts of peatland subsidence

The parallel loss of peat carbon and of land elevation is inevitable once drainage starts. In a comprehensive review of the subsidence of organic soils globally, Stephens *et al.* (1984) conclude that “even with optimum water-table control for good production, subsidence will continue at an undesirable rate”. Eventually, subsidence often brings the land surface to an elevation where flood risk is high, drainage of excess rain water by gravity is impeded and flooding by river or sea water becomes possible. In extreme cases, such as the Netherlands (Schothorst, 1977; Hoogland *et al.*, 2012; Querner *et al.*, 2012), the Fenlands of the UK (Hutchinson, 1980) or the Sacramento Delta in the USA (Deverel and Leighton, 2010), the land surface may end up below sea level.

2.3 Peat loss after drainage is highest in the tropics and in deep fibric peat

Being driven by biological processes, the long-term rates of subsidence in drained peatlands are strongly dependent on temperature, so that the highest subsidence rates will be found in tropical climates (Stephens *et al.*, 1984; Andriesse, 1988; see Figure 2). In temperate climates, long-term subsidence rates after peatland drainage are typically in the range of 0.5 to 2 cm yr^{-1}, while in the tropics they are in the range of 2 to 6 cm yr^{-1}, with the variation within these climate zones being explained largely by peat type and water table depth. The corresponding long-term carbon emission rates for peatlands drained for agriculture (cropland and industrial plantations) are around 8 t C ha^{-1} yr^{-1} in temperate climates and 14–15 t C ha^{-1} yr^{-1} in the tropics (excluding the emission spike shortly after drainage; Hooijer *et al.*, 2012; Hooijer *et al.*, 2014) as published in numerous scientific papers and summarized by IPCC (2013) and FAO (Page and Hooijer, 2014; Table 1).

In fibric peat in the tropics, extremely high subsidence rates are reported, that amount to metres of elevation loss in the first decades after drainage (Andriesse, 1988; Wösten *et al.*, 1997; Hooijer *et al.*, 2012). This may be attributed to this peat consisting almost entirely of organic material (> 99%), with the mineral component being so limited that no ‘mature’ top layer develops that is more resistant to decomposition. As the chemical and structural characteristics of the top peat layer do not change over time, neither does the rate of peat loss as long as management conditions remain the same.

Some tropical peat, however, has higher mineral content and is more resistant to decomposition. This is typically true in areas of shallow peat, that are often near rivers or that remain where deep peat has largely been oxidized already after decades of drainage. Subsidence rates in such areas are often around 2 cm yr^{-1} (Dradjad *et al.*, 2003; Othman *et al.*, 2011).

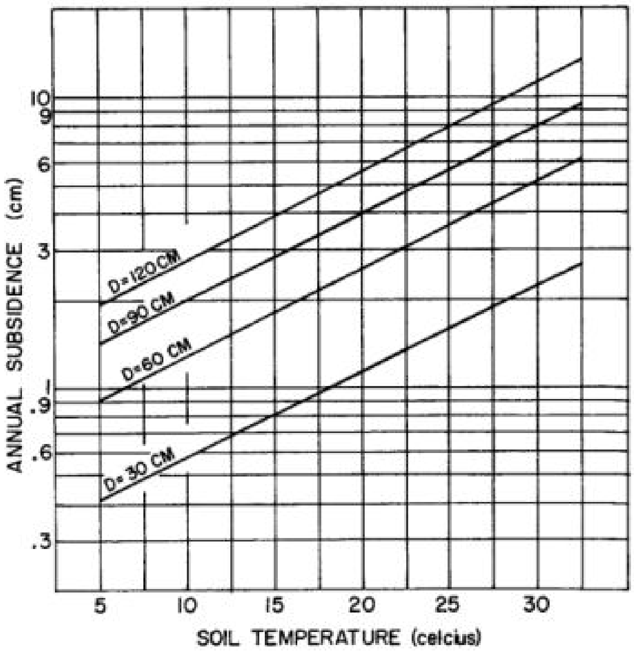

Figure 2 Relation between temperature, water table depth (D) and subsidence rate (from Stephens *et al.*, 1984).

Table 1 Emission factors from drained peatlands as presented in the FAO publication: Towards climate-responsible peatlands management (Page and Hooijer, 2014; summarizing numbers in IPCC (2013) per climate zone). The tropical plantation emission factor is averaged over *Acacia* and oil palm plantations.

			*Unit**	Forest	Shrubland	Grassland	Rice	Cropland	Plantation	General
Boreal	CO_2		1	0.25—0.93	—	5.7	—	7.9	—	—
	DOC		1	—	—	—	—	—	—	0.12
	CH_4	land	2	2—7	—	1.4	—	0	—	—
	CH_4	ditch	2	217	—	527—1 165	—	—	—	—
	N_2O		2	0.22—3.2	—	9.5	—	13	—	—
Temperate	CO_2		1	2.6	—	5.3—6.1	—	7.9	—	—
	DOC		1	—	—	—	—	—	—	0.31
	CH_4	land	2	2.5	—	1.6—39	—	0	—	—
	CH_4	ditch	2	217	—	527—1 165	—	—	—	—
	N_2O		2	2.8	—	1.6—8.2	—	13	—	—
Tropical	CO_2		1	5.3	5.3	9.6	9.4	14	15	—
	DOC		1	—	—	—	—	—	—	0.82
	CH_4	land	2	4.9	4.9	7	143	7	2.7—26.2	—
	CH_4	ditch	2	—	—	—	—	—	—	2259
	N_2O		2	2.4	—	5	0.4	5	1.2—3.3	—

* 1: t C ha^{-1} yr^{-1}; 2: kg ha^{-1} yr^{-1}

2.4 Peat loss is not dependent on water table depth alone

Most studies into peat loss and subsidence after drainage have reported a relation with water table depth, either average annual values in subsidence studies and most CO_2 flux studies, or instantaneous values in a few short-term CO_2 flux studies. Few studies however report correlation co-efficient (R^2) values for this relation that are above 0.5, indicating that there are factors other than water table depth that affect peat loss. This is true for both temperate and tropical peats.

It is thought that peat loss in agricultural areas is affected by a combination of several management factors, including fertilizer application, higher top soil temperature after removal of the original vegetation cover, and greater air entry into the soil after it is disturbed (Jauhiainen *et al.*, 2014). All of these factors enhance bacterial and fungal activity and therefore peat loss. Together, they may have an effect on peat decomposition rates that is as strong as that of water table depth alone. As a result of this, recent studies in drained tropical peatland (Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012; Husnain *et al.*, 2014) report relations with intercepts that suggest substantial peat loss (carbon emission and subsidence) even if the average water table were at the peat surface (Figure 3), while Gandois *et al.* (2013) report substantial impacts of logging on the characteristics of undrained tropical peat, even without any drainage.

The implication is that peat loss in tropical peatland that is used for agriculture will likely always be substantial, even in the hypothetical case that water levels are brought up close to the surface. Subsidence and carbon emission cannot be reduced to negligible rates in any management regime that requires clearing, soil disturbance or fertilization. To reduce peat loss, it is necessary to not only raise water levels but also to reduce these other disturbances.

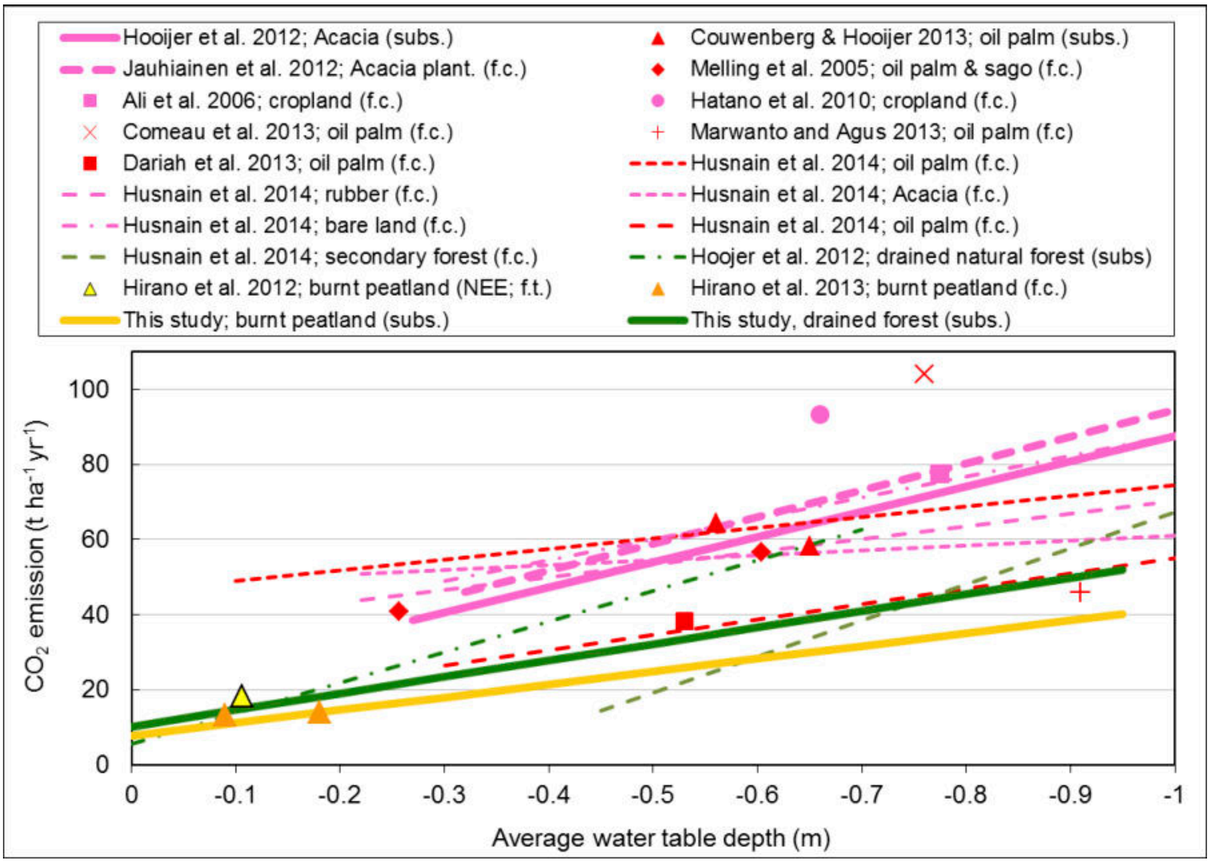

Figure 3 Comparison of relations between average water table depth and CO_2 emission (or carbon loss, in the case of subsidence studies) as determined in other peatlands in SE Asia, mostly Indonesia. From Hooijer *et al.* (2014).

Note: Studies in forest, burnt peatland, oil palm plantations and other types of cropland and plantations are indicated by green, orange, red and purple lines and symbols respectively. The results of subsidence studies are shown as thick solid lines. Results of flux measurements are not corrected for autotrophic ('root') respiration except for Jauhiainen et al. (2012) who reduced total soil emission values by 12% to determine actual heterotrophic respiration caused by peat oxidation, and Hirano et al. (2013) who chose sites with no or little vegetation growth in order to exclude autotrophic respiration.

2.5 Subsidence after drainage remains more or less constant for a long period

Beyond the initial drainage phase, where water table depths are maintained at a constant level relative to the peat surface, the oxic zone above the water table in which peat oxidation occurs moves down through the peat layer as subsidence proceeds (van den Akker, 2008; Couwenberg and Hooijer, 2013). New peat material is therefore constantly added to the oxic zone, which ensures a nearly constant rate of peat oxidation where the peat material is poor in mineral components and predominantly fibric or hemic. Therefore subsidence remains more or less constant during most of the time after drainage within an agricultural setting. The greatest slowdown in subsidence occurs in the first years after initial drainage, as the main cause of subsidence shifts from physical compression and compaction to biochemical oxidation. Extrapolation of future subsidence rates in peatland should therefore be based solely on subsidence data collected during the period of secondary (oxidative) subsidence that does not include the initial period of physical compression and compaction.

A gradual slowdown in subsidence rates, as subsidence results in reduced water table depths, has been well documented in numerous regions including the Netherlands, the UK and the USA as shown in this report. This slowdown is sometimes followed by a rapid acceleration as flooding frequency/duration increases and water levels are lowered by installation of pumped drainage systems. This pattern of slowdown and acceleration has added to the realization, amongst scientists and peatland managers, that the rate of subsidence in drained peat will in fact remain nearly constant in time as long as water table depth remains constant. This is true beyond the initial few years when physical processes dominate subsidence, and up to the final years in situations where the remaining bottom layer of peat has a high mineral content.

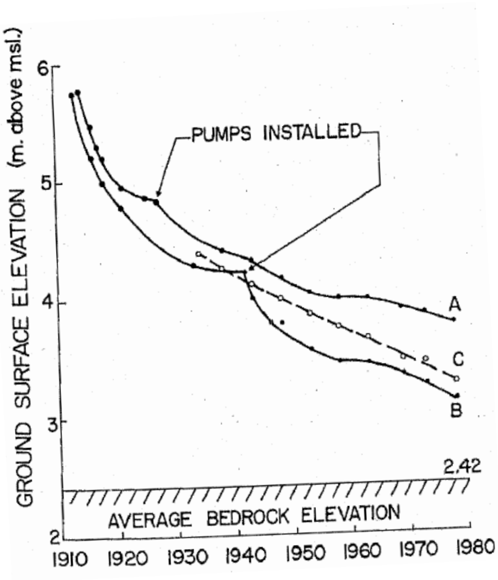

Figure 4 Historical patterns of subsidence in the Everglades, USA, showing the response to water management interventions to lower water levels. The first months of subsidence were not monitored, hence initial subsidence rates are underestimated. The codes A, B and C are separate monitoring locations under different water management. When subsidence caused drainage problems, pumps were installed to lower water levels again, but this resulted in accelerated subsidence and eventually greater drainage problems.

2.6 Peatland water management that maintains a high water table depth can reduce subsidence only by a limited amount

Earlier assessments of the relation between peat loss and water table depth in the tropics (Wösten *et al.* 1997; Hooijer *et al.*, 2010) that were based on limited data suggested intercepts through zero. This implied that carbon emission and subsidence could be reduced substantially by raising water levels, without changing the other causes of peat loss, namely fertilization and disturbance to vegetation cover and the peat surface. In theory, based on the derived relation presented in Hooijer *et al.* (2010), it would thus be possible to reduce peat loss by a third through reducing an average water table depth from 0.75 m (the typical water table depth in *Acacia* plantations on the Kampar Peninsula, Hooijer *et al.*, 2012;

Jauhiainen *et al.*, 2012) to 0.5 m (the highest average water table depth that is possible under best management).

With the benefit of recent studies, it is now clear that the relation between water table depth and peat loss is ‘flatter’ than previously thought. The impact of raising water levels will therefore be less effective; a rise from 0.75 m to 0.5 m would reduce peat loss by only 20% at most (Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012), not 33% as would be the case if the slope intercept were through zero.

These quantitative assessments make clear that improved water management in drained plantations can only reduce subsidence by a limited amount, probably not much more than 20 % (compared to ‘business as usual’) in *Acacia* or oil palm plantations as both crops need a relatively deep water level for adequate growth.

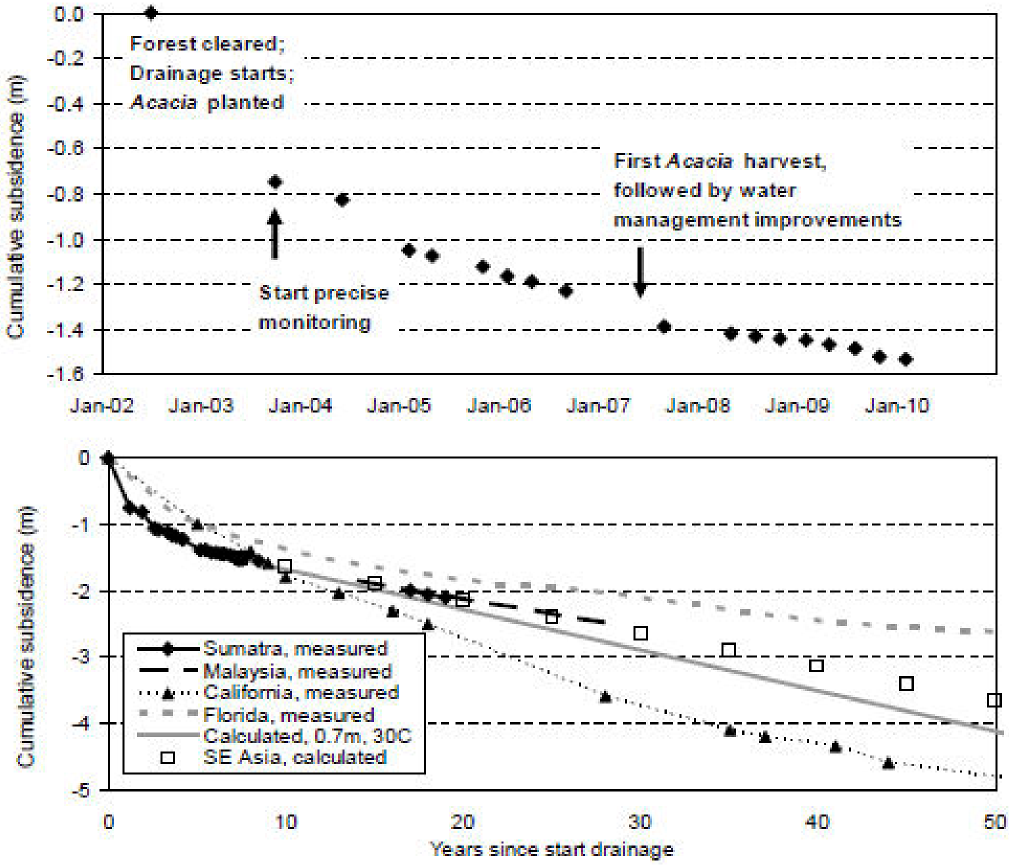

Figure 5 Subsidence rates in tropical and sub-tropical peatlands (from Hooijer *et al.*, 2012).
Top: Average subsidence rates as measured at 14 locations in *Acacia* plantations on the Kampar Peninsula, over the first 9 yrs after drainage. It should be noted that measurements started after canals had been constructed and drainage started, so in fact this graph underestimates total subsidence since the start of drainage (the same is true for measurements in the Everglades, see bottom graph). **Bottom**: as measured at a larger number of drained peatland locations in Sumatra, Malaysia (from Wösten *et al.*,1997, based on DID Malaysia 1996), Mildred Island in the California Sacramento Delta (Deverel and Leighton, 2010) and Florida Everglades. The Everglades record is averaged from three records presented by Stephens and Speir (1969); as the first two years after completing the drainage system in 1912 were missing from the subsidence record, which started in 1914, we added a subsidence of 22.5 cm yr^{-1} for those years, which is the average subsidence rate over 1914 and 1915 and therefore almost certainly an underestimate of actual initial subsidence. Also shown are long-term calculated subsidence rates for SE Asia, applying both the relation determined for Florida Everglades (Stephens *et al.*, 1984), assuming a water depth of 0.7 m and an average temperature of 30 ° C, and the relation found for SE Asia in this paper.

Couwenberg and Hooijer (2013) summarised published subsidence rates for relevant studies in SE Asia and find an average subsidence rate of 4.1 cm yr^{-1} (Table 2). The subsidence rates for the Kampar Peninsula ('this study' in Table 2 based on Hooijer *et al.*, 2012) show that even at water table depths of 50-70 cm in line with best practice management prescriptions, subsidence rates of 4-5 cm yr^{-1} can be expected.

Table 2 Published subsidence rates and derived carbon emissions in SE Asia. From Couwenberg and Hooijer (2013). This study refers to subsidence measurements on the Kampar Peninsula.

Reference	Land use	Years since drainage / measuring duration (y) / no. of measurement sites	Water table depth (m)	Subsidence rate ($cm\ y^{-1}$)	Volumetric C density ($g\ cm^{-3}$)	Calculated C loss ($t\ ha^{-1}\ y^{-1}$)
DID & LAWOO (1996)	OP (Phase I)	> 12 / 17–21 / 16	-	2.7	0.042[1]	12.0
	OP (Phase II)	> 28 / 4 / 10	0.53	3.8	0.042[1]	16.0
Maswar (2011)	OP	> 15 / 1.2 / 5	0.60	5.0	0.041[2]	20.4
Othman *et al.* (2011)	OP	2–6 / 7–8 / 2–10	0.41	4.5	0.044[3]	19.8
This study	*Acacia* (6A)	3–8 / 2 / 125	0.70	5.0	0.041[4]	20.3
	OP (5OP)	4–7 / 3 / 29	0.56	3.9	0.045[4]	17.6
	OP (19OP)	15–20 / 3 / 42	0.65	3.7	0.043[4]	15.9
Overall mean			0.58	4.1	0.042	17.4

[1] DBD (0.07 $g\ cm^{-3}$) and C concentration (60 %) from the same area (Salmah *et al.* 1992).
[2] Assumed DBD 0.08 $g\ cm^{-3}$ and C concentration 51 %; DBD from auger samples (~0.01 $g\ cm^{-3}$) discarded.
[3] Assumed DBD 0.08 $g\ cm^{-3}$ and C concentration 55 %; Othman *et al.* (2011) report DBD and C concentration of the upper peat only.
[4] Assumed C concentration of 55 %.

Note: This table excludes data from shallow peat (< 1.6 m), peat with high mineral content (> 5 %), subsidence records < 1 year long and areas that were (potentially) drained < 3 years ago. It therefore reflects the best measurements available for deep fibric peat that is found on the Kampar Peninsula and most other large peat domes in Indonesia.

2.7 Likely implications for the Kampar Peninsula

The SBSMP project used the results of subsidence monitoring and other data to define the likely impacts of peatland drainage and subsidence on peat drainability in plantations on the Kampar Peninsula (Figure 6). The tentative conclusions of this projection, that were at the time approved by APRIL (who manage the largest plantation extent on Kampar Peninsula), were reported as follows (Hooijer *et al.*, 2008):

"*For this location, which appears to be representative for many other plantations in Pelalawan in terms of peat depth and drainage gradient, it was found that up to 2.5 m subsidence can be sustained before the area will become undrainable and less suitable for plantations. Note that 1.4 m of subsidence has already occurred here, within 6 years, as water management practice in these plantations has been well below 'APRIL best practice'; dams are now being constructed to bring up water levels to target range and to reduce subsidence.*

The following tentative conclusions were drawn on expected plantation drainability lifespan:

- *About 25 years if water management continued as up to 2006 (previous water management target).*

- *About 50 years if water management on current (new, 2007) target [of 0.7 m on average] and subsidence reduced to 5 cm/y (on average; more in first years, less in later years). Additional water management measures would be required within 25 years; drainage to 1 m below the 'free' gravity drainage limit would be possible through construction of dikes and flap-gates that will keep out tidal waters.*
- *A plantation drainability lifespan over 50 years requires a further reduction of subsidence rate by raising water levels above the current target [of 0.7 m]. This may require use of alternative pulp wood species that are more tolerant to high water levels.*

In short, peatland drainage for *Acacia* was identified to be an unsustainable production system that would likely encounter drainability and flooding issues within decades. The SBMSP project proposed new targets for water management, making clear that these could somewhat extend the lifetime of the plantation but not make it sustainable in the longer term.

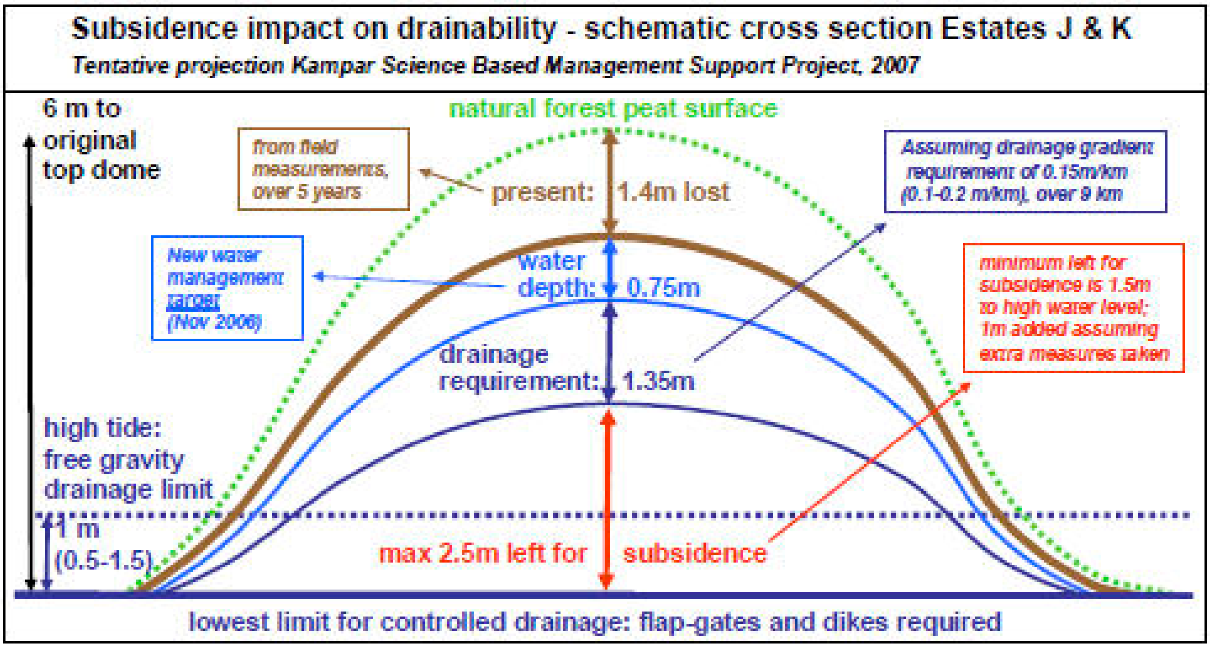

Figure 6 Subsidence impacts on drainability in schematic cross section through Estates J and K (in Pelalawan), in APRIL Acacia plantations. From Hooijer *et al.* (2008). Note that this projection was created with APRIL to define the problem scope and the degree to which it was expected that the rate of subsidence and flood risk increase could realistically be reduced by improved water management.

3 Landscape morphology and peat characteristics of the Kampar Peninsula

The Kampar Peninsula is probably the largest peat dome landscape in Sumatra and Kalimantan, and must count as one of the greatest single peat and peat carbon deposits not only within the tropics but also globally. This chapter describes the area in the context of understanding the likely long-term impacts of drainage.

3.1 Elevation model

For this study, we have constructed an elevation model as explained in Annex B, from LiDAR and SRTM data. The resulting elevation map is shown in Figure 7. Figure 8 presents the elevation distribution in the study area determined from the LiDAR DTM shown in Figure 7.

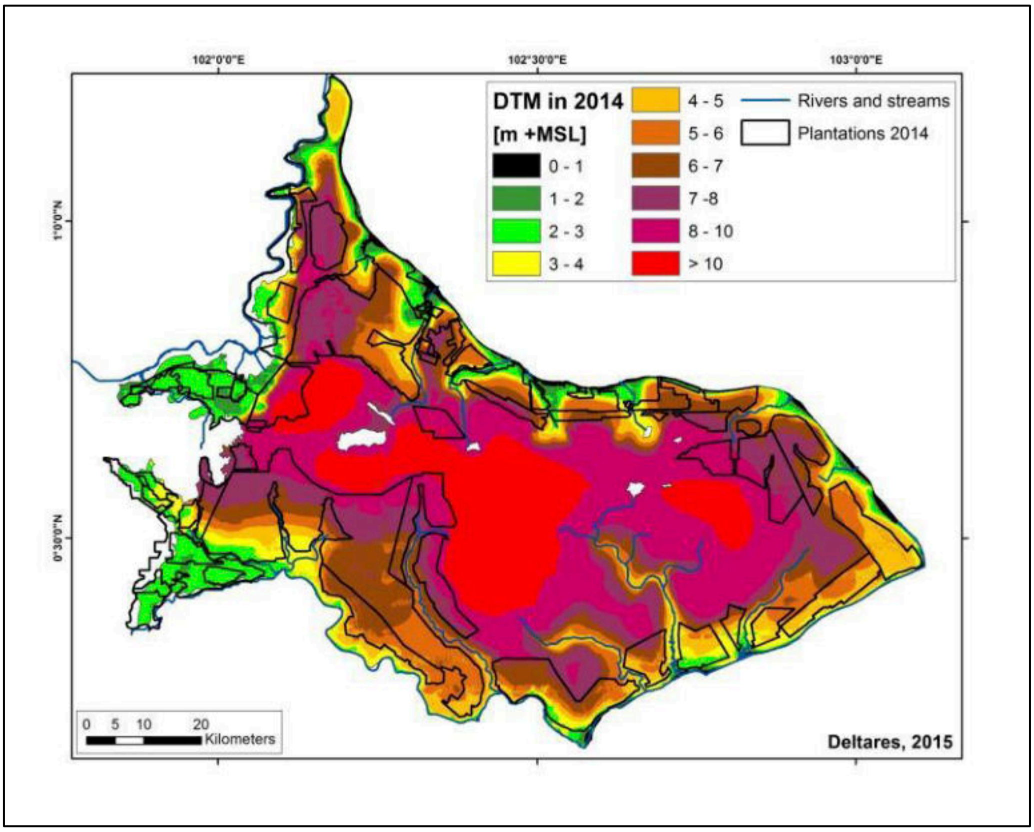

Figure 7 Elevation map for the Kampar Peninsula (see Annex B for explanation). Shown as well are the plantations (black line).

From the elevation distribution shown in Figure 8 and Table 3 we can see that most of the oil palm plantations are located on peat with the lowest elevations, with 48.4 % and 64.1 % of industrial and small holder oil palm plantations, respectively located on land less than 3 m +MSL while for *Acacia* plantations this is much less at 7.8 %. The majority (58.1 %) of the *Acacia* plantations are located on land with peat surface elevations more than 6 m +MSL, while only*Acacia* plantations exist on elevations more than 10 m +MSL.

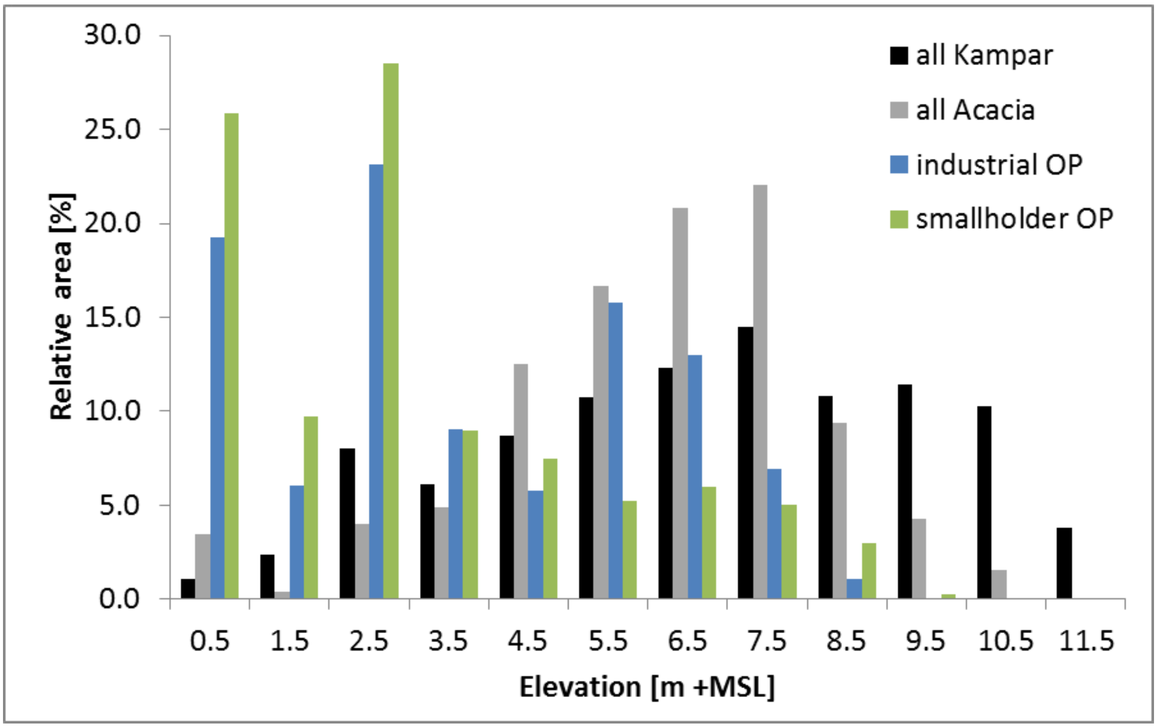

Figure 8 Relative distribution of surface elevation in the LiDAR-derived DTM, for the whole Kampar study area (black bars), as well as for all Acacia plantations (grey bars) and industrial (blue bars) and small holder (green bars) oil palm plantations.

Table 3 Elevation characteristics of LiDAR-derived DTM for the whole study area, as well as for all *Acacia* plantations and industrial and small holder oil palm plantations.

Elevation characteristics	Whole study area	*Acacia* plantations	Industrial OP	smallholder OP
Mean [m]	6.8	6.4	4.3	3.7
% <2 m	3.4	3.8	25.3	35.6
% <3 m	11.4	7.8	48.4	64.1
% <4 m	17.5	12.7	57.5	73.0
% <6 m	36.9	41.9	79.1	85.8
% <8 m	63.7	84.8	99.0	96.8
% <10 m	85.9	98.4	100.0	100.0
% <12 m	100.0	100.0	100.0	100.0

3.2 Peat thickness of the Kampar Peninsula

The elevation model shown in Figure 7 has been used to create a map of minimum peat thickness, by assuming a uniform peat basal depth of 2 meters above sea level (+ MSL).[1]

[1] The full method used in this minimum peat thickness analysis will be published separately in 2016.

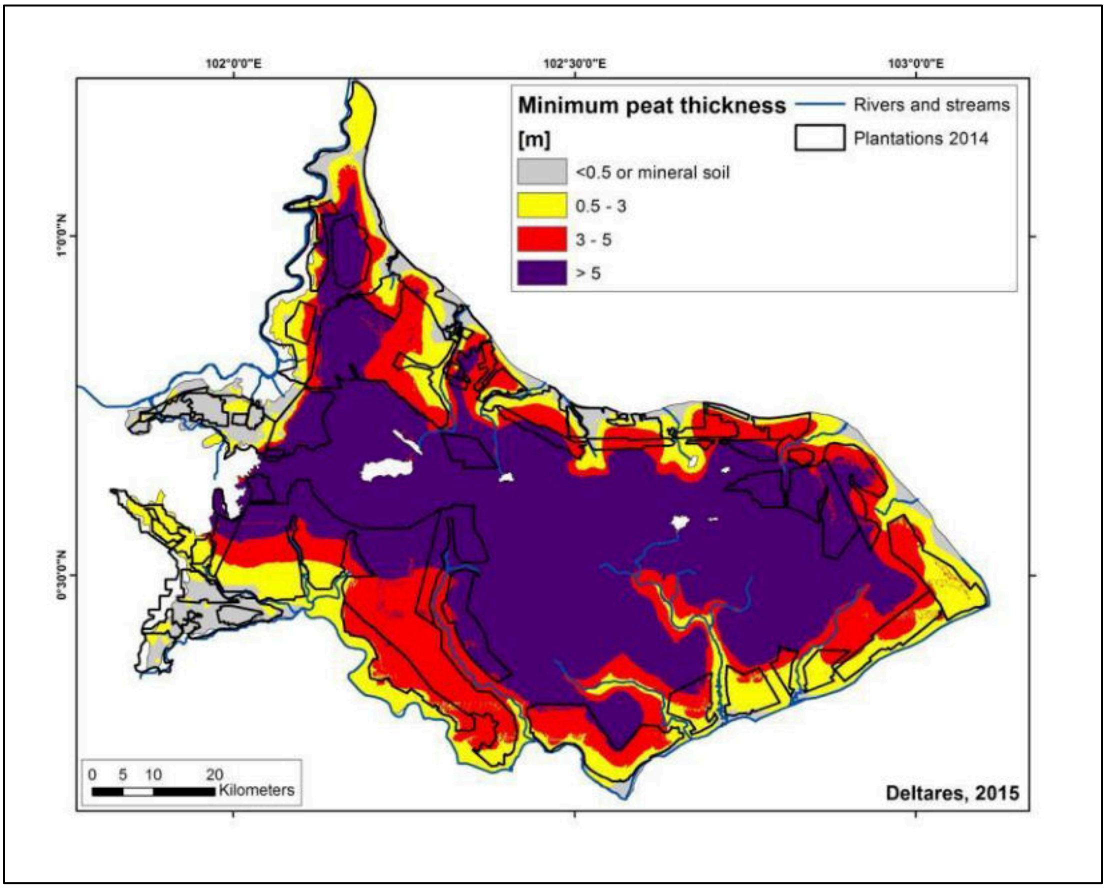

Figure 9 Map of minimum peat thickness for the Kampar Peninsula as derived from the elevation model shown in Figure 7 and an assumed peat base (i.e. elevation where the peat overlies the mineral soil) at 2 m above mean sea level (MSL) (see Annex C for explanation). Shown as well are the plantations (black line).

Figure 10 shows that while patterns in the shape of the peat base may exist for smaller areas, no such shape is evident for the Kampar Peninsula as a whole. A horizontal peat basal surface is therefore the best approximation. Assuming a peat base at 2 m +MSL is justified by the finding that for 99.0% of the 577 peat thickness measurements available to us for the Kampar Peninsula, the peat base is below 2 m +MSL (Figure 10, Table 11 in Annex C). In fact, the peat base was below MSL for 71.2 % of measurements. Therefore, the minimum peat map underestimates peat thickness by several metres. This underestimation is even greater if we account for the fact that peat thickness measurements in the field tend to systematically underestimate actual peat thickness; the most common error is that the bottom is often assumed to be reached when the auger gets stuck in wood that is in fact above the true base of the peat deposit.

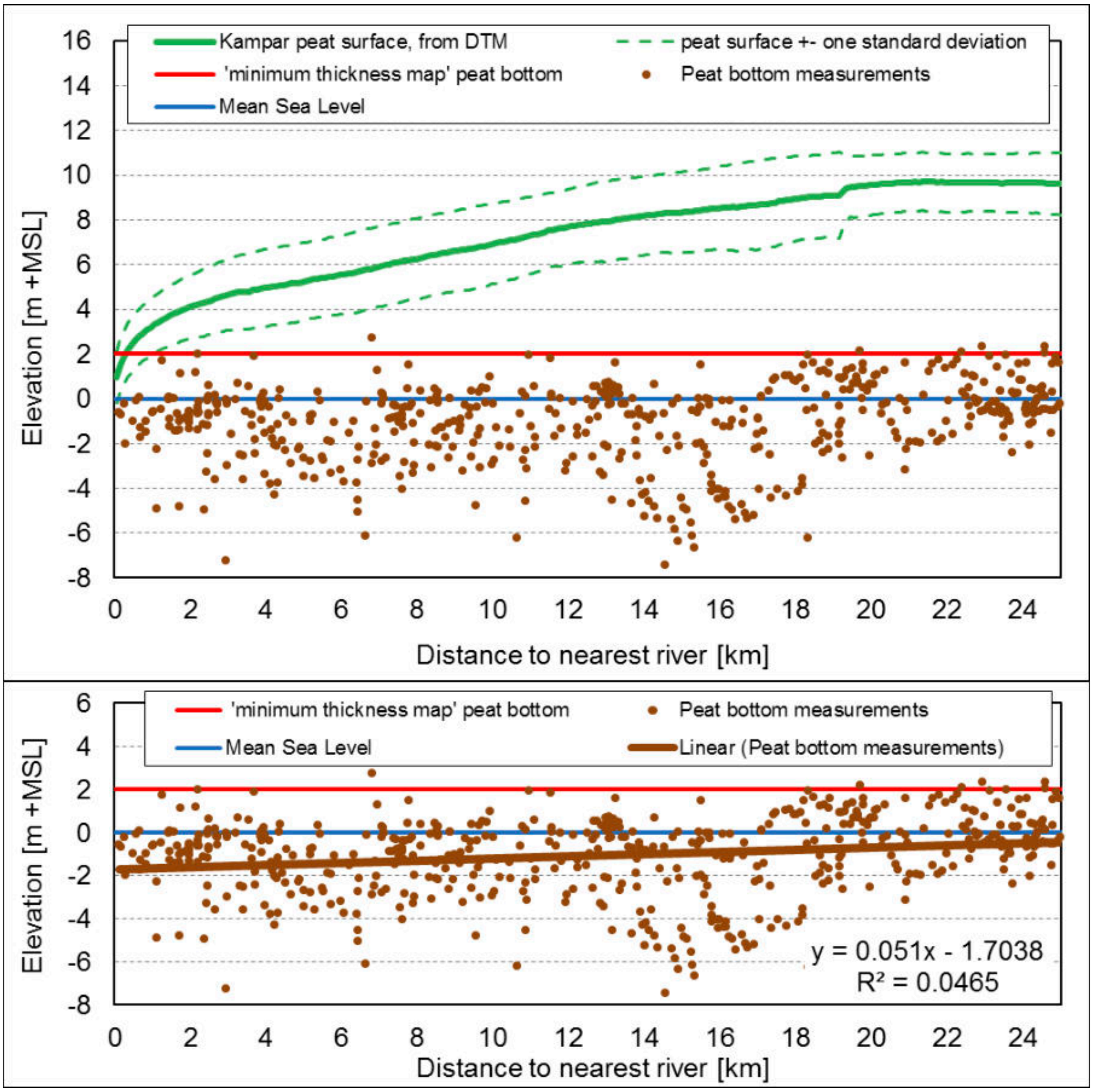

Figure 10 Average peat surface elevation and peat base cross sections through the Kampar Peninsula, showing that the Kampar Peninsula's basal mineral soil layer lies below gravity drainage level, and usually even below mean sea level (MSL).

Table 4 shows minimum peat thickness conditions in plantations on the Kampar Peninsula. It is evident that most of the Kampar Peninsula (73.8 %) consists of peat over 3 m minimum thickness, and 50.8 % and 25.5 % of the area is over 5 m and 7 m thickness respectively. At least 62.7 %, 29.5 % and 4.2 % of the total plantation area is on peat over 3 m, 5 m and 7 m respectively. For *Acacia* plantations these percentages are 77.2 %, 38.5 % and 6.0 %.

For comparison existing peat extent and thickness maps for the Kampar Peninsula study area are presented in Figure 11.

Table 4 Minimum peat thickness in existing plantations on the Kampar Peninsula. *Note: Total areas as presented here differ from other tables since calculations are done on a grid of 100 x 100 m and do not exactly cover the vector boundary lines.*

Area	Total area [ha]	Min. peat thickness class: 0.5 - 3 m [ha]	[%]	3 - 5 m [ha]	[%]	5 - 7 m [ha]	[%]	>7 m [ha]	[%]	average min. peat thickness [m]
Kampar Peninsula whole	678058	124325	18.3	156174	23.0	171426	25.3	172921	25.5	4.86
All plantations	305023	70253	23.0	101214	33.2	77106	25.3	12922	4.2	4.15
All *Acacia* plantations	211394	42224	20.0	81899	38.7	68617	32.5	12768	6.0	4.47
All OP plantations	93629	28029	29.9	19315	20.6	8489	9.1	154	0.2	2.96
industrial *Acacia* plantation (APP & affiliated)	52829	15470	29.3	19117	36.2	17425	33.0	94	0.2	4.07
industrial *Acacia* plantation (APRIL & affiliated)	158565	26754	16.9	62782	39.6	51192	32.3	12674	8.0	4.61
industrial oil palm plantation	35767	9562	26.7	12139	33.9	3352	9.4	0	0.0	3.2
smallholder oil palm plantation	57862	18467	31.9	7176	12.4	5137	8.9	154	0.3	2.76

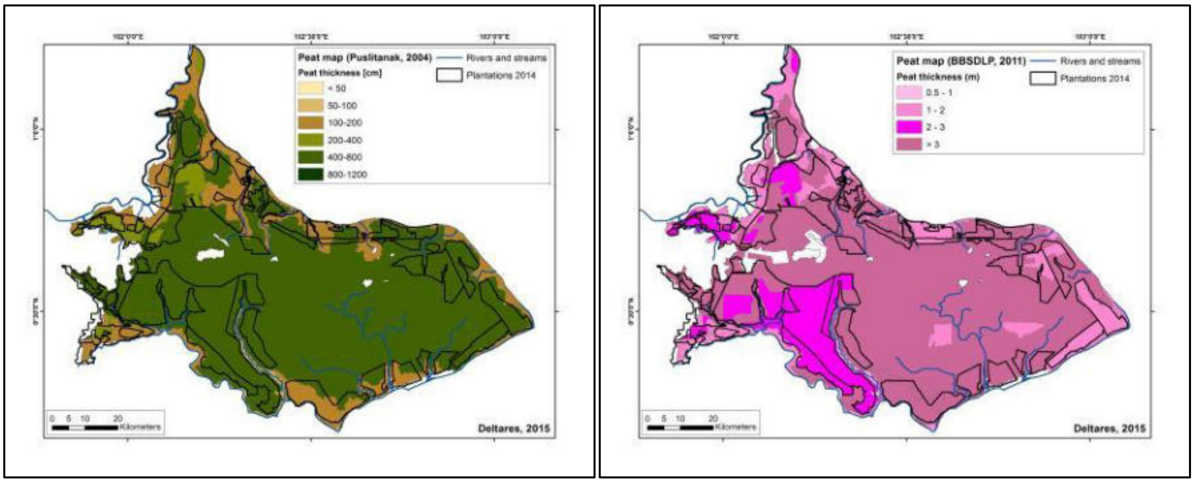

Figure 11 Existing peat extent and thickness maps for the Kampar Peninsula study area. (LEFT) Puslitanak map of 2004 and (RIGHT) BBSDLP map of 2011.

We have also tentatively created a map of more likely peat thickness (Figure 12), by assuming the peat base is at 1 m below MSL as we find to be true for the Kampar as a whole (Table 11). This map provides a better idea of the total peat stock of the area. However, we advise using only the minimum peat thickness map in further assessments, for two reasons. First, the peat stock below mean sea level, and probably below high tide level (which roughly corresponds with 2 m +MSL) is not available to oxidation (as it will always be waterlogged) and therefore is not relevant to carbon emission projections; predictions of future emissions that use total peat stock usually overestimate emissions. Second, any peat thickness map using an assumed constant peat basal level, while being useful for large-scale mapping, should be improved with local data to create a map that is suitable for detailed land use planning.

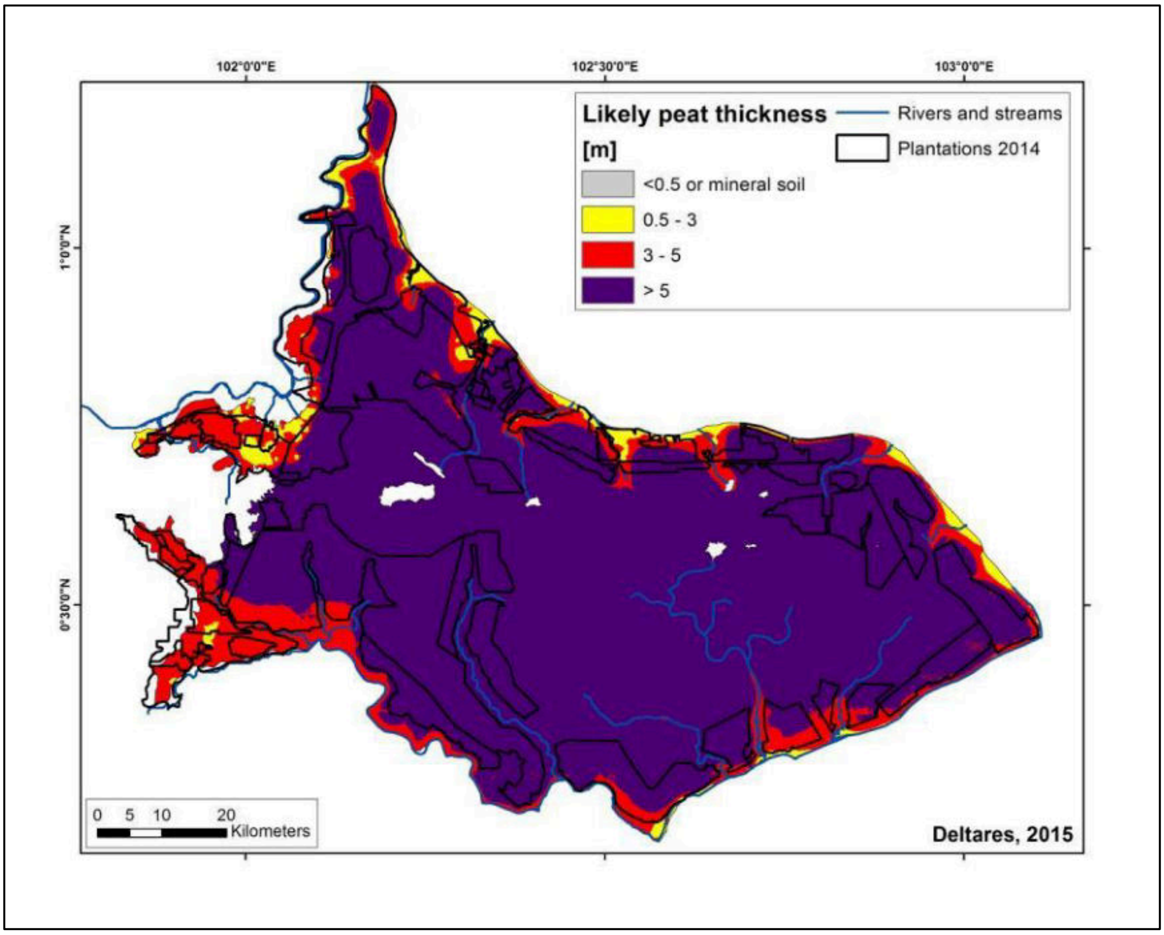

Figure 12 Map of likely peat thickness for the Kampar Peninsula as derived from the elevation model shown in Figure 7 and an average peat base (i.e. elevation where the peat overlies the mineral soil) at 1 m below mean sea level (MSL) (see Table 11). Shown as well are the plantations (black line).

3.3 Peat characteristics

The peat of most of the Kampar Peninsula is highly fibric in nature, as are most peatlands in SE Asia (Page *et al.*, 2011). Bulk density of such peat is only around 0.075 g cm^{-3} and ash content is below 1 % (Hooijer *et al.*, 2012). This means that as organic material is lost from the dried out peat surface, there is no mineral residue that can accumulate to cause the top peat layer to 'mature' in time as is the case for peat with higher mineral content. In such conditions, peat loss and subsidence rates will remain constant as long as water table depth below the peat surface is constant, as explained in this report.

4 Land use on the Kampar Peninsula

We have determined the area of *Acacia* and oil palm plantations on the Kampar Peninsula as explained in Annex A. The total area covered by *Acacia* (HTI) concessions in 2014 is 292,659 ha or 43.4 % of the Kampar Peninsula peatland area (applying the peat extent mapped by Wahyunto *et al.*, 2003; Table 5). The total area covered by industrial-scale oil palm concessions is 73,498 ha, or 10.9 % of the Kampar Peninsula peatland area. Combined, industrial plantation concessions cover 54.3 % of the Kampar Peninsula peatland area. Most of this area, but not all, has already been developed into plantations, i.e. cleared, drained and planted.

It was found that 62 % (182,625 ha) of HTI concessions (using the MoF 2010 concession data; Table 5) was converted to plantation by 2014 (i.e. the land had a drainage pattern consistent with a productive plantation as seen in 2014 Landsat images). For APRIL and APP plantations, these numbers are 60 % (131,965 ha) and 70 % (50,661 ha) respectively. APRIL has a far greater concession area on the Kampar Peninsula than APP (220,061 ha versus 72,598 ha; MoF 2010 numbers).

An additional 28,331 ha of apparently productive *Acacia* plantations were delineated outside the 2010 MoF concession boundaries (26,123 ha by APRIL, 2,208 ha by APP; concessions with white numbers as shown in Figure 13). This brings the total 2014 area of productive *Acacia* plantations on the Kampar Peninsula to 210,957 ha, of which 158,088 ha (74.9 %) is managed by APRIL and 52,869 ha (25.1 %) by APP (Table 5).

The drained oil palm plantation area covered 83,270 ha in 2014, of which 41.9 % was attributed to industrial-scale plantations (judging from drainage patterns) and 58.1 % to smallholder plantations (but potentially associated with industrial estates). 62.9 % (52,361 ha) of the oil palm production takes place within the official MoF 2010 concession boundaries, and 30.7 % outside (Table 5). On the Kampar Peninsula, oil palm plantations tend to be nearer to rivers than *Acacia* plantations, and are therefore at lower elevations (Figure 8) and on the shallower peat (Table 4).

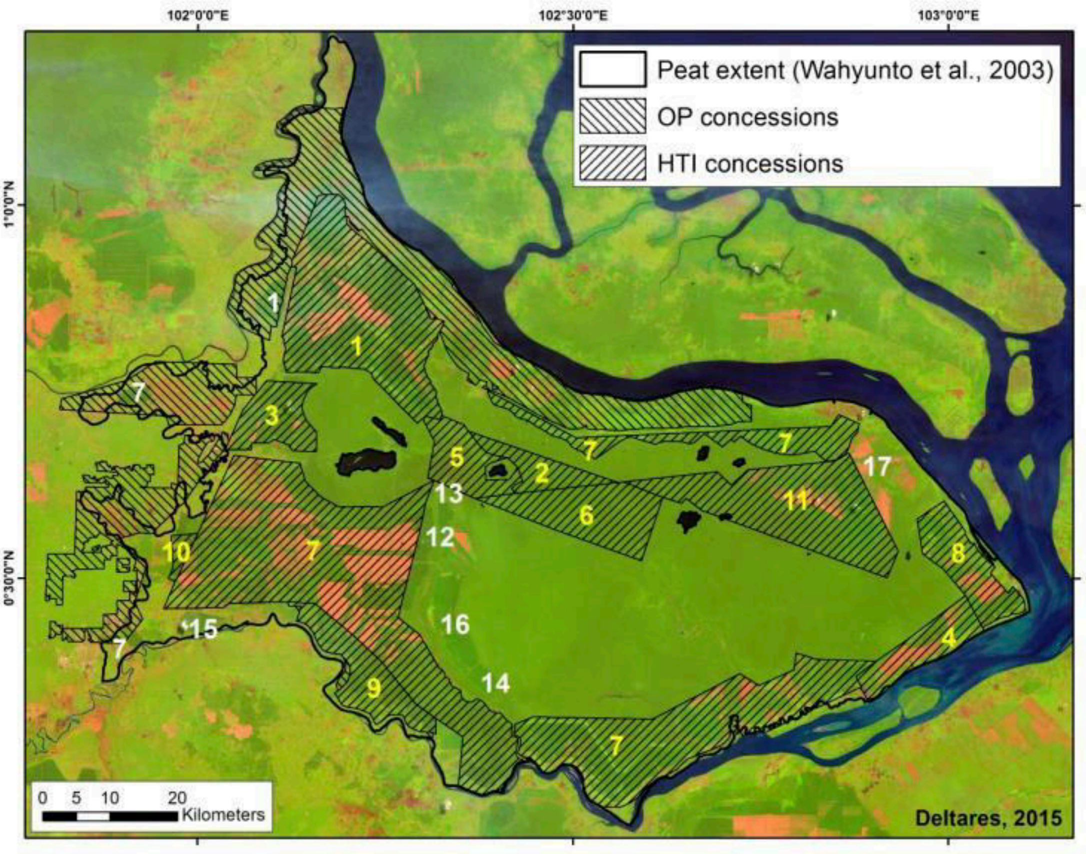

Figure 13 Map of *Acacia* and oil palm plantation concessions, used as input to the analysis. Note that concession boundaries crossing the KP study area boundary (as defined by the peat extent of Wahyunto *et al.*, 2003) are shown here but are excluded in the areas shown in Table 10 (Annex A). Concessions outside the KP are not shown on this map. It should also be noted that the concession boundaries available to us in this analysis are from the Ministry of Forestry (MoF) 2010 map as also used in the WACLIMAD and QANS projects (Mawdsley *et al.,* 2013) and are not complete; they exclude a number of concessions listed in Table 10 (Annex A), that were identified from additional maps listed in Annex E. Numbers shown on the map correspond with HTI concessions listed in Table 10 (Annex A). Yellow numbers for concession boundaries from the MoF 2010 map, white numbers at approximate locations of concessions derived from other sources listed in Annex E.

Table 5 Current (2014) HTI (*Acacia*) and oil palm concession and land use areas on the Kampar Peninsula and derived statistics from comparison with the official MoF 2010 concession boundaries. Where comparison with official MoF 2010 concession boundaries was not possible this is indicated by n.a. (not applicable). Number (No.) in table corresponds with the number shown on the map in Figure 13.

No.	Ownership / Affiliation	Concession	Concession area on peat according to GIS data [ha]	Drained area concession [ha]	Drained area inside concession [ha]	Drained area outside concession [ha]	Drained area as % of total concession
		MOF 2010 HTI licenses (*Acacia*)					
1	APP	PT. Arara Abadi	44963	34562	33453	1109	77
2	APP	PT. Balai Kayang Mandiri	6352	0	0	0	0
3	APRIL	PT. Ekawana Lestari Darma	9485	7430	6721	709	78
4	APP	PT. Mitra Hutani Jaya	9538	6807	6646	161	71
5	APRIL	PT. National Timber and Forest Product	9240	3025	3023	2	33
6	APRIL	PT. Putra Riau Perkasa	16594	0	0	0	0
7	APRIL	PT. Riau Andalan pulp & paper	137989	96952	94136	2816	70
8	APP	PT. Satria Perkasa Agung Unit Serapung	11745	9291	9118	173	79
9	APRIL	PT. Selaras Abadi Utama	12496	8949	7847	1102	72
10	APRIL	PT. Tuah Negeri	1492	2384	1357	1027	160
11	APRIL	PT. Uniseraya	32765	13225	12860	365	40
		Subtotal (APP)	**72598**	**50661**	**49218**	**1443**	**70**
		Subtotal (APRIL)	**220061**	**131965**	**125943**	**6021**	**60**
		Total (MOF 2010 licenses)	**292659**	**182625**	**175161**	**7465**	**62**
		outside MOF 2010 HTI licenses (*Acacia*)					
1	APP	PT. Arara Abadi	n.a.	2208	n.a.	n.a.	n.a.
7	APRIL	PT. Riau Andalan pulp & paper	n.a.	2061	n.a.	n.a.	n.a.
12	APRIL	CV. Alam Lestari	n.a.	14922^	n.a.	n.a.	n.a.
13	APRIL	CV. Bhakti Praja Mulia	n.a.	0#	n.a.	n.a.	n.a.
14	APRIL	CV. Harapan Jaya	n.a.	0#	n.a.	n.a.	n.a.
15	APRIL	CV. Mutiara Lestari	n.a.	1538	n.a.	n.a.	n.a.
16	APRIL	PT. Madukoro	n.a.	0#	n.a.	n.a.	n.a.
17	APRIL	PT. Triomas FDI	n.a.	7602	n.a.	n.a.	n.a.
		Subtotal (APP)	**n.a.**	**2208**	**n.a.**	**n.a.**	**n.a.**
		Subtotal (APRIL)	**n.a.**	**26123**	**n.a.**	**n.a.**	**n.a.**
		Total (*Acacia* outside MOF 2010 licenses)	**n.a.**	**28331**	**n.a.**	**n.a.**	**n.a.**
		oil palm plantations					
		Subtotal (industrial oil palm)	**n.a.**	**34875**	**24159**	**10717**	**n.a.**
		Subtotal (smallholder oil palm)	**n.a.**	**48395**	**28202**	**20192**	**n.a.**
		Total (oil palm)	**73498**	**83270**	**52361**	**30909**	**n.a.**

^includes area of concession No. 13, 14 and 16.
#Area included in area of concession No. 12.

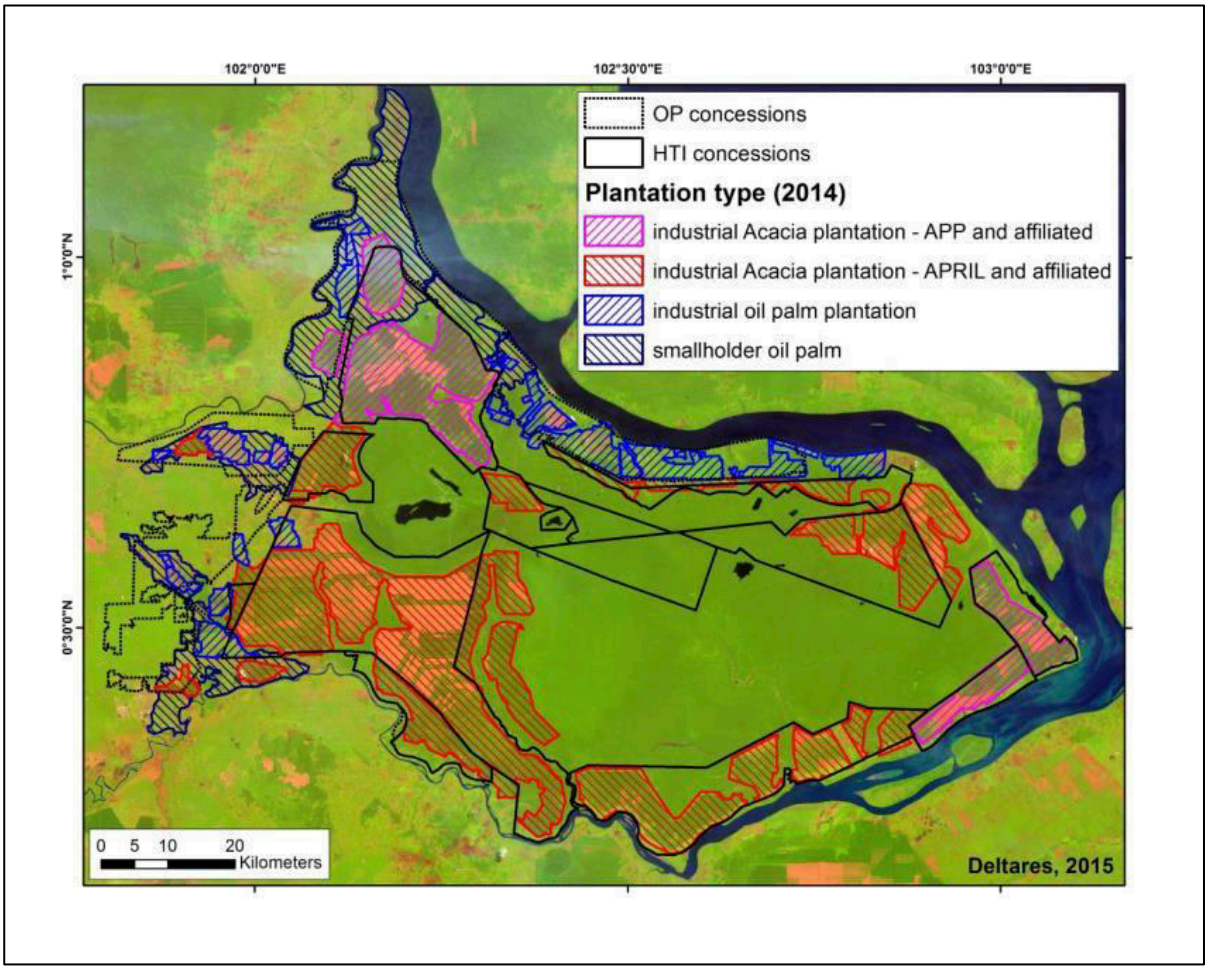

Figure 14 Current (2014) extent of *Acacia* and oil palm plantations on the Kampar Peninsula, and MoF 2010 concession boundaries.

5 The potential impact of drainage on subsidence and flood risk on the Kampar Peninsula

Peatland drainage leads to peat loss that not only generates significant loss of carbon and, hence, high emissions of greenhouse gases but through land subsidence will also lead to flooding and the forced ending of production systems with gravity-based drainage. This future for drained peatlands is inevitable as Section 2 of this report explains. What is less clear is the time period over which these impacts will occur, which requires detailed analysis for individual peatland landscapes. This section of the report presents a new analysis of the likely future impacts of drainage on subsidence, flood risk, fire risk and carbon emissions. We use the elevation model and peat map presented in Section 3 and apply subsidence rates to project the likely impact of current drainage on future drainage problems and flood risk.

5.1 Landscape scale subsidence and flood risk assessment

The analysis presented here applies observed subsidence rates across the Kampar peatland landscape to project the extent and timing of potential drainability and flooding issues within industrial *Acacia* plantation and oil palm concessions as well as areas identified as smallholder oil palm.

5.1.1 Landscape scale subsidence model

Annual subsidence rates have been applied to the elevation model presented in Section 3 with the conservative assumption that only industrial plantations and smallholder oil palm areas would be affected by drainage and subsidence, i.e. the subsidence that takes place in areas outside plantations that are also affected by plantation drainage is not included in the analysis.

It should be noted that the hydraulic conductivity of the Kampar Peninsula peat is extremely high, at between 50 and 200 m d^{-1} according to different analysis approaches and datasets (Hooijer *et al.*, 2009). In combination with the great depth of this peat, this means that the drainage impact of canals extends over long distances (up to several kilometers; DID Sarawak 2001; Hooijer *et al.*, 2012). By only accounting for impacts within plantation boundaries and not around them, we are therefore substantially underestimating overall impact of drainage on the Kampar Peninsula.

We have applied both a ‘Business As Usual’ subsidence rate of 5 cm yr^{-1} as was measured in *Acacia* plantations on the Kampar Peninsula (Table 2), and a lower ‘Best Management Practice’ subsidence rate of 3.5 cm yr^{-1} that is likely to be the best achievable outcome of best practice management. The outcomes of calculations applying these two subsidence rates thus present the ‘business as usual’ and ‘best practice minimum’ scenarios for future flood risk and production loss.

5.1.2 Flood risk calculation

As the peatland surface subsides, it will eventually reach a point where flooding will occur. Flood risk was assessed by determining the area of peatland that lies below two elevation thresholds (see also Figure 15):

1) High Water Level (HWL) - This is the level at which flooding by river water becomes possible and is represented by a single elevation threshold across the whole landscape. The HWL is associated with a high likelihood of flooding and the most severe threshold defined;
2) Free Drainability Limit (FDL) – This is the level at which subsidence across the landscape lowers the drainage gradient to rivers to a point that gravity-based drainage becomes problematic and so is associated with less severe flooding impacts than HWL. For any point on the peatland the FDL is located at a higher elevation than the HWL and is defined by a 0.2 m km^{-1} conveyance gradient from the HWL at the river (DID Sarawak 2001; Hooijer *et al.*, 2015) plus 50 cm for crop requirements. The difference between HWL and FDL therefore gradually increases from the river to the interior of the peatland.

The levels for HWL and FDL that were applied in this analysis are presented in Annex D.

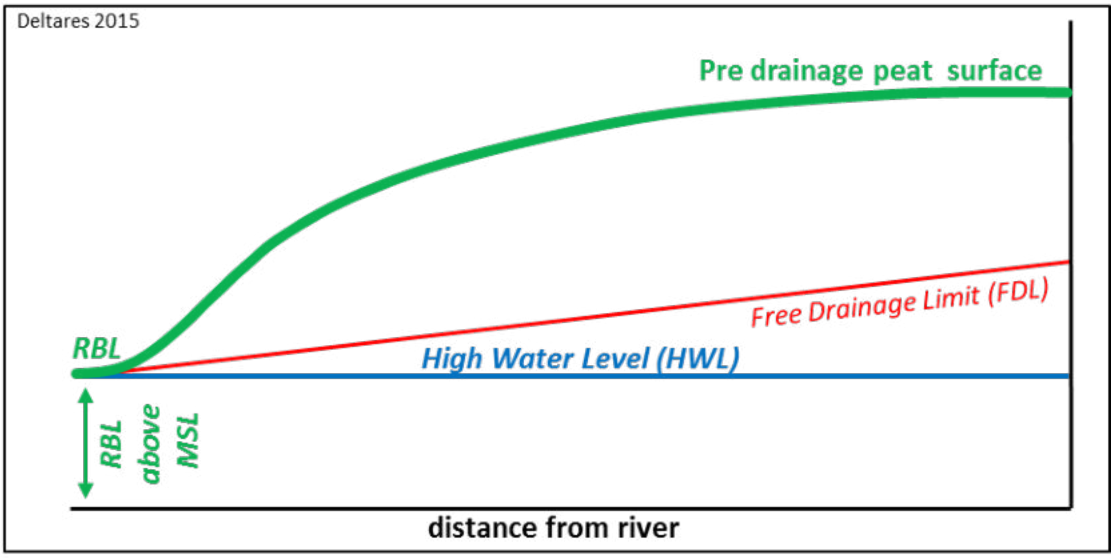

Figure 15 Illustration of the High Water Level (HWL, the level of severe flood risk) and Free Drainage Limit (FDL, the level below which drainage by gravity becomes impeded and inundation after heavy rainfall is likely) drainage limits in relation to River Bank Level (RBL), which is the elevation of the river side that is known to flood frequently.

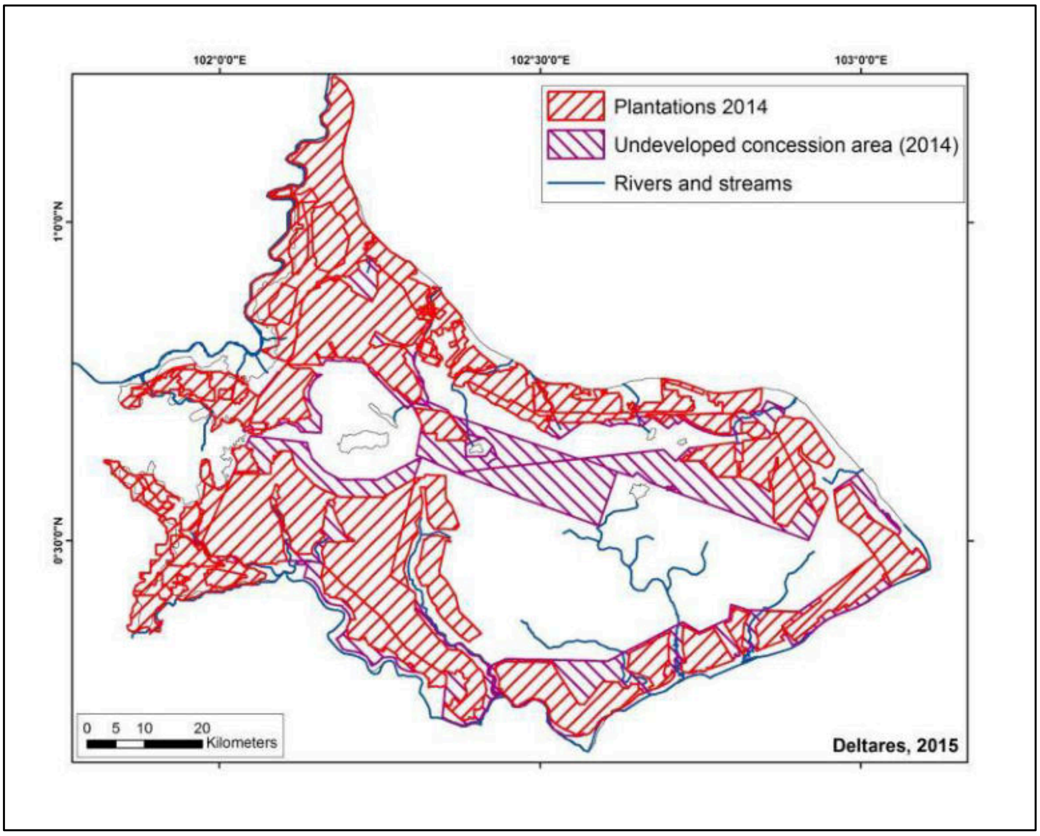

Figure 16 Existing plantation areas (including smallholders) and undeveloped concession areas in 2014.

5.1.3 Flooding and drainability in possible plantation expansion areas

A considerable part, 110,000 ha, of the Kampar Peninsula is under concession license but has not been developed yet into plantations (Figure 16). Assuming that these undeveloped concession areas will be developed in future, we present an additional scenario for flooding and drainability conditions on the Kampar Peninsula in Table 7.

5.2 The impact of drainage on subsidence and flood risk

Three assessments of the impact of drainage on subsidence and flood risk are presented:

- A 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} on existing plantations only (5.2.1)
- A 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} on existing plantations and undeveloped concession areas (5.2.2)
- A comparison of the 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} and 'Business As Usual' subsidence rate of 5 cm yr^{-1} on existing plantations (5.2.3)

5.2.1 Impact on existing plantations

The flooding and drainability impacts on existing developed plantations under a 'Best Management Practice' scenario with a subsidence rate of 3.5 cm yr^{-1} are presented in Table 6. The flooding and drainability conditions are projected 150 years into the future at 25 year time steps for different peatland land user groups. The area of peatland that lies below the

HWL, between the HWL and FDL and below the FDL are shown in Table 6 for different years into the future.

Overall this analysis finds that the Kampar Peninsula will be irreversibly changed by drainage, even if only areas that are already drained are considered (Figure 16). Already, by 2014, 14 % of the area is below HWL i.e. subject to flooding by river water, while an additional 17% is below FDL i.e. likely to experience drainability problems. The total area that has either flooding or drainability problems is 31% according to the data available.

Within 25 years, the existing plantation area below HWL, FDL and HWL will increase to 32, 38 and 71 % respectively. Within 50 years, this will have become 45, 37 and 83 %, and within 100 years 73, 25 and 98 %, i.e. nearly the entire plantation area that now exists.

It is clear from this analysis that the current use of the Kampar Peninsula for drainage-based plantations even under a Best Management Practice scenario is not a sustainable production system and that these impacts will begin to be experienced within the coming decades (Figure 18).

There are clear differences between the timing of when the impacts of subsidence on drainability and flooding will affect different user groups (Table 6, Figure 19). Smallholder oil palm plantations tend to be located nearest the rivers in the lowest lying areas (on average 3.7 m +MSL; Table 3; Figure 8), and therefore no less than 39 % of these already experienced flooding problems by 2014 according to our elevation data. By 2064, after 50 years of further subsidence, this is projected to be 74 %. For industrial oil palm plantations, that are at a slightly higher elevation of 4.3 m + MSL on average (Table 3; Figure 8), these numbers are 29 % and 55 % respectively. Industrial *Acacia* plantations are least affected by flooding by river water in the short to medium term, with 5 % and 37 % below HWL in 2014 and in 50 years respectively. However an additional 18 and 46 % of *Acacia* plantations are below FDL at these times.

In the long term the differences in flood risk for the different user groups disappear, as nearly all plantations on the Kampar Peninsula are likely to flood eventually if drainage is continued. By 2114, after an additional 100 years of continued subsidence, 68 % of *Acacia* plantations is projected to be below HWL and 87 % of oil palm plantations (both smallholder and industrial).

Table 6 Areas that are frequently flooded (below HWL) or have impeded drainability (below FDL), in ha and as % of total area, for the different types of plantations which are already developed in 2014 within the Kampar Peninsula study area, in the 'Best Management Practice' scenario applying a subsidence rate of 3.5 cm yr^{-1}. Note 1: FDL presents the area that is ONLY below the FDL level but not below the HWL level. Note 2: total areas as presented here differ from other tables since calculations are done on a grid of 100 x 100 m and do not exactly cover the vector boundary lines. The areas for the 'Business As Usual' scenario are provided in Annex D.

Year	Time in future (yrs)	Area below the following drainage limit:					
		High Water Level (HWL)		Free Drainage Limit (FDL)		HWL+FDL	
		ha	% of total area	ha	% of total area	ha	% of total area
All plantations							
2014	0	39742	13.5%	51079	17.4%	90821	30.9%
2039	25	94773	32.3%	112559	38.3%	207332	70.6%
2064	50	132525	45.1%	109738	37.4%	242263	82.5%
2114	100	215402	73.4%	72944	24.8%	288346	98.2%
2164	150	278471	94.8%	15163	5.2%	293634	100.0%
All *Acacia* plantations							
2014	0	10795	5.1%	36923	17.5%	47718	22.7%
2039	25	46163	21.9%	102412	48.7%	148575	70.6%
2064	50	77648	36.9%	96558	45.9%	174206	82.8%
2114	100	143281	68.1%	63015	29.9%	206296	98.0%
2164	150	196123	93.2%	14377	6.8%	210500	100.0%
Industrial *Acacia* plantations (APRIL & affiliated)							
2014	0	10208	6.5%	28098	17.8%	38306	24.3%
2039	25	35778	22.7%	80913	51.3%	116691	74.0%
2064	50	57927	36.7%	77801	49.3%	135728	86.0%
2114	100	110359	70.0%	43269	27.4%	153628	97.4%
2164	150	143853	91.2%	13882	8.8%	157735	100.0%
Industrial *Acacia* plantations (APP & affiliated)							
2014	0	587	1.1%	8825	16.7%	9412	17.8%
2039	25	10385	19.7%	21499	40.7%	31884	60.4%
2064	50	19721	37.4%	18757	35.5%	38478	72.9%
2114	100	32922	62.4%	19746	37.4%	52668	99.8%
2164	150	52270	99.1%	495	0.9%	52765	100.0%
All oil palm plantations							
2014	0	28947	34.8%	14156	17.0%	43103	51.8%
2039	25	48610	58.5%	10147	12.2%	58757	70.7%
2064	50	54877	66.0%	13180	15.9%	68057	81.9%
2114	100	72121	86.8%	9929	11.9%	82050	98.7%
2164	150	82348	99.1%	786	0.9%	83134	100.0%
Industrial oil palm plantations							
2014	0	9999	28.7%	5602	16.1%	15601	44.9%
2039	25	17019	48.9%	4754	13.7%	21773	62.6%
2064	50	19065	54.8%	8873	25.5%	27938	80.3%
2114	100	30240	86.9%	4488	12.9%	34728	99.8%
2164	150	34757	99.9%	25	0.1%	34782	100.0%
Smallholder oil palm plantations							
2014	0	18948	39.2%	8554	17.7%	27502	56.9%
2039	25	31591	65.3%	5393	11.2%	36984	76.5%
2064	50	35812	74.1%	4307	8.9%	40119	83.0%
2114	100	41881	86.6%	5441	11.3%	47322	97.9%
2164	150	47591	98.4%	761	1.6%	48352	100.0%

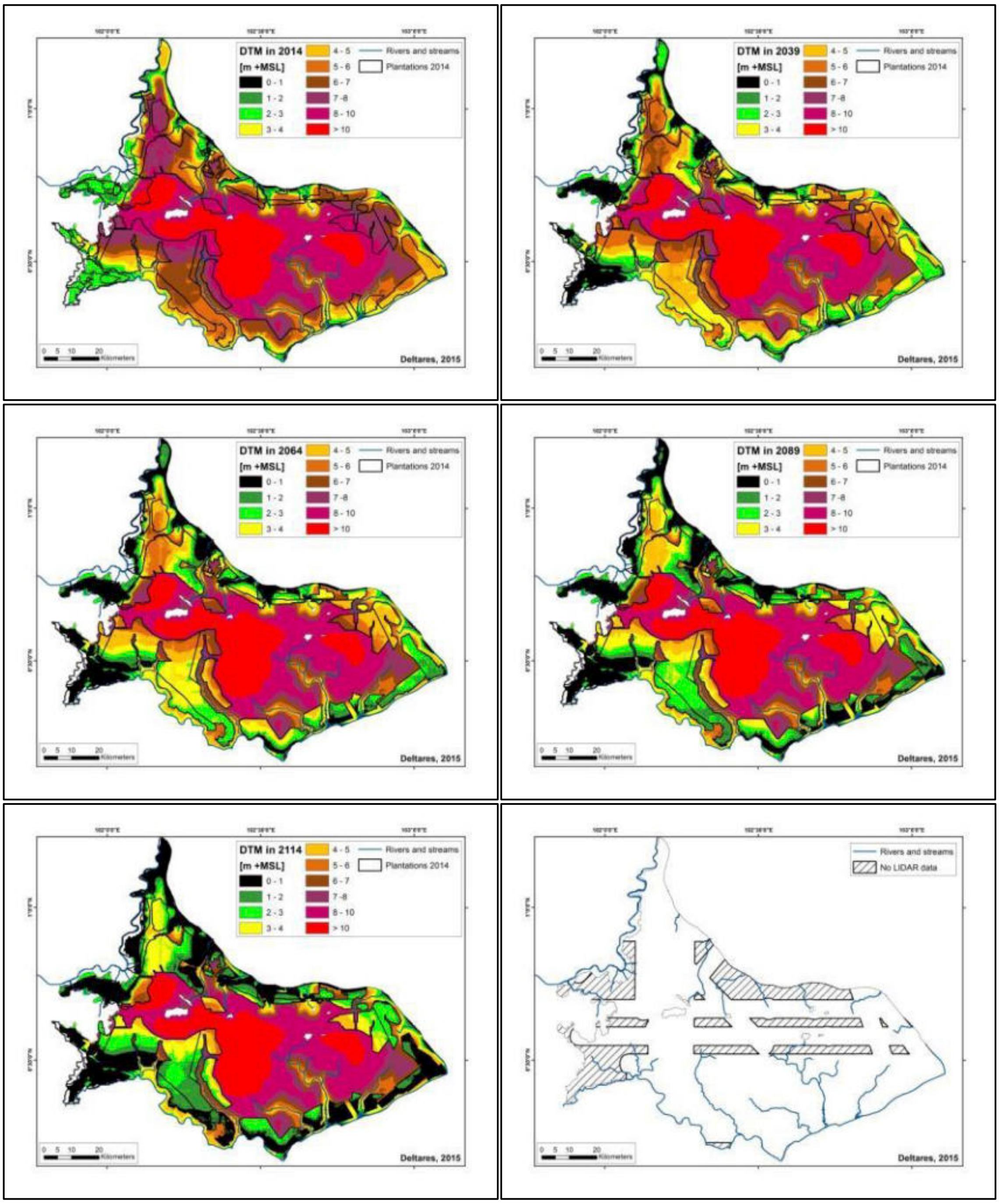

Figure 17 DTM at 0, 25, 50, 75 and 100 years after 2014 applying a ‘Best Management Practice’ subsidence rate of 3.5 cm yr^{-1} for the developed plantation areas. The right bottom map shows the area where the DTM is less accurate since for those areas no LiDAR data are available. See also the confidence map shown in Figure 35.

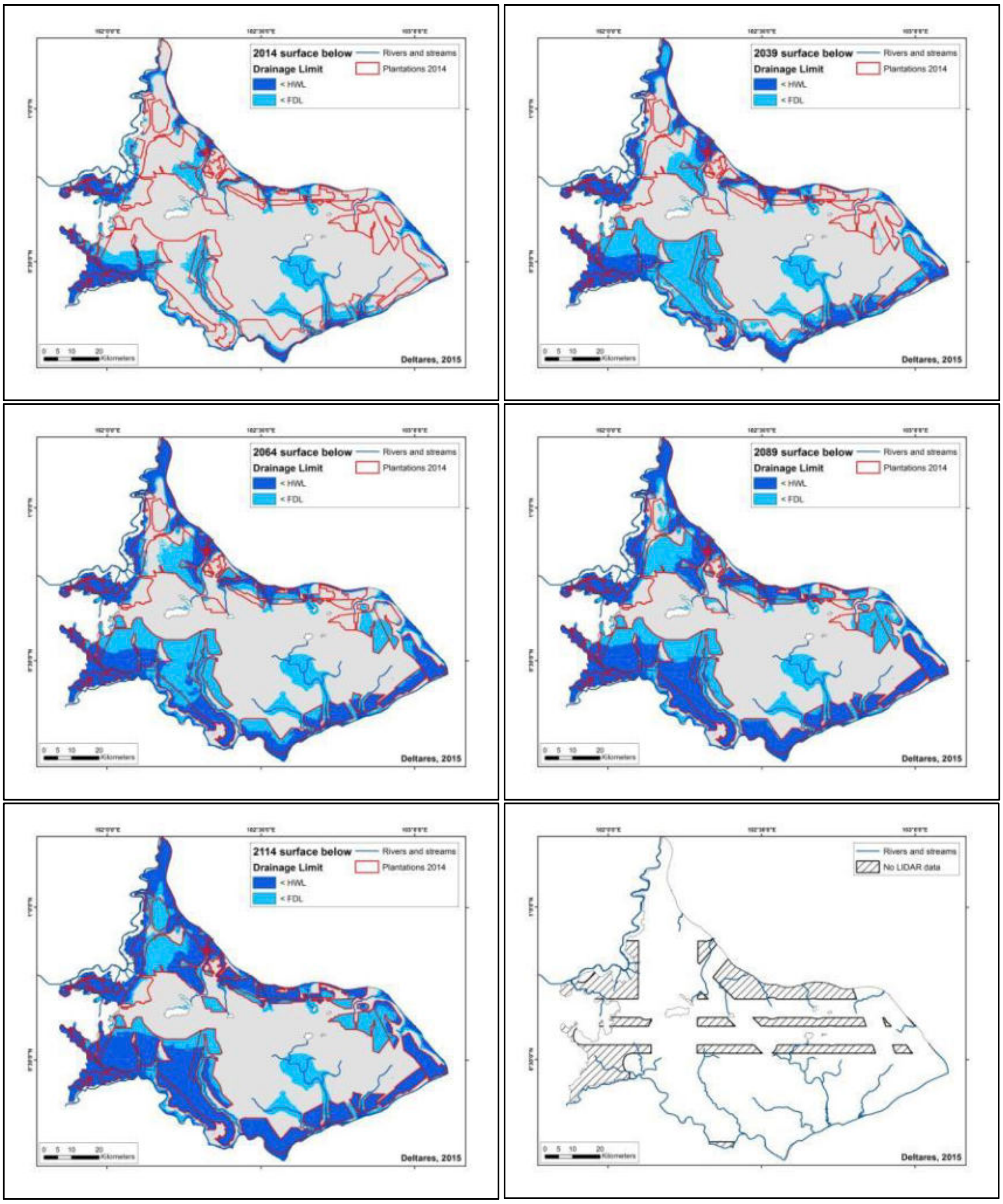

Figure 18 Flood extent projection for 0, 25, 50, 75 and 100 applying a 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} to existing plantations (Figure 14) and flooding thresholds after 2014 (the date for which the DTM was created using LiDAR data). The associated areas are presented in Table 6. The flood extent projections applying a 'Business As Usual' subsidence rate of 5 cm yr^{-1} are shown in Figure 45. The right bottom map shows the area where the Flood extent projection will be less accurate since for those areas no LiDAR data are available. See also the confidence map shown in Figure 35.

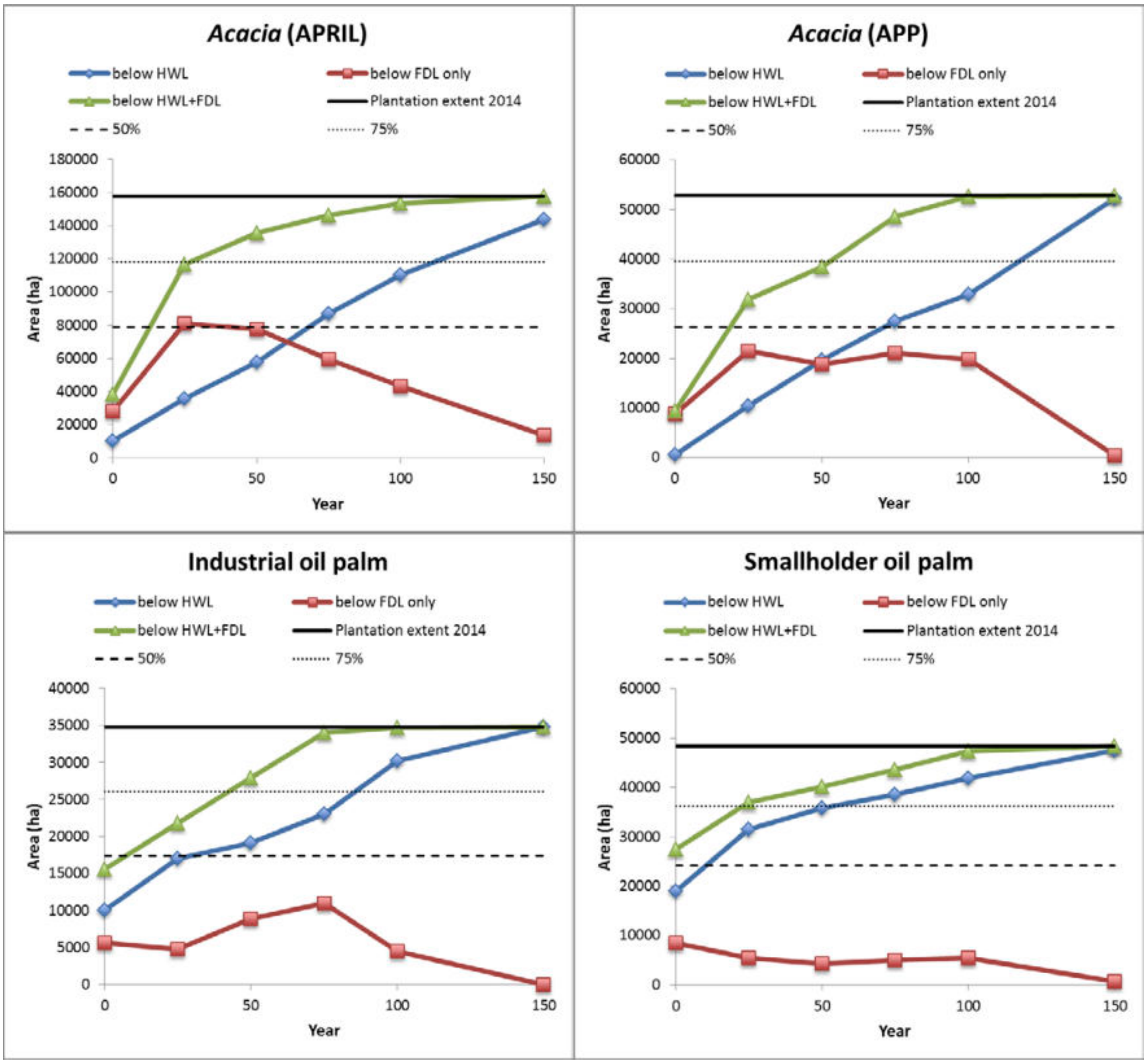

Figure 19 Changes in drainability and flooding problems as indicated by the area of land below the High Water Level (HWL), Free Drainage Limit (FDL) and combined HWL and FDL for the existing plantations of different user groups on the Kampar Peninsula, see also Table 6.

5.2.2 Existing plantations and undeveloped concession areas

If undeveloped pulp wood (HTI) concession areas in 2014 are drained in the future, this will increase the area affected by drainage. The potential impacts on future flood risk of drainage of the existing plantations and undeveloped concession areas were therefore assessed. Hooijer *et al.* (2012) found that in the first five years following drainage the total amount of subsidence is 1.42 m, which includes the physical processes during the primary phase of subsidence. The subsequent subsidence rate for this analysis is then assumed to be 3.5 cm yr^{-1}, the 'Best Management Practice' subsidence rate as for the analysis of existing plantation areas.

The results of this analysis show that within 25 years, the area below the combined High Water Level and Free Drainage Limit increases from 207,332 ha (Table 6) to 273,957 ha

(Table 7). However, because the undeveloped concessions are mostly located in the higher interior of the peatland, the proportion of the drained peatland below the combined High Water Level and Free Drainage Limit falls from 71 % to 68 %. Nonetheless, practically the whole area of concessions is affected by drainage problems and flooding within 100 years.

5.2.3 Comparison of subsidence rates as a proxy for water management

A key finding from this analysis is that the effect of improved water management on the rate of the development of drainability and flood risk problems over time is limited. For *Acacia* plantations, for example, a 'Business As Usual' subsidence rate of 5 cm yr^{-1} is projected to result in drainability and flooding problems for 76 % of the area within 25 years, while a 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} leads to drainability and flooding problems for 71 % of the area in this time period (Table 8). Similarly for oil palm, the impact of improved water management is marginal on preventing drainability and flooding problems over the next fifty years. Improved water management may lengthen the lifetime of the whole area under production but this is generally by much less than 25 years and in all cases, the whole plantation area is affected by drainability and flooding problems within 150 years for both the 'Business As Usual' and 'Best Management Practice' subsidence rates.

Table 7 Areas that are frequently flooded (below HWL) or have impeded drainability (below FDL), in ha and as % of total area, for the full concession areas including areas that were not developed by 2014. Note that FDL presents the area that is ONLY below the FDL level but not below the HWL level. Note that for the undeveloped concession areas an initial subsidence rate of 1.42 m was applied over the first 5 years to account for the initial spike in subsidence directly after drainage (Hooijer *et al.*, 2012), for the subsequent years a 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} was applied. Note 1: FDL presents the area that is ONLY below the FDL level but not below the HWL level. Note 2: total areas as presented here differ from other tables since calculations are done on a grid of 100 x 100 m and do not exactly cover the vector boundary lines.

Year	Time in future (yrs)	Area below the following drainage limit:					
		High Water Level (HWL)		Free Drainage Limit (FDL)		HWL+FDL	
		ha	% of total area	ha	% of total area	ha	% of total area
All plantations							
2014	0	42982	10.6%	66505	16.5%	109487	27.1%
2039	25	128014	31.7%	145961	36.2%	273975	67.9%
2064	50	170041	42.1%	159862	39.6%	329903	81.7%
2114	100	267475	66.3%	130916	32.4%	398391	98.7%
2164	150	354458	87.8%	49229	12.2%	403687	100.0%
All *Acacia* plantations							
2014	0	14035	4.4%	52349	16.3%	66384	20.7%
2039	25	79411	24.8%	135809	42.4%	215220	67.1%
2064	50	115171	35.9%	146677	45.8%	261848	81.7%
2114	100	195358	60.9%	120985	37.7%	316343	98.7%
2164	150	272114	84.9%	48441	15.1%	320555	100.0%
Industrial *Acacia* plantations (APRIL & affiliated)							
2014	0	13077	5.2%	40227	16.1%	53304	21.4%
2039	25	60367	24.2%	110463	44.3%	170830	68.6%
2064	50	85740	34.4%	123895	49.7%	209635	84.2%
2114	100	150572	60.4%	94424	37.9%	244996	98.3%
2164	150	205547	82.5%	43564	17.5%	249111	100.0%
Industrial *Acacia* plantations (APP & affiliated)							
2014	0	958	1.3%	12122	17.0%	13080	18.3%
2039	25	19044	26.7%	25346	35.5%	44390	62.1%
2064	50	29431	41.2%	22782	31.9%	52213	73.1%
2114	100	44786	62.7%	26561	37.2%	71347	99.9%
2164	150	66567	93.2%	4877	6.8%	71444	100.0%
All oil palm plantations							
2014	0	28947	34.8%	14156	17.0%	43103	51.8%
2039	25	48603	58.5%	10152	12.2%	58755	70.7%
2064	50	54870	66.0%	13185	15.9%	68055	81.9%
2114	100	72117	86.7%	9931	11.9%	82048	98.7%
2164	150	82344	99.1%	788	0.9%	83132	100.0%
Industrial oil palm plantations							
2014	0	9999	28.7%	5602	16.1%	15601	44.9%
2039	25	17018	48.9%	4757	13.7%	21775	62.6%
2064	50	19064	54.8%	8876	25.5%	27940	80.3%
2114	100	30242	86.9%	4488	12.9%	34730	99.8%
2164	150	34759	99.9%	25	0.1%	34784	100.0%
Smallholder oil palm plantations							
2014	0	18948	39.2%	8554	17.7%	27502	56.9%
2039	25	31585	65.3%	5395	11.2%	36980	76.5%
2064	50	35806	74.1%	4309	8.9%	40115	83.0%
2114	100	41875	86.6%	5443	11.3%	47318	97.9%
2164	150	47585	98.4%	763	1.6%	48348	100.0%

Table 8 Comparison of percentage of minimum areas that are frequently flooded (below HWL) or have impeded drainability (below FDL) and subsidence rate ('Best Management Practice' 3.5 cm yr^{-1} compared to 'Business As Usual' 5 cm yr^{-1}) as a % of total existing plantation area already developed in 2014 within the study area. Note 1: FDL presents the area that is ONLY below the FDL level but not below the HWL level. Note 2: total areas as presented here differ from other tables since calculations are done on a grid of 100 x 100 m and do not exactly cover the vector boundary lines.

Year	Time in future (yrs)	Percentage of area below the following drainage limit by subsidence rate:					
		HWL		FDL		HWL+FDL	
		3.5 cm/yr	5 cm/yr	3.5 cm/yr	5 cm/yr	3.5 cm/yr	5 cm/yr
All *Acacia* plantations							
2014	0	5.1	5.1	17.5	17.5	22.7	22.7
2039	25	21.9	29.5	48.7	46.3	70.6	75.7
2064	50	36.9	52.8	45.9	38.4	82.8	91.2
2114	100	68.1	91.7	29.9	8.3	98.0	100.0
2164	150	93.2	100.0	6.8	0.0	100.0	100.0
Industrial *Acacia* plantations (APRIL & affiliated)							
2014	0	6.5	6.5	17.8	17.8	24.3	24.3
2039	25	22.7	30.0	51.3	49.5	74.0	79.5
2064	50	36.7	53.5	49.3	38.2	86.0	91.7
2114	100	70.0	89.7	27.4	10.3	97.4	100.0
2164	150	91.2	100.0	8.8	0.0	100.0	100.0
Industrial *Acacia* plantations (APP & affiliated)							
2014	0	1.1	1.1	16.7	16.7	17.8	17.8
2039	25	19.7	27.9	40.7	36.6	60.4	64.5
2064	50	37.4	50.5	35.5	39.1	72.9	89.6
2114	100	62.4	97.7	37.4	2.3	99.8	100.0
2164	150	99.1	100.0	0.9	0.0	100.0	100.0
Industrial oil palm plantations							
2014	0	28.7	28.7	16.1	16.1	44.8	44.8
2039	25	48.9	51.5	13.7	15.7	62.6	67.2
2064	50	54.8	60.2	25.5	36.2	80.3	96.4
2114	100	86.9	99.9	12.9	0.1	99.8	100.0
2164	150	99.9	99.9	0.1	0.1	100.0	100.0
Smallholder oil palm plantations							
2014	0	39.2	39.2	17.7	17.7	56.9	56.9
2039	25	65.3	68.6	11.2	10.4	76.5	79.0
2064	50	74.1	78.9	8.9	10.1	83.0	88.9
2114	100	86.6	97.6	11.3	2.4	97.9	100.0
2164	150	98.4	100.0	1.6	0.0	100.0	100.0

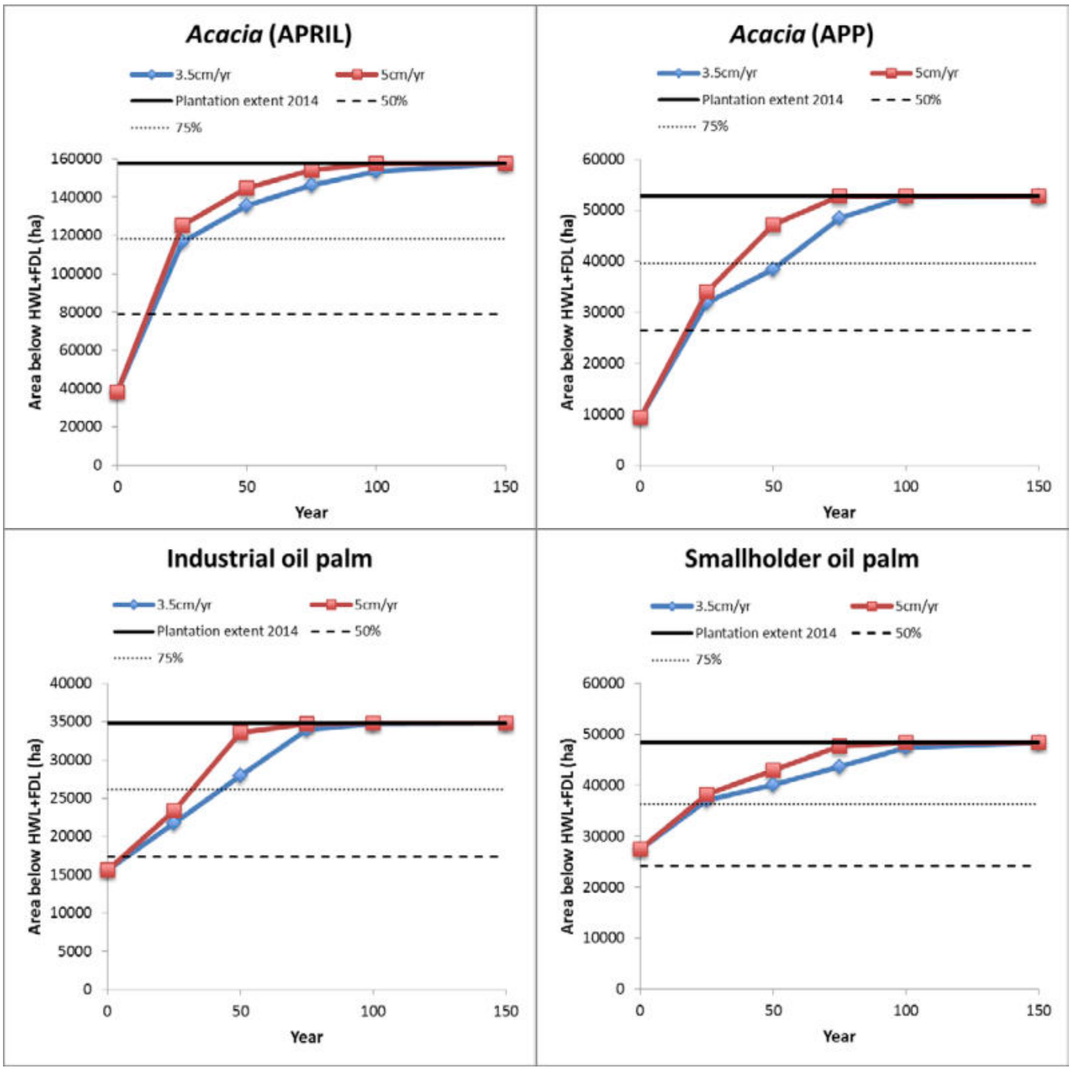

Figure 20 Changes in drainability and flooding problems as indicated by the area of land below the combined HWL and FDL for the existing plantations of different user groups on the Kampar Peninsula under different subsidence rates of 3.5 cm yr^{-1} (‘Best Management Practice’) and 5 cm yr^{-1} (‘Business As Usual’).

6 The potential impact of drainage on carbon emissions on the Kampar Peninsula

As nearly all of the Kampar Peninsula is covered with peat (Figure 22), nearly all plantations on the Kampar Peninsula will be emitting carbon from peat oxidation. Emissions are calculated for the current (2014) active plantation extent.

We have applied an Emission Factor (EF) of 15 t C ha^{-1} yr^{-1} which is the IPCC (2013) EF for plantations in general (including both *Acacia* and oil palm plantations) that corresponds to a 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} as explained in Chapter 3. Note that IPCC (2013) in fact applies a higher EF for Acacia, of 20 t C ha^{-1} yr^{-1}, based partly on studies on the Kampar Peninsula (Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012), and a lower value of 11 t C ha^{-1} yr^{-1} for oil palm, but we have chosen to use the middle value presented by IPCC for reasons of simplification. Given that *Acacia* is the dominant crop of the Kampar Peninsula, the use of the middle value is conservative and results in a lower emission estimate.

The calculated emissions exclude most emissions in the first 5 years after drainage, when a spike in emissions occurs as the initial breakdown rate of fresh 'labile' peat is much higher. Hooijer *et al.* (2012) estimate the annual emission in the first 5 years to be 178 t CO_2 ha^{-1} yr^{-1} or 49 t C ha^{-1} yr^{-1}; recent studies in Kalimantan confirm this spike and find even higher emissions in that initial period (79 t C ha^{-1} yr^{-1}; Hooijer *et al.*, 2014). These numbers also exclude the CH_4 (methane) emission that occurs from plantation canals, which is reported to be 1.7 t C ha^{-1} yr^{-1} for tropical peatlands by the 2013 IPCC guidelines (IPCC, 2013; FAO, 2014). Despite this potentially high impact, we do not use these numbers in the current assessment which aims to be conservative. Furthermore, we have excluded emissions from canals for log transport outside concessions, for the same reason. This will reduce carbon loss to levels that are typical for degraded lands and a fraction of plantation emissions (IPCC, 2013; Hooijer *et al.*, 2014). Finally, we also exclude emissions from peatland outside of plantations that is affected by plantation drainage.

Given that we have excluded several emission sources (fire, methane), and also areas (logging canals, impact zones around plantations), we consider the emission numbers resulting from this study to be conservative. The calculated emissions for the plantation areas currently in production (Table 5) are presented in Table 9. For the total productive plantation area on the Kampar Peninsula, the annual emissions in 2014 from peat oxidation are estimated to be 4.4 Mt C yr^{-1} under a 'Best Management Practice' scenario that assumes a subsidence rate of 3.5 cm yr^{-1}.

Table 9 Calculated annual carbon emission for current productive plantation (*Acacia* + oil palm) areas (Table 5).

Productive plantation area on Kampar Peninsuala, 2014	Area in production [ha]	Annual carbon emission using IPCC 2013 'plantation' EF for area in production [Mt C yr^{-1}]
industrial *Acacia* plantation (APP & affiliated)	52869	0.8
industrial *Acacia* plantation (APRIL & affiliated)	158088	2.4
industrial oil palm plantation	34875	0.5
smallholder oil palm plantation	48395	0.7
Subtotal industrial *Acacia* plantation	**210956**	**3.2**
Subtotal oil palm plantations	**83270**	**1.2**
Total	**294227**	**4.4**

6.1 The potential impact of drainage on fire occurrence on the Kampar Peninsula

The hotspots recorded by the MODIS Aqua and Terra satellites over the period 2000-2014 are shown in Figure 21. It is very striking to note that, to date, fires have hardly affected the forested parts of the Kampar Peninsula, but have been confined almost entirely to plantation areas and areas directly adjoining plantations. It is evident that fires only occur in drained peatlands, and therefore commonly inside or near plantations. This observation supports earlier studies in Borneo which showed a similar relationship between peat drainage and fire occurrence (Page *et al.*, 2002; Hoscilo *et al.*, 2011).

While carbon emissions due to fire are not considered in this assessment, the close relation between fire occurrence and peatland drainage suggests that this should be included in further assessments.

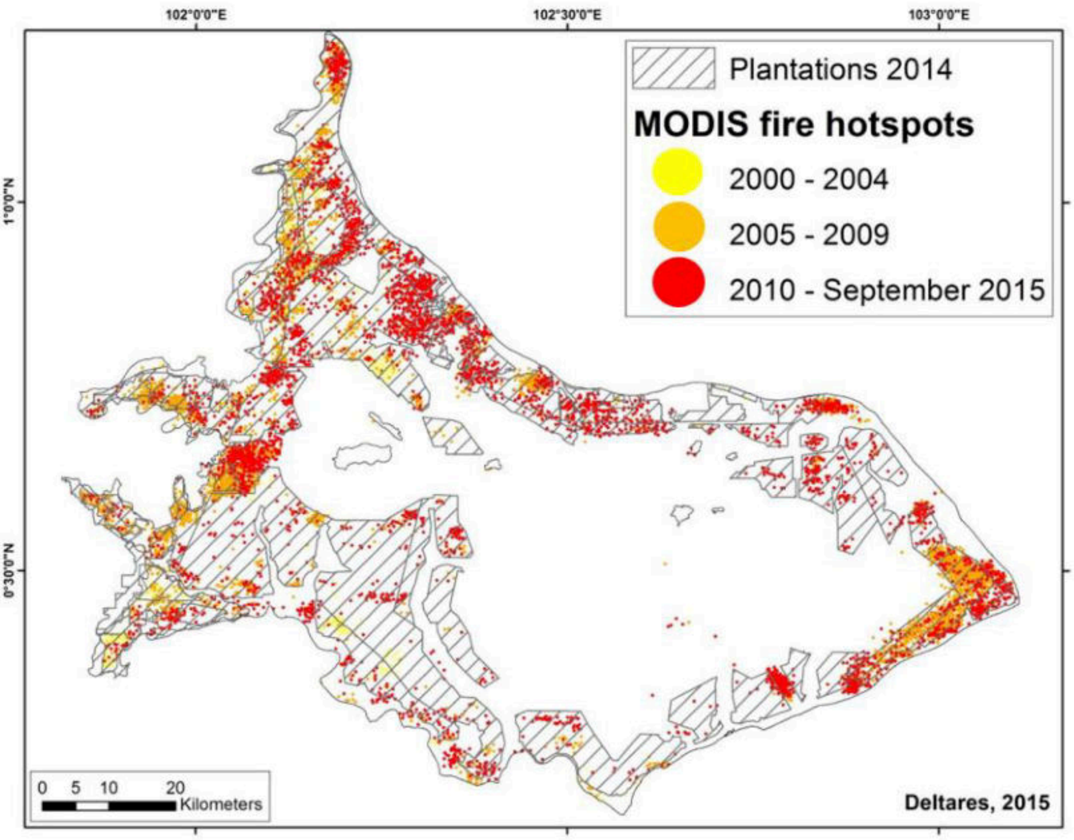

Figure 21 Extent of 2014 industrial pulp and palm plantations and fires in the study area. Fire hotspots are concentrated almost entirely in or near plantation areas.

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Annex A - Details of Kampar subsidence assessment

The Kampar Peninsula (KP) was selected as the focus area for this study because it was most suitable in a number of ways:

1. At 674,200 ha (applying data from Wahyunto *et al.*, 2003[2]; Figure 22) it is likely to be the biggest single peat dome in SE Asia, in extent but certainly in peat volume as the peat is over 5 m in depth almost everywhere and over 10 m in much of it (Hooijer and Vernimmen, 2013), and in the tropics.

Figure 22 Study area depicted by the dashed peat extent area (Wahyunto *et al.*, 2003) of the Kampar Peninsula. In the background a composite Landsat 8 image of 24 April (most northern part of the study area) and 18 June 2013.

2. It makes up a substantial part (almost 10 %) of the total peat extent in Sumatra, of 7.2 Mha (Hooijer and Vernimmen, 2013), and probably over 25 % of its peat volume and belowground carbon stock.

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[2] In this study, we have followed the definition of peat extent (but not thickness) provided by Wahyunto *et al.* (2003); also known as the 'Wetlands International Peat Atlas', which however presents the official Indonesian peat map as produced by Puslitanak (Ministry of Agriculture) around 2000, which to our knowledge is still the most accurate for Indonesia as a whole.

3. Forest clearing and peat drainage in this area is mostly for *Acacia* plantations and relatively easily identified, unlike other peat domes that are impacted by multiple conversion processes in often interrelated and confusing ways.
4. Data availability (elevation, peat thickness, peat type, subsidence rate, emission rate) is far better than any peat area in SE Asia outside the EMRP area in Central Kalimantan, thanks to earlier studies by Deltares (ProForest and Deltares, 2005; Hooijer *et al.*, 2009; Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012; Couwenberg and Hooijer, 2013; Hooijer and Vernimmen, 2013; Vernimmen *et al.*, 2014) and also UGM (who conducted peat thickness surveys in the northern part some years ago, and with whom the airborne LiDAR data for the southern half of the KP were collected in 2014, partly for MIPP and SPPC; see Annex B) and of course the companies active here (most of the peat thickness data points used in this study were collected by APRIL[3]). Some additional peat thickness data for its concessions were provided by APP.

Focusing on the KP therefore allows a far more robust and confident assessment of the impact of pulp and paper industry on peatlands than is possible for any other area in Indonesia in 2015[4].

Data on concession boundaries
As a starting point, we used the Ministry of Forestry (MoF) map of 2010 on *Acacia* pulp wood (HTI) and agricultural plantation (oil palm) concessions in Sumatra as also used in the WACLIMAD and QANS projects (Mawdsley *et al.*, 2013; Figure 13). For the HTI concessions, ownership was determined as the MIPP project focusses on the pulp sector (Table 10).

Determining current development status of concessions
The actual land use/cover status of plantation concessions on the KP in 2014 was assessed manually from cloud free Landsat images (24 April 2013, 18 June 2013 and 21 June 2014). This was done for *Acacia* plantations and oil palm plantations, as well as some areas of unclear use. Because the actual land use types in some cases appeared to cross concession boundaries, and it can be hard to distinguish productive and unproductive areas, we started ‘from scratch’ by digitizing all individual primary and secondary canals within plantations (Figure 23). Where an area had a drainage pattern that was consistent with a plantation development that land use status was assigned to it regardless of whether the area was within an official concession boundary. However, the concession type ‘overruled’ observed drainage patterns: if drainage patterns looked consistent with OP, but the area was located in an *Acacia* (HTI) plantation, the area was considered to be an *Acacia* plantation (or vice versa) (Figure 24). Smallholder oil palm plantations were assigned to areas which were clearly disturbed as visible from the Landsat imagery by their fragmented pattern. Small (tertiary) canals could for most of the time not be discerned due to the Landsat image resolution (30 m), but primary or secondary drainage canals along the perimeter of the area are often present as these areas were often in the vicinity of industrial oil palm plantations (Figure 25).

[3] Data from APRIL used in this study were shared with Deltares in the SBMSP project (Hooijer *et al.*, 2009) and are free to be used by Deltares for other purposes.
[4] Projects are ongoing that will allow expansion of this analysis to most of Sumatra by 2016.

The land uses distinguished are:

1. Industrial *Acacia* plantations, divided by APP or APRIL concession ownership or affiliation
2. Industrial oil palm plantations
3. Smallholder oil palm plantations

Table 10 Overview of HTI (*Acacia*) concessions in the study area including ownership or affiliation with Asia Pacific Resources International Limited (APRIL) and Asia Pulp and Paper (APP) and license number as provided by the Ministry of Forestry or the local Bupati. Number (No.) in table corresponds with the number shown on the map in Figure 13. Official license area obtained from the 2012 Ministry of Forestry data and information book (http://www.dephut.go.id/uploads/files/Buku Pemanfaatan Final 2012.pdf; last accessed 19 August 2014). Size of the area for concessions 1 – 11 determined from the MoF 2010 GIS boundary (UTM48N projection). Note that some official license areas (notably 1, 2, 7) include land that is outside the Kampar Peninsula peatland that is therefore excluded from the analysis. The 'Concession area on peat according to GIS data' applies to Kampar Peninsula data and is used in our analysis.

No.	Ownership / Affiliation	Concession	License No.	Official total license area (incl. non-peat and outside KP) [ha]	Concession area on peat according to GIS data [ha]
1	APP	PT. Arara Abadi	743/Kpts-II/1996	299975@	44963#
2	APP	PT. Balai Kayang Mandiri	20/Menhut-II/2007	22250@	6352
3	APRIL	PT. Ekawana Lestari Darma	733/Kpts-II/1997	9300	9485
4	APP	PT. Mitra Hutani Jaya	101/Menhut-II/2006	9240	9538
5	APRIL	PT. National Timber and Forest Product	21/Menhut-II/2007	9300	9240
6	APRIL	PT. Putra Riau Perkasa	104/Menhut-II/2006	15640	16594
7	APRIL	PT. Riau Andalan pulp & paper	327/Menhut-II/2009	350165@	137989#
8	APP	PT. Satria Perkasa Agung Unit Serapung	102/Menhut-II/2006	11830	11745
9	APRIL	PT. Selaras Abadi Utama	522.21/IUPHHKHT/XII/2002/005	13600	12496
10	APRIL	PT. Tuah Negeri	215/Menhut-II/2007	1480	1492
11	APRIL	PT. Uniseraya	214/Menhut-II/2007	33360	32765
		Subtotal (MoF 2010 GIS boundaries)			**292659**
12	APRIL	CV. Alam Lestari	SK Bupati	4784	-
13	APRIL	CV. Bhakti Praja Mulia	SK Bupati	5843	-
14	APRIL	CV. Harapan Jaya	522.21/IUPHHKHT/I/2003/016	5048	-
15	APRIL	CV. Mutiara Lestari	SK Bupati	122	-
16	APRIL	PT. Madukoro	SK Bupati	14825	-
17	APRIL	PT. Triomas FDI	522.21/IUPHHKHT/I/2003/012	9625$	-
		Subtotal (non-MoF 2010 concessions)		**40247**	**-**
		Total (MoF 2010 + non-MoF 2010 concessions)			**332906**

@part of concession area not on Kampar Peninsula.
#Excludes the non-MoF 2010 concession areas shown in Figure 13 (white numbers 1 and 7).
$Concession not included in the 2012 Ministry of Forestry data and information book. Therefore area was obtained from http://hutanriau.org/dataset/resource/25c4e62f-bac8-4181-9cd8-0a6ce2280f59; last accessed 19 August 2014.

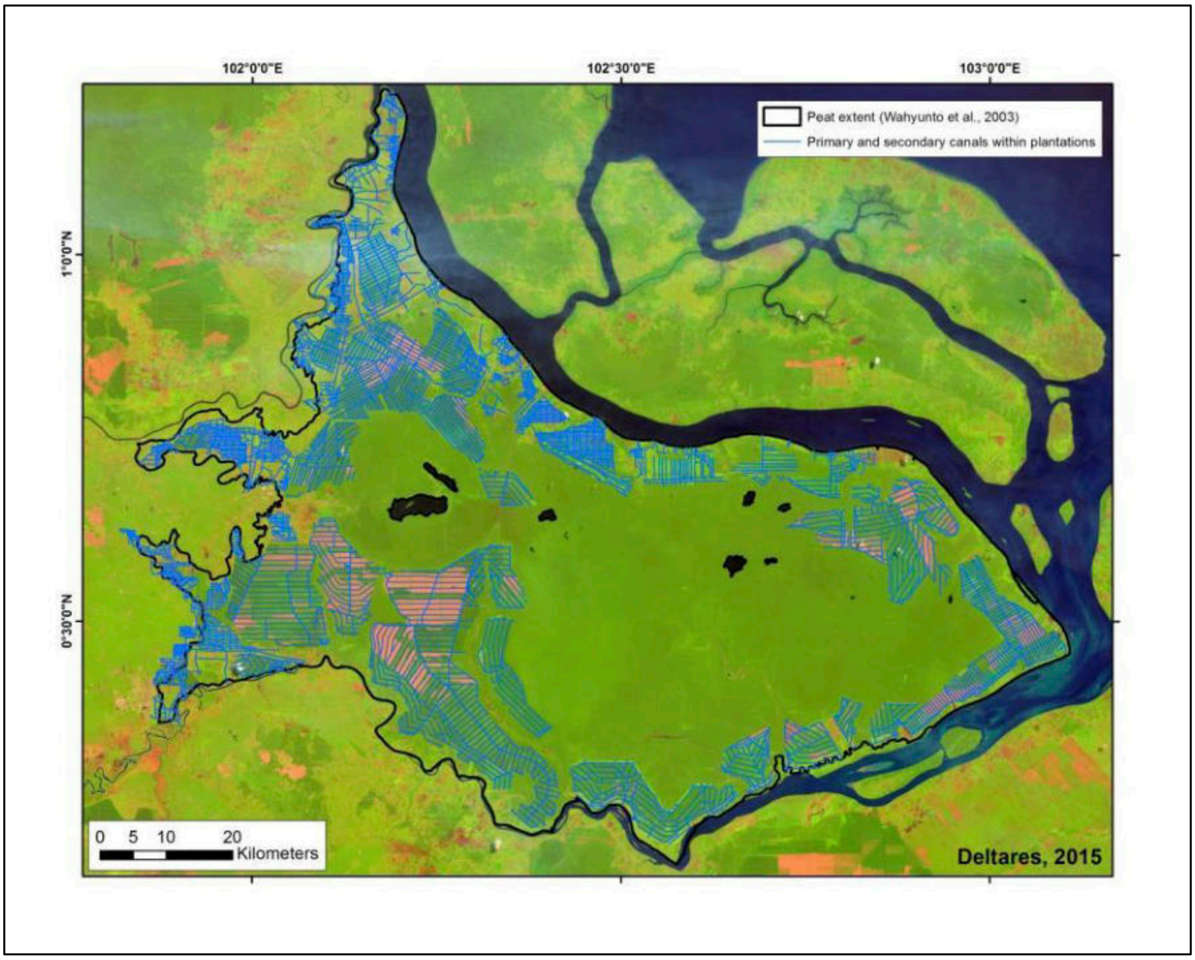

Figure 23 Digitized primary and secondary canals within plantations. Note that logging canals outside concessions are not shown here.

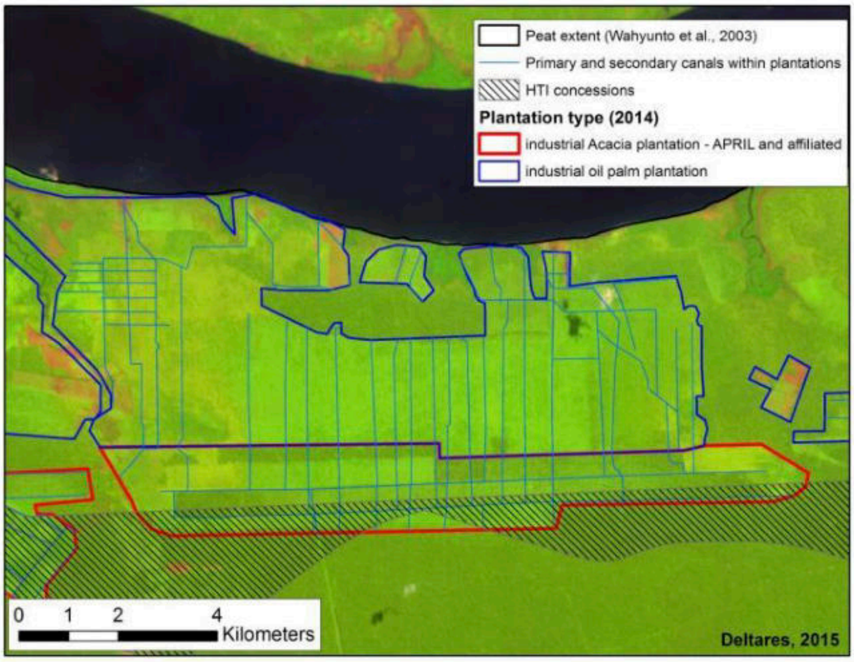

Figure 24 Illustration of digitization and classification of industrial *Acacia* plantation because this area is located within an official HTI concession. From the drainage pattern however this might be classified as an industrial oil palm plantation.

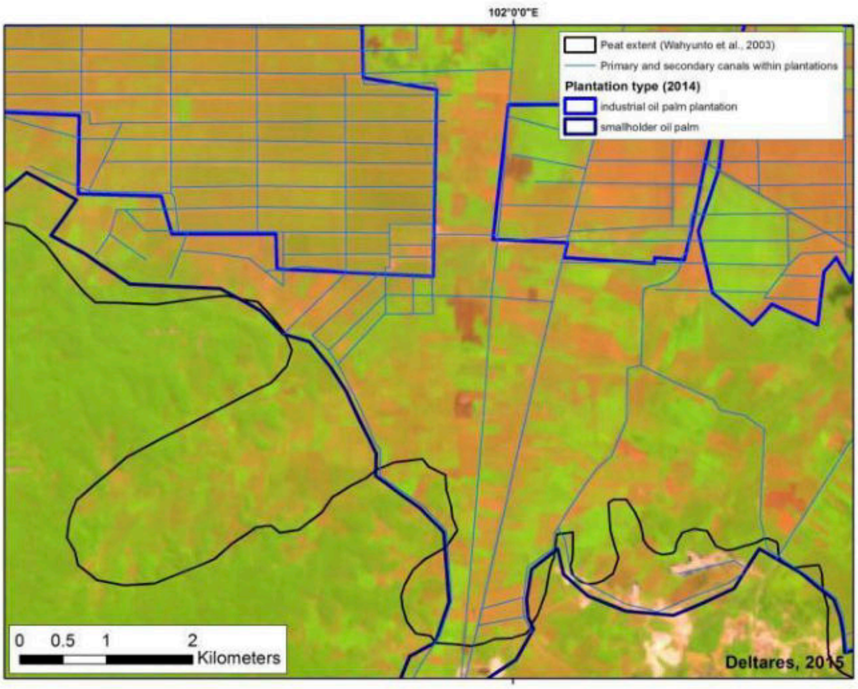

Figure 25 Illustration of digitization of smallholder oil palm plantation. Shown is a fragmented pattern bordered by a perimeter canal.

Annex B – Elevation model for the Kampar Peninsula

Deltares has previously attempted to create an elevation model (DTM, digital terrain model) for the Kampar Peninsula in the SBSMP project (2008) using SRTM90 and field survey data (both collected around 2000, largely pre-drainage and pre-subsidence) (Hooijer *et al.*, 2009) and in the QANS project (2013) using geomorphological relationships derived from ICESat-GLAS satellite LiDAR elevation (Hooijer and Vernimmen, 2013). A far more accurate (within 0.5 m for 73.3 % of the study area; see further below) elevation model has now been created using LiDAR data flown in strips. The steps are explained here.

For the SPPC project LiDAR was flown for the southern part of the Kampar Peninsula[5] (Figure 26). LiDAR data for the northern part of the Kampar Peninsula was available through the Peatland Best Practice Management Project[6] (PBPMP; Figure 26). The LiDAR data were acquired in 'strip' mode, i.e. not full coverage to considerably reduce costs. Strip spacing between individual LiDAR flight lines for the SPPC LiDAR data was 5 km whereas this ranged between 5 and 10 km for the PBPMP LiDAR data.

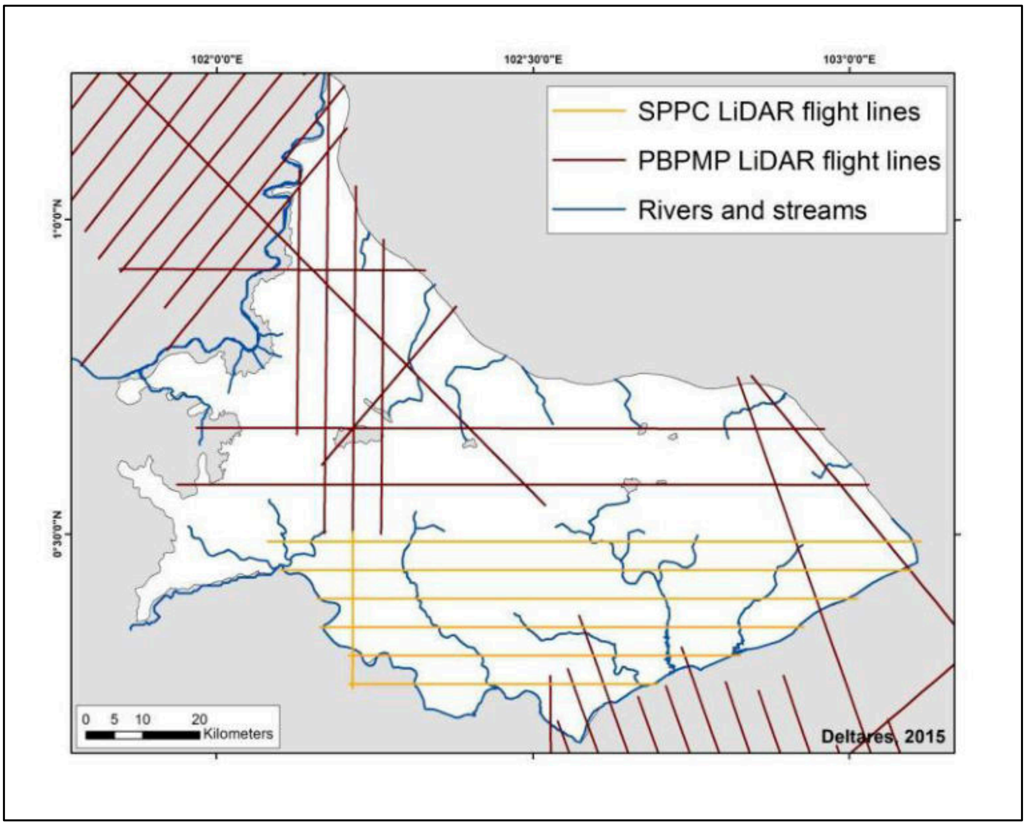

Figure 26 LiDAR flight lines over the Kampar Peninsula as acquired by the SPPC (orange lines) and the PBPMP (brown lines) projects.

[5] https://www.deltares.nl/en/projects/lidar-data-large-scale-peatland-management-flood-risk-assessment/

[6] https://www.deltares.nl/en/projects/reducing-impact-plantation-operations-peatlands-indonesia-2

The raw LiDAR data were processed by taking the 0.1 percentile elevation value within a 25 m grid as representing the peat surface. To avoid any possible edge effects the 2 outer most cells along the LiDAR strip were removed from the dataset thereby effectively reducing the strip width with 100 m.

The two datasets were brought together, for which the SPPC LiDAR data were first referenced to MSL using the same geoid to MSL correction (-0.706 m) applied to the PBPMP LiDAR data. The resulting data are shown in Figure 27.

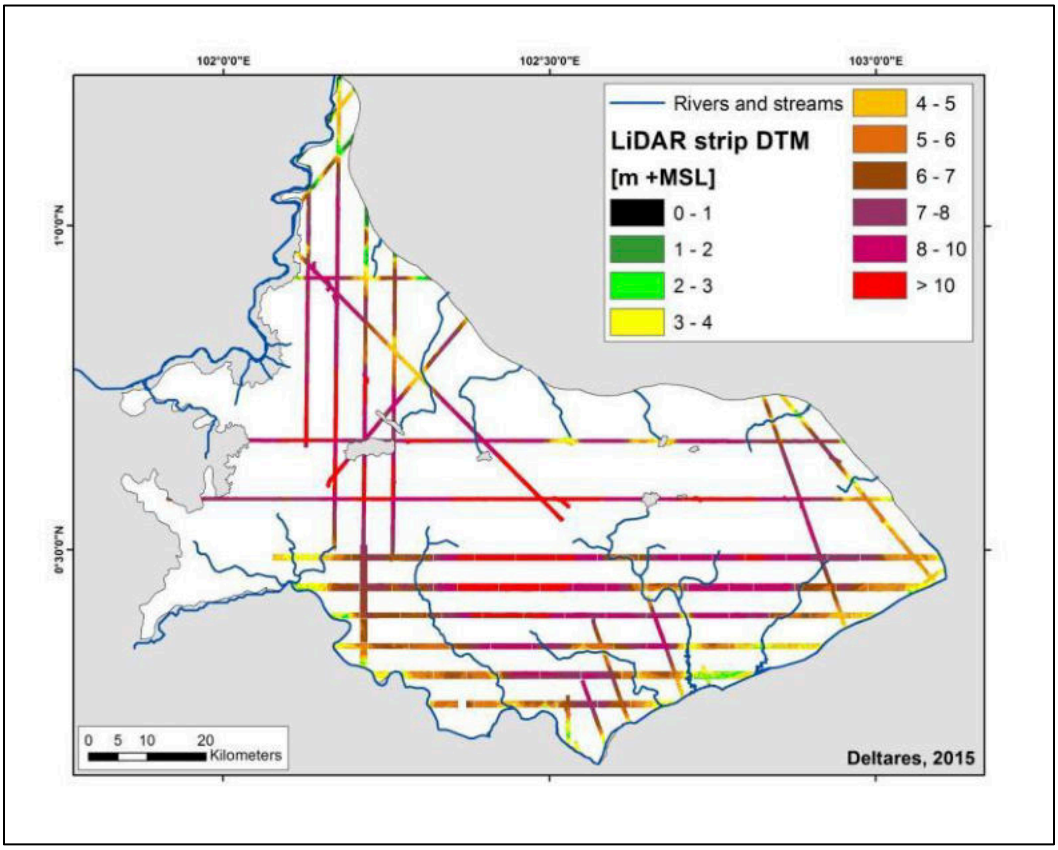

Figure 27 Processed LiDAR strip data for the Kampar Peninsula peatland study area.

Before a full coverage elevation model could be created contour lines were drawn between the LiDAR strips which follow the shape of the peat dome. Before these contour lines were drawn, the location of natural streams and rivers were first identified from cloud free Landsat satellite images (Figure 28). Landsat images were also used to identify the shape of peat dome in case the LiDAR strip data itself did not provide sufficient information to complete the drawing of the contour lines.

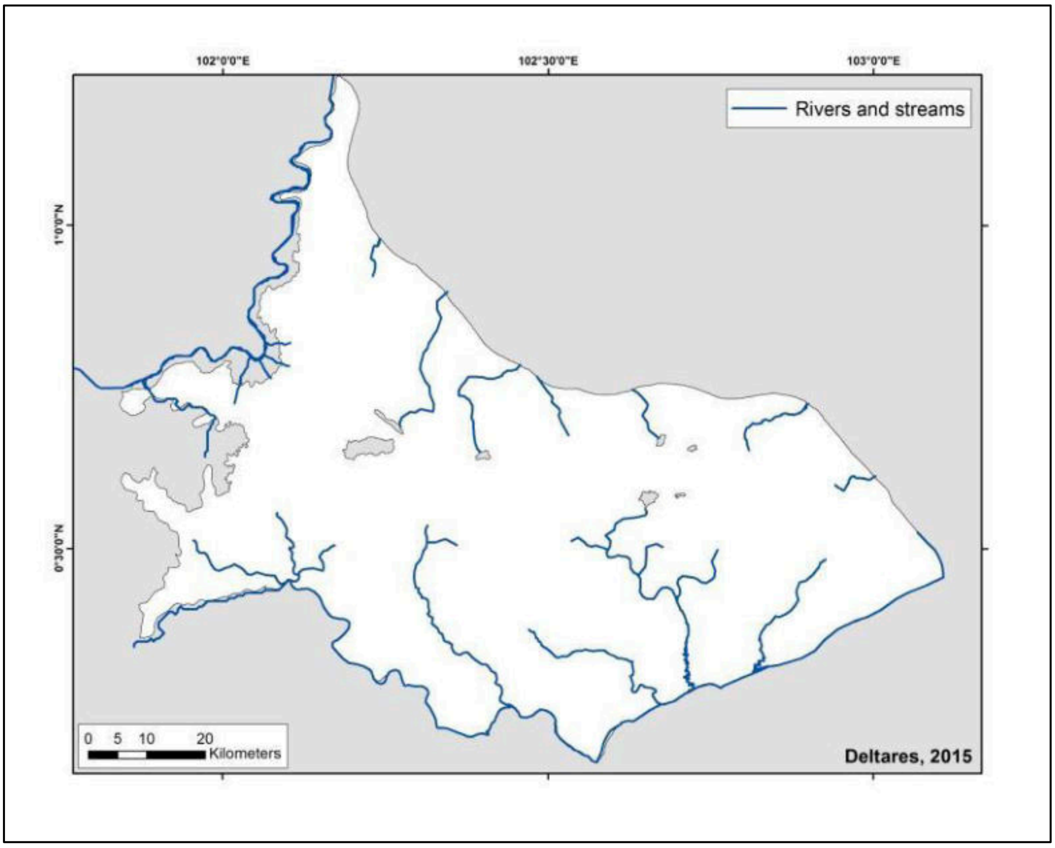

Figure 28 Location of natural streams and rivers as identified from cloud free Landsat images.

From Figure 26 it is clear that parts of the Kampar Peninsula are not covered with LiDAR data. Less accurate elevation data sources with lower spatial and vertical resolution, such as data from the Shuttle Radar Topography Mission (SRTM, 30 and 90 m spatial resolution, 1 m vertical resolution, acquired in February 2000; Figure 29) are available for the Kampar Peninsula and could possibly be used to help fill these gaps. Before SRTM elevation data can be used the data need to be filtered first since SRTM is not a terrain model but rather a vegetation surface model. Furthermore it is important to realize that SRTM is referenced to the EGM96 geoid model and needs to be linked to Mean Sea Level (MSL) first.

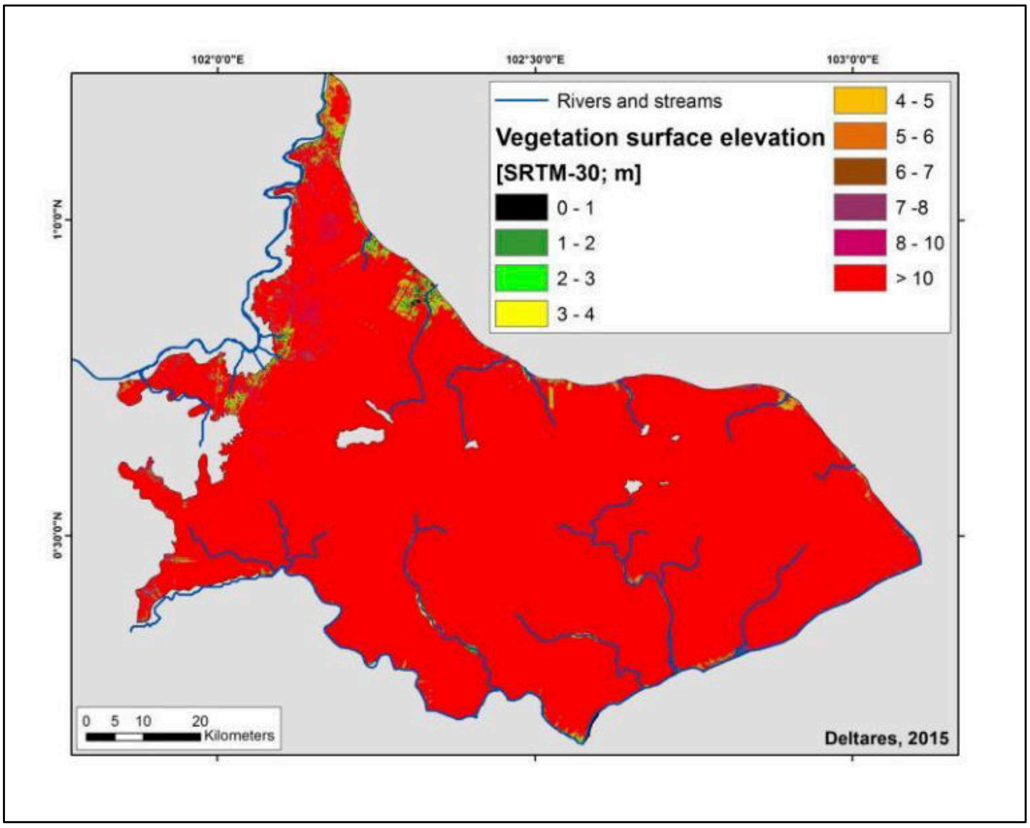

Figure 29 SRTM-30 elevation data acquired in February 2000 over the Kampar Peninsula, Riau. Elevations over 10 m occur only in forested areas (at least on peatland) and are considered to be representative for forest canopy; they are shown in red to mark areas for which SRTM-30 does not allow creation of a peat surface elevation model.

The filtering steps to remove the vegetation signal follow the same steps as described in detail in Hooijer *et al.* (2015). In short the steps are as follows:

1. A minimum filter is applied to the data, and set to select the lowest value in a 250 x 250 m (for SRTM-30, approximately 64 cells of 30 x 30 m) block of cells.
2. From LiDAR data we know that coastal peatlands in Sumatra are not higher than 10-12 m +MSL. All remaining cells after step 1 which have elevation values above 10 m were therefore removed from the data.
3. Median (canal) filter: After application of the ‘minimum filter’, the SRTM data may in some areas be dominated not by the actual peat surface but by values that represent canal sides and canal water levels, which can be over a metre below the peat surface where water levels are low. Such ‘canal’ levels are removed by applying a filter that removes cell values that are more than 2 m below the median (most common) value in the surrounding 8 cells.
4. The resulting elevation model represents the peat surface in open areas, but does not provide an accurate representation where dense vegetation occurs. Vegetation elevation in such areas is further removed by applying a ‘slope filter’, that uses the peatland characteristic in the study area as in the rest of SE Asia of the surface slope being only very rarely being above 2 m km^{-1} to remove all data points that are elevated above the general surface by more than this slope. This

filter is applied over a radius of 3 km around each point, removing all cells that are elevated above the general surface by more than this slope.

The remaining data after above filtering steps are shown in Figure 30.

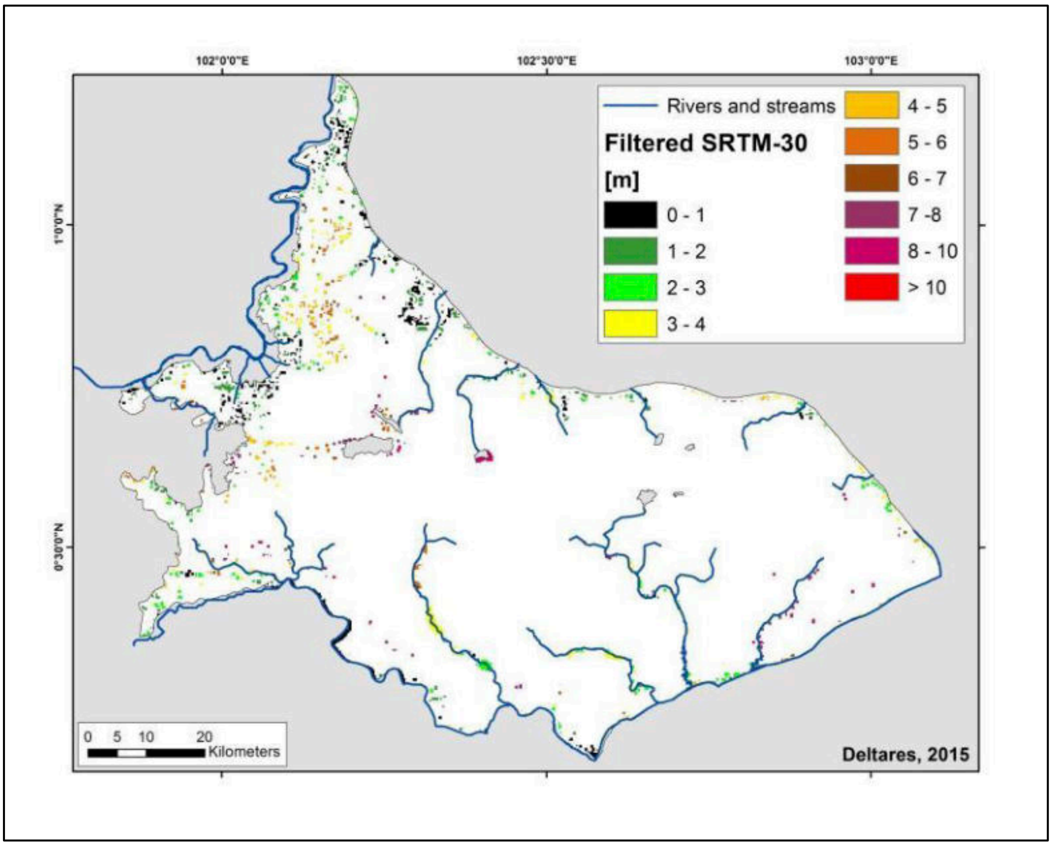

Figure 30 Remaining SRTM-30 data points after filtering.

To determine the accuracy of the filtered elevation data and determine the geoid to MSL correction, the data were compared with overlapping LiDAR data. This was done for the whole Riau Province as well as for the Jambi and South Sumatra Provinces (for which LiDAR data are also available through the PBPMP project) and only for those grid cells which were not on peat according to the Puslitanak 2003 peat map for Sumatra (Wahyunto *et al.*, 2003) to avoid cells which possibly have subsided in between the time of acquirement of the different data sets. Prior to the comparison the LiDAR data were resampled to the filtered SRTM-30 (250 m) resolution by taking the median value within the filtered window size. The comparison for the Riau Province is shown in Figure 31.

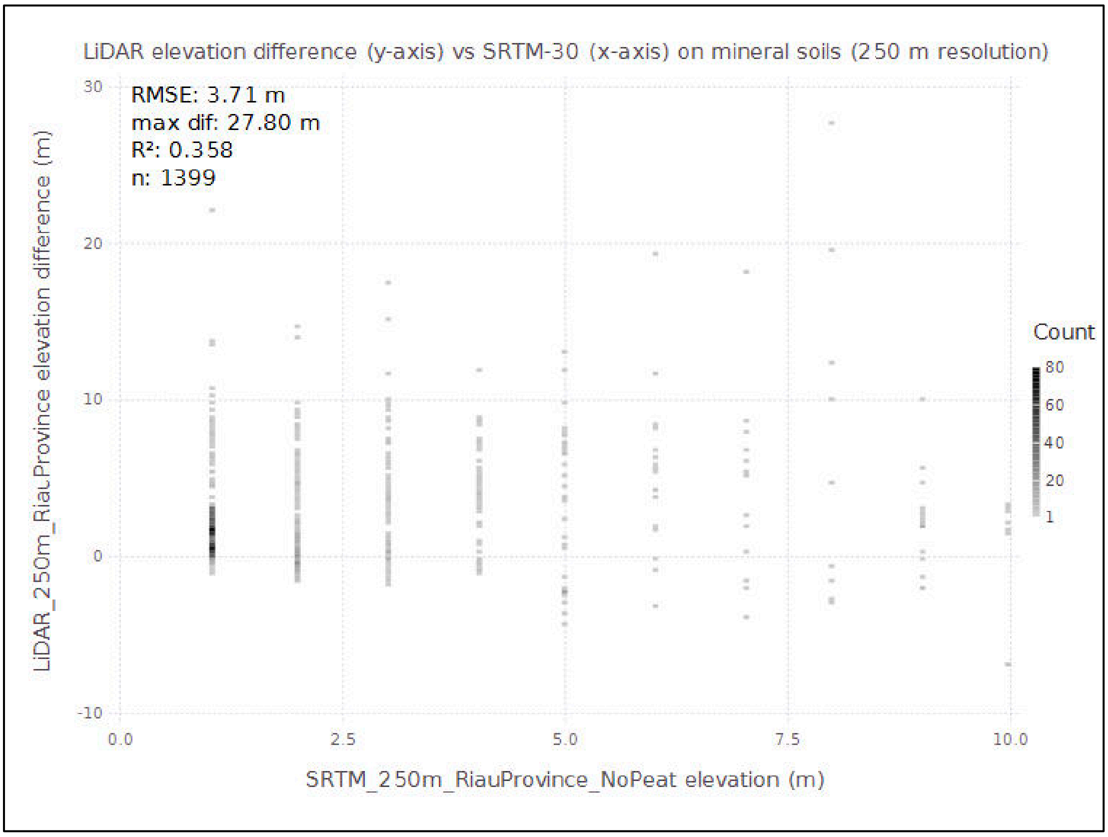

Figure 31 Comparison between LiDAR and filtered SRTM-30 for the Riau Province.

When inspecting Figure 31, it is clear that the majority of the remaining filtered SRTM-30 data points is either at 1 or 2 m (74.3 %). For the other two Provinces Jambi and South Sumatra, this is 67.7 and 66.3 % respectively. For all three Provinces together the average deviation between 1 and 2 m SRTM cells with LiDAR is +0.66 m. If this geoid to MSL correction is applied to the SRTM elevation values, the majority 67.1% of the data values deviates within 1 m from the LiDAR data, whereas 91.9% deviates within 2 m.

In areas where no LiDAR data or filtered and corrected SRTM-30 data were available, additional contour lines were drawn to aid the interpolation (Figure 32). In addition to these contour lines the elevation of the coastline was set to 0 m +MSL. The elevation model (DTM; Figure 33) has been generated through inverse distance interpolation using the LiDAR strip data, the filtered and corrected SRTM-30 data and contour lines.

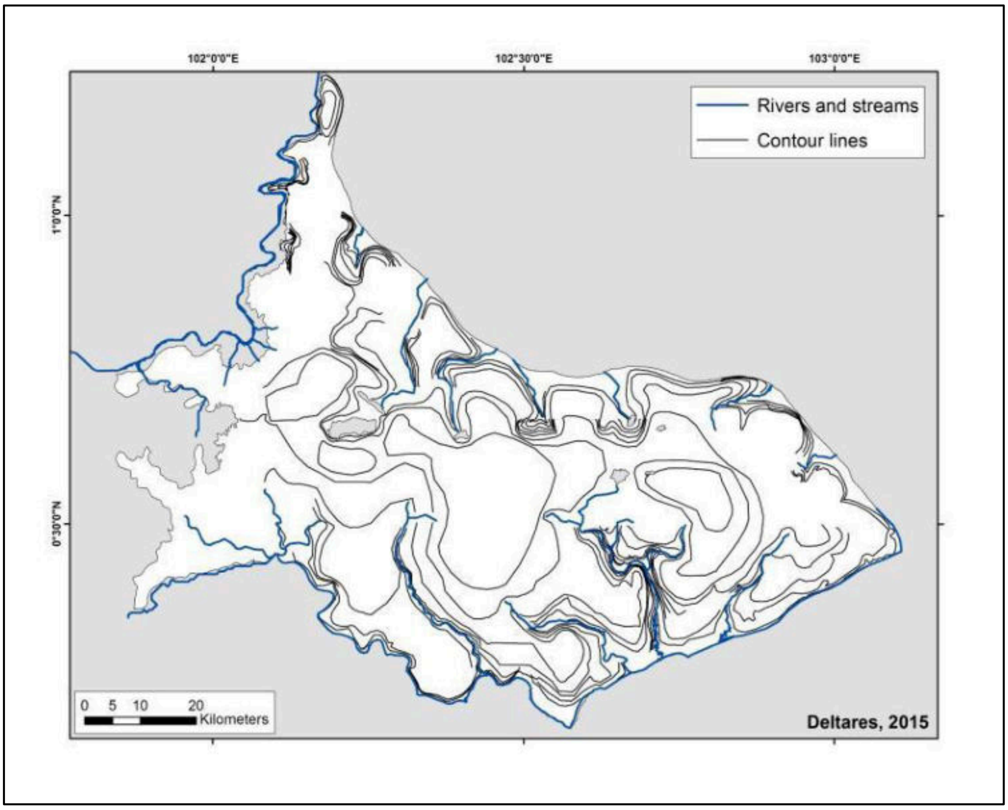

Figure 32 Elevation contour lines based on interpretation of LiDAR strip data.

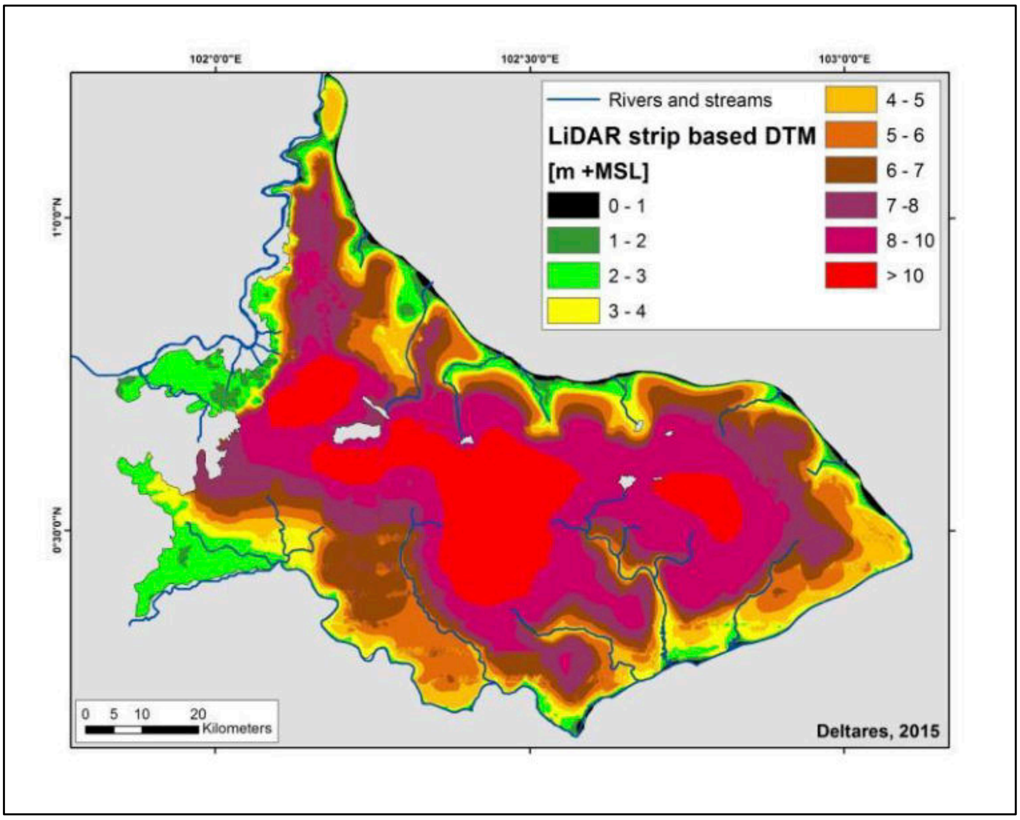

Figure 33 Elevation model for the KP peatland study area based on LiDAR data.

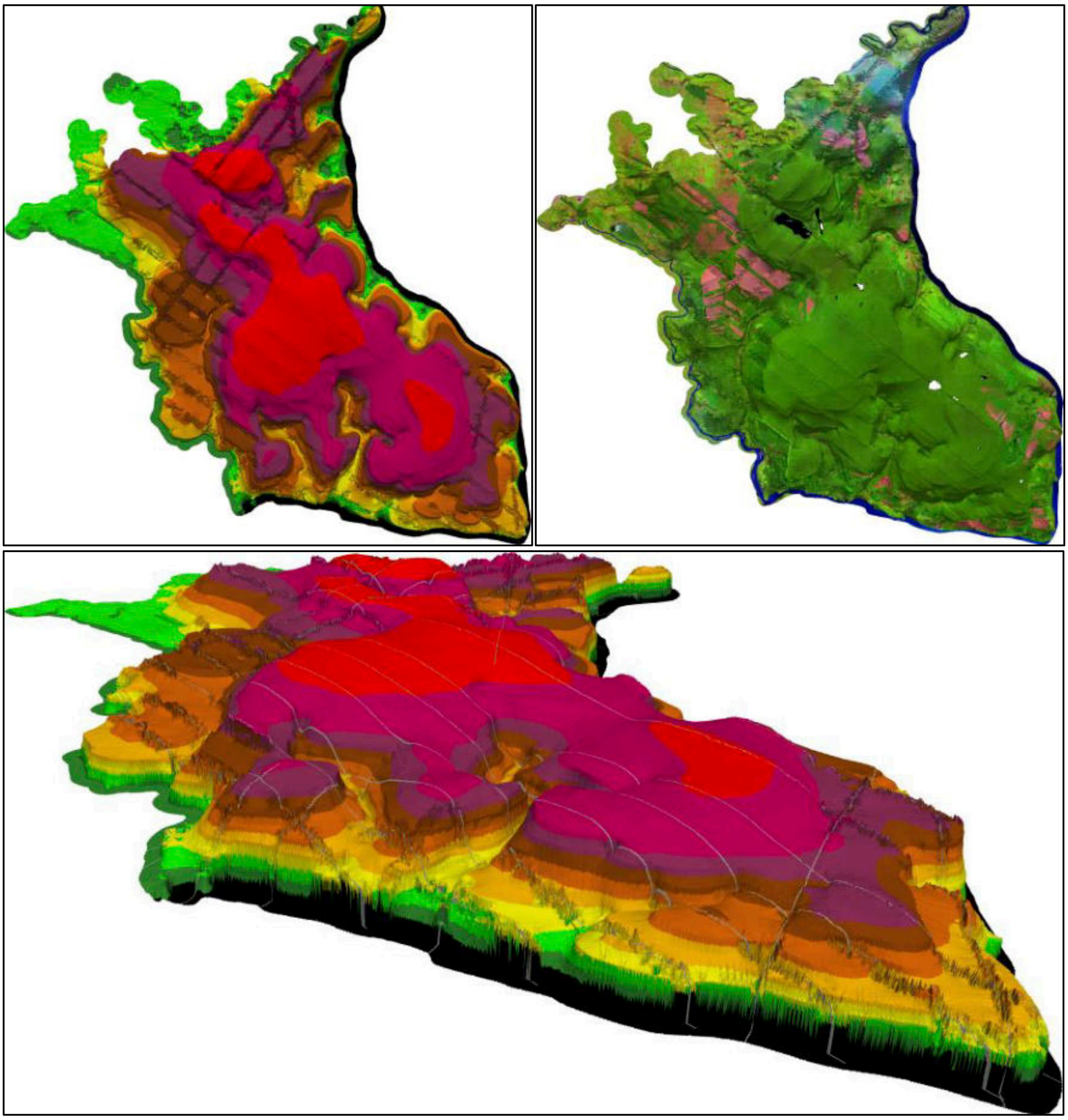

Figure 34 Three-dimensional DTM versions of the study area, with elevation intervals as in Figure 33. The bottom image also shows the location of the LiDAR flight lines.

We realize that the elevation model will not everywhere be as accurate as on the location of the LiDAR strip data. A confidence map (Figure 35) has therefore been created which accompanies the elevation model (Figure 33). Four confidence classes are defined as follows:

1. On the LiDAR strip data, accuracy is within 0.25 m
2. Within 3 km from the LiDAR strip data, accuracy is for 90% of the area within 0.5 m, and within 1 m for 100 % of the area (based on findings in Vernimmen *et al.*, 2014)

3. More than 3 km from the LiDAR strip data, where there are filtered and corrected SRTM-30 data, within 1 m for 67 % of the area and within 2 m for 92 % of the area.
4. More than 3 km from the LiDAR strip data, where there are no SRTM-30 data available estimated 75 % of the area within 2 m.

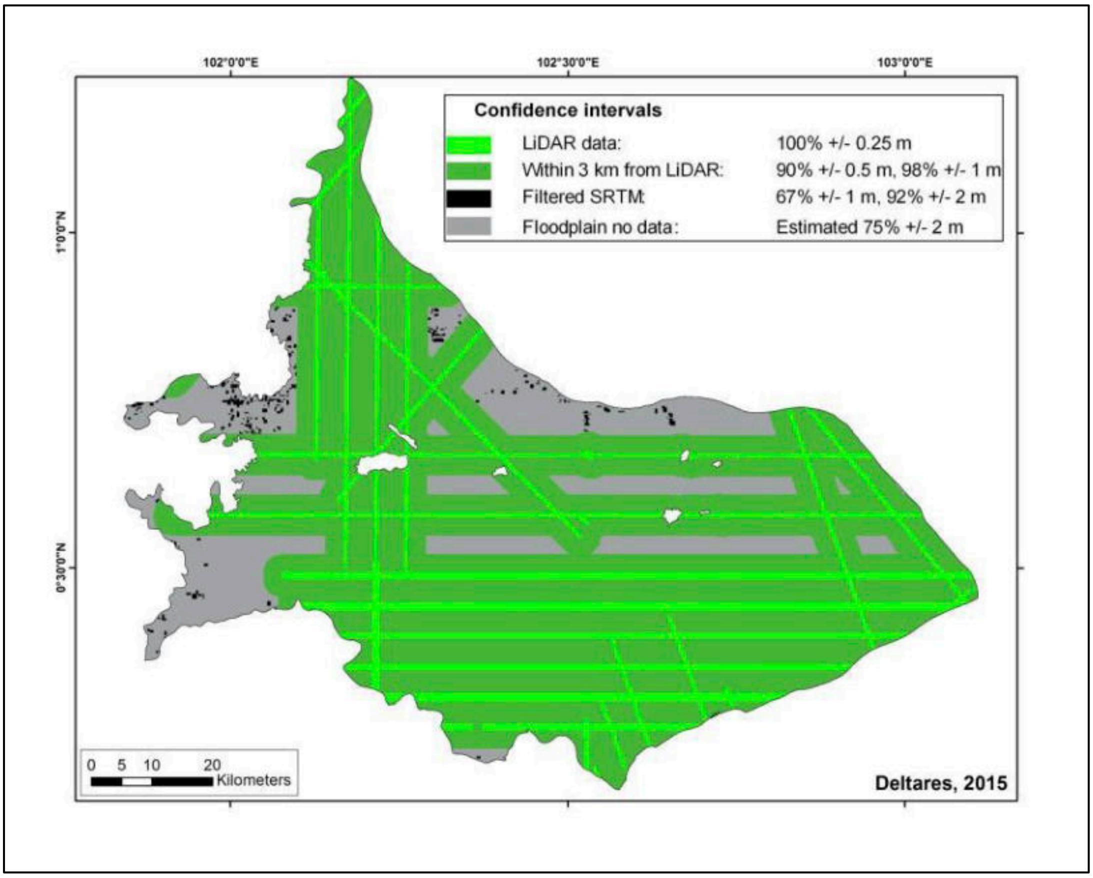

Figure 35 Elevation confidence map for elevation model shown in Figure 33. Confidence classes as explained in text.

Annex C – Peat thickness and carbon stock model of the Kampar Peninsula

Peat thickness data and model

The peat thickness and position of the peat bottom in the Kampar Peninsula peat dome need to be quantified before it is possible to understand current and future impacts of drainage on carbon emission and flooding. A total of 577 peat thickness measurements (with an average peat thickness of 8.0±2.7 m), as collected in the QANS project (521 measurements) from several sources (Hooijer and Vernimmen, 2013) and provided by APP through the PBPMP project (56 measurements), were available for the Kampar study area to determine the position of the peat bottom (Figure 36).

Of the 577 peat thickness measurements 122 (21.1 %) were located on the LiDAR strip data as shown in Figure 35. An additional 358 peat thickness measurements (62.0 %) were located within 3 km distance from the LiDAR strip data. The remaining 97 (16.8 %) peat thickness measurements were located in areas which have the lowest elevation confidence (see explanation in Annex B). For those peat thickness measurements with the highest confidence in elevation the average peat bottom position is at -0.88±1.99 m below MSL (Table 11).

Table 11 Statistics on peat bottom position determined from peat thickness measurements and the LiDAR elevation model. Distinction has also been made for the separate elevation confidence classes as explained in Annex B.

		Elevation confidence classes			
	All	**1**	**2**	**3**	**4**
Average [m MSL]	-1.02	-0.88	-1.14	-2.30	-0.75
St. dev. [m]	1.82	1.99	1.70	0.65	1.98
n	577	122	358	2	95
min [m MSL]	-9.04	-9.04	-7.24	-2.76	-5.04
max [m MSL]	2.71	1.95	2.71	-1.84	2.53
% <0 m +MSL	71.2	63.1	76.3	100.0	62.1
% <2 m +MSL	99.0	100.0	99.4	100.0	95.8

From Figure 37 it is evident that the peat surface elevation and peat thickness, plotted as a function of distance to the nearest major river (excluding smaller black water rivers, as these are part of the peat dome system and also are not fully mapped), yield nearly identical regression lines although it is noted that the variation in peat thickness is much greater than in elevation, and the regression line for peat thickness therefore has a lower R^2 (of 0.39, vs 0.63 for elevation). It follows that the elevation of the peat bottom, which is calculated by subtracting peat thickness from surface elevation, must be close to Mean Sea Level on average and must be close to horizontal, as is also evident from Figure 37. Indeed, the average peat bottom elevation calculated over this dataset is -1.02±1.82 m below MSL.

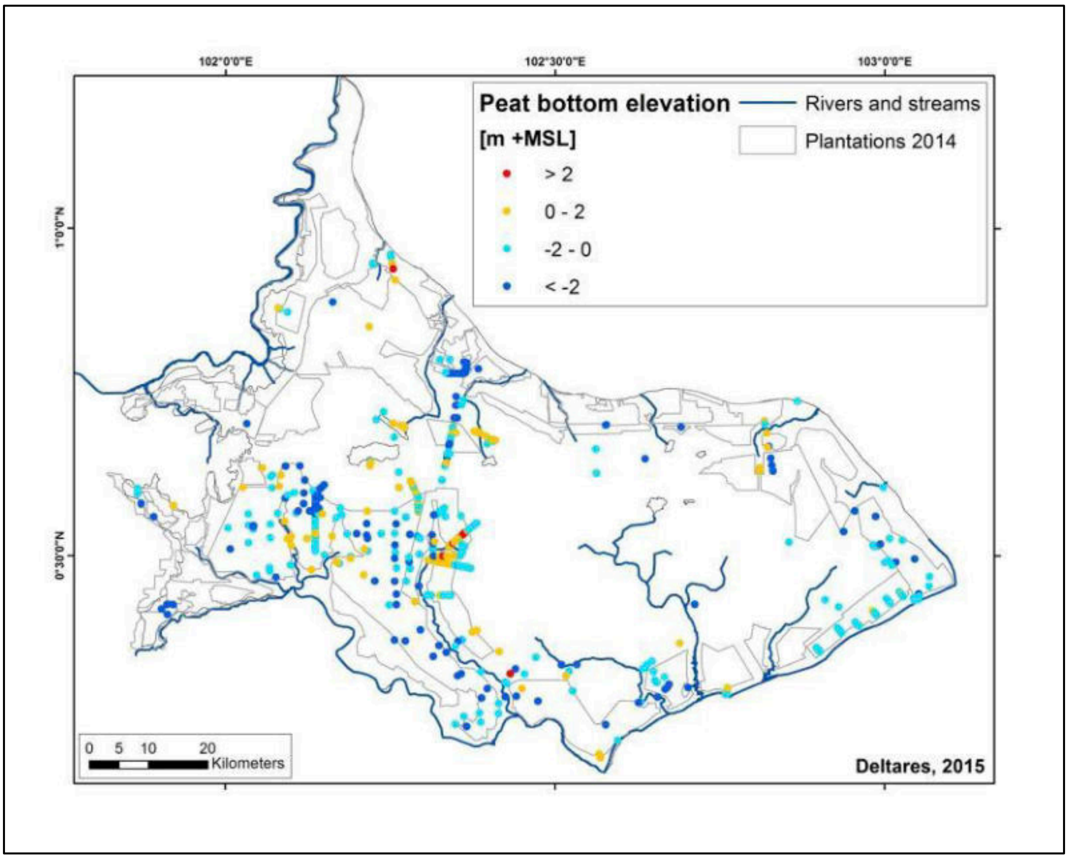

Figure 36 Peat bottom elevation determined for peat thickness measurement locations in the Kampar study area where elevation data are available from the LiDAR DTM (Figure 7).

The high standard deviation of 1.82 m shows that the position of the peat bottom has substantial variation in space. This is also clear from Figure 37, which shows the peat bottom elevation to vary from almost 3 m above to 9 m below Mean Sea Level. However, the most important aspect is to know whether the peat bottom is above or below the level below which frequent flooding becomes inevitable.

Very close to the coast and in the coastal lowland rivers, the average flood level is at least 2 m +MSL (see also Annex C), which corresponds with normal river levels and highest high tides. Of the 577 observation points, the peat bottom is more than 2 m +MSL in only 1.0 % of cases, which are all found very close to the coast or rivers (Figure 36). We therefore consider a map of the depth of peat above 2 m +MSL to accurately represent MINIMUM peat thickness as is presented in Figure 9.

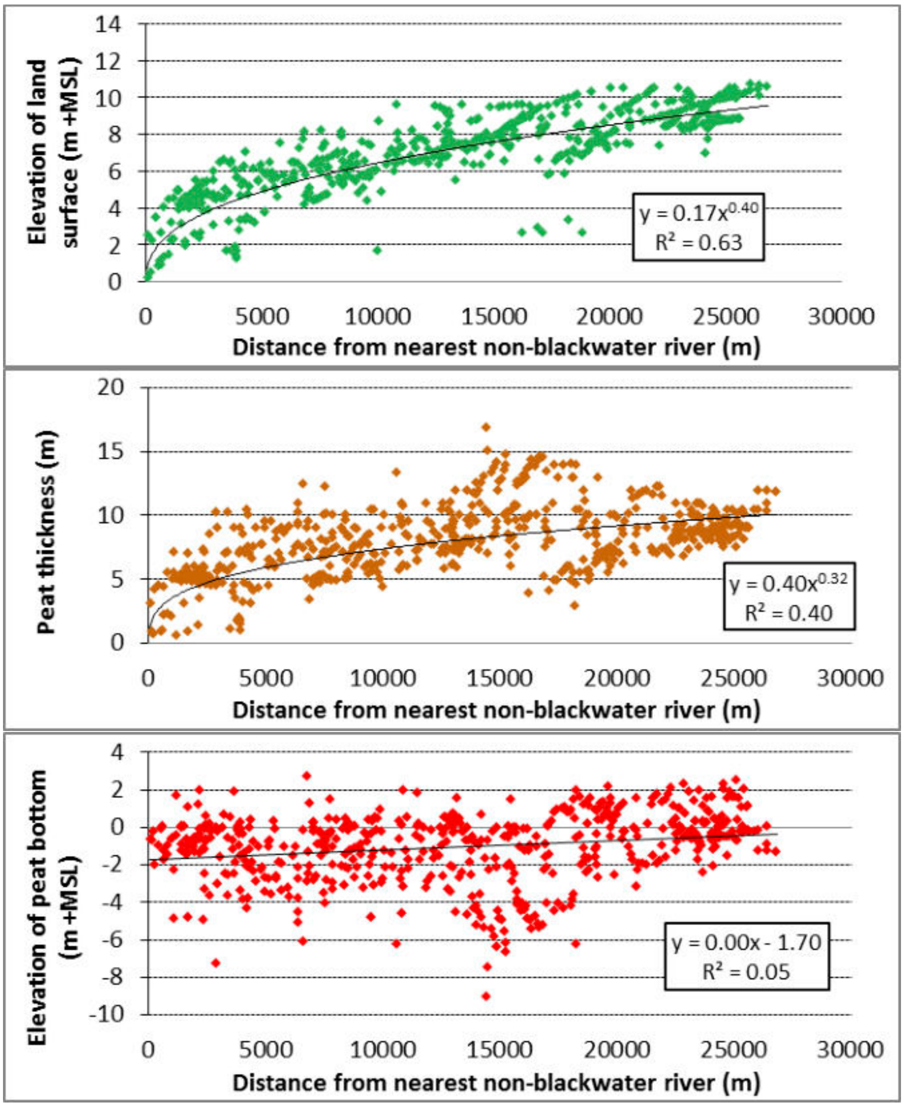

Figure 37 Synthesized profiles on peat surface elevation (top), peat thickness (middle) and peat bottom elevation (bottom) of the Kampar Peninsula study area where elevation data are available from the LiDAR-derived DTM as shown in Figure 7.

Carbon stock model

In order to quantify the potential future carbon loss it is necessary to know how much carbon is stored in the Kampar peat dome. The amount of carbon stored in a unit volume of peat is estimated by multiplying the bulk density (BD) by the carbon concentration (CC) of dry peat. For all peat a BD value of 0.09 g cm^{-3} and a uniform CC value of 56 % is applied, following Page *et al.* (2011), who used these average values to calculate the SE Asia tropical peatland carbon pool. The resulting carbon density is 0.0504 g cm^{-3}. Applying this value to the minimum peat thickness map of the Kampar study area (Figure 9), a total amount of carbon of 1.6 Gt (giga tonnes) is determined, which is 2.8 % of Indonesia's estimated below ground carbon pool of 57.4 Gt (Page *et al.*, 2011). The distribution of the carbon stock is shown in Figure 38.

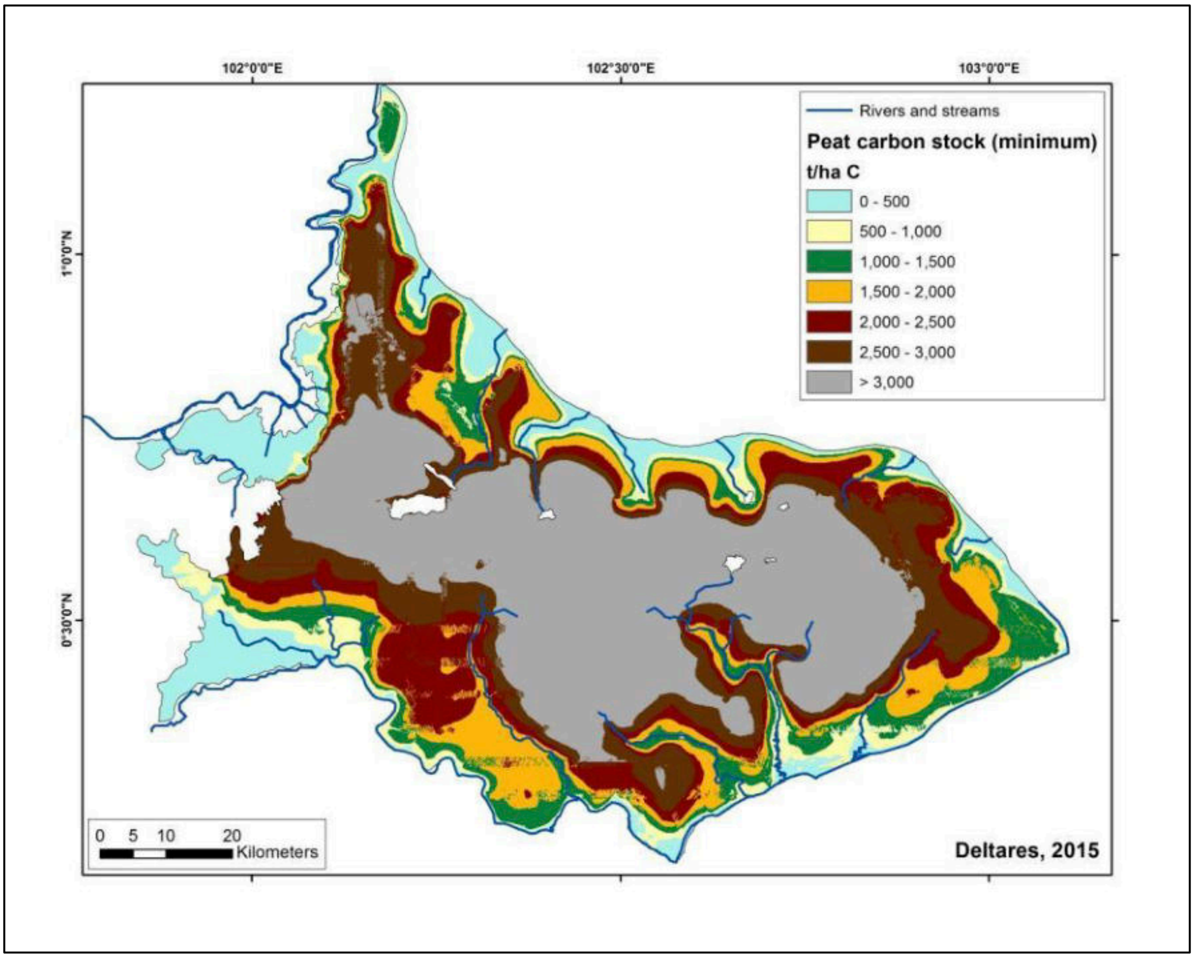

Figure 38 MINIMUM peat carbon stock map. Calculated using the minimum peat thickness map (Figure 9) multiplied by a carbon density of 0.0504 g cm^{-3}.

A more likely carbon stock is estimated from the likely peat thickness map derived by applying an average peat bottom position of 1 m below MSL (Table 11) to the elevation model. A total amount of carbon of 2.6 Gt (4.6 % of Indonesia's estimated below ground carbon pool of 57.4 Gt; Page *et al.*, 2011) is determined. The distribution of the carbon stock is shown in Figure 39.

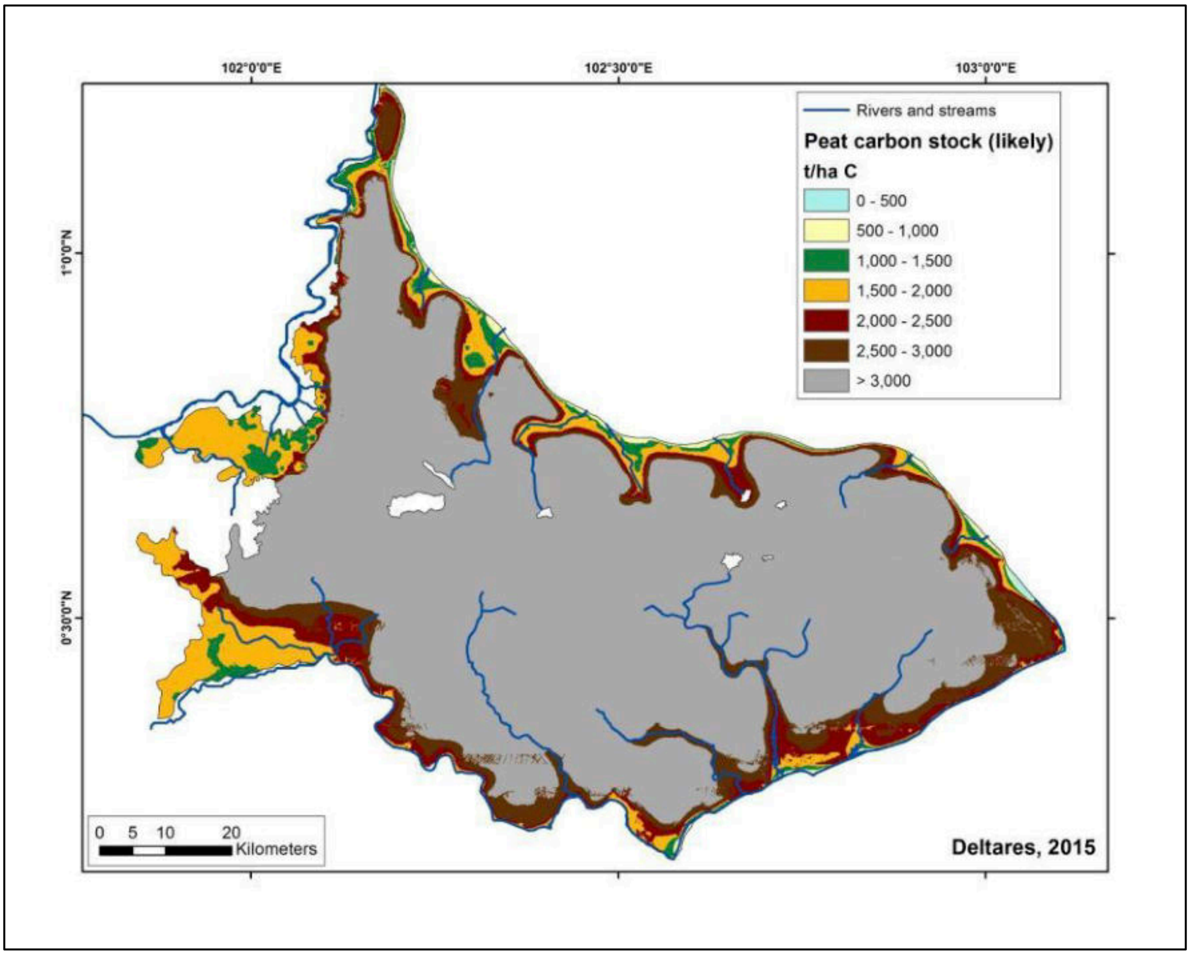

Figure 39 Likely peat carbon stock map. Calculated using the likely peat thickness map (from the elevation model with a fixed average peat bottom position of 1 m below MSL) multiplied by a carbon density of 0.0504 g cm^{-3}.

Annex D – Subsidence and flooding projections for the Kampar Peninsula

Flood risk types

1. Defining the Coastal and River High Water Levels, HWL

The High Water Level (HWL) represents the elevation that can be reached by sea and river levels for prolonged periods. HWL therefore represents the elevation below which the land surface would be flooded periodically and for long periods without feasible options to remove flood waters[7]. Where subsidence is allowed to bring the peat surface below HWL, agriculture will almost certainly be impossible.

HWL along the coast

Along the coast, tidal HWL is determined by tidal regime and storm surges. Tidal flooding occurs where the land surface is below the upper limit of the astronomic high tide level of the sea surface. As peak high tides occur only over short periods of less than a day, they can sometimes be managed (using ‘flap gate’ systems, or sometimes pumping in small urban areas) near the coast, but usually only as long as they do not coincide with extreme rainfall events. In the long term, such a coincidence of conditions is almost inevitable and flooding to at least high tide level is likely. Such events may be rare and brief, and may not end agricultural productivity by themselves, but they will complicate management, reduce yields and bring up water management cost.

Astronomical tidal range could be determined for four tidal stations in the vicinity of the study area (Figure 40). The tidal range in the Kampar River is almost 2 m higher compared to the Siak River (Figure 41). Astronomical tide peak for the Kampar River is 2.5 m +MSL whereas for the Siak River entrance this is 1.4 m +MSL. To the maximum astronomical tide levels an estimated 0.5 m storm surge was added. In the model we have therefore applied a tidal HWL along the coast of 1.9 m +MSL from the Siak River entrance up to 3 m +MSL in the Kampar River. Tidal HWL in the Panjang Strait was estimated through linear interpolation between tidal HWL levels at the Siak River entrance and Kampar River. These levels were in strong agreement with embankment levels as determined from LiDAR strip crossings, which along the Panjang Strait ranged from 1.5 to 3 m +MSL.

[7] While pumping can solve flooding problems in small urban areas and some larger areas in Europe and the USA, this solution is almost certainly not feasible in rural areas in SE Asia, because i) the protected agricultural investments here are too low to justify the very high cost and ii) rainfall intensities are far higher than in other parts of the world, requiring proportionally more pumping capacity.

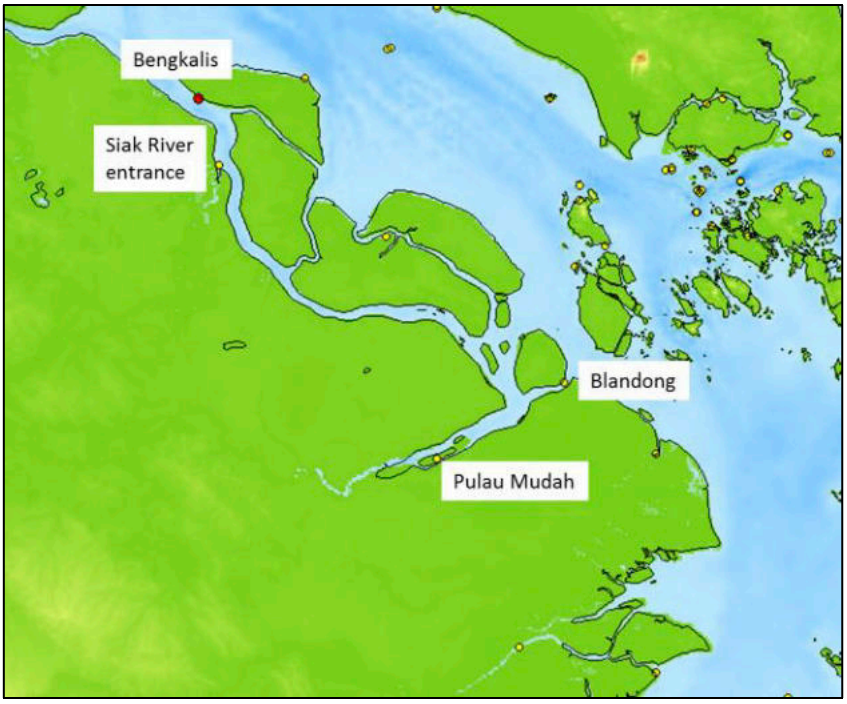

Figure 40 Location of tidal stations in the vicinity of the Kampar Peninsula study area.

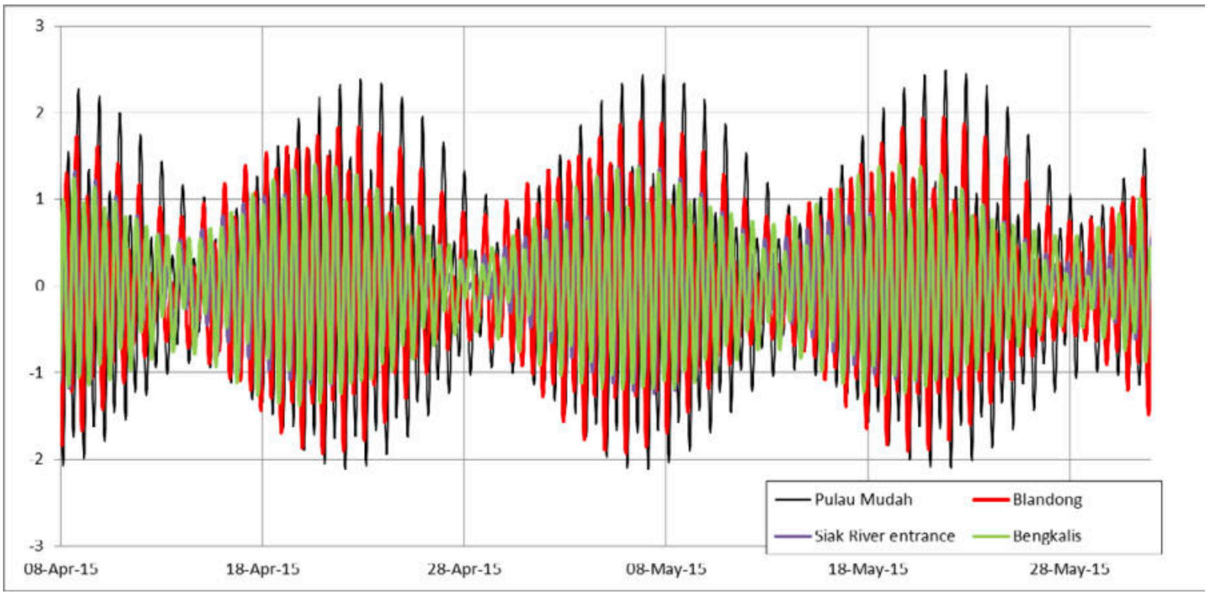

Figure 41 Astronomical tidal range for the period April – May 2015 for 4 IHO (International Hydrographic Organization) tidal stations in the vicinity of the Kampar Peninsula study area. Astronomical tide data were extracted using the Delft Dashboard available from https://publicwiki.deltares.nl/display/OET/DelftDashboard. For location of the tidal stations see Figure 40.

HWL along rivers

Both Siak and Kampar rivers are known to be tidal for more than 100 km inland (Cecil *et al.*, 1993). Further away from the coast, HWL is increasingly determined by river discharge and less by tidal regime. As we don't have any water level measurements for the Kampar River we have based it on the River Bank Level (RBL) which is defined as the elevation of the river side (levee) that is known to flood frequently. The RBL points were determined at those locations where the LiDAR strips (Figure 27) crossed the Kampar River. RBL points gradually increased with distance from the coast from 3 m until 3.5 m +MSL for the Kampar River. This is 0.5 m above high tide level. Along the Siak River no clear embankments were found, and as such it was decided to also add 0.5 m on top of the 1.9 m high tide level as determined for the Siak River entrance tidal station.

The HWL levels as determined from the analysis above were used to construct a plane as proxy for the high water level. The interpolated HWL plane is shown in Figure 42. It should be noted though that the HWL applied here will actually be somewhat higher than the RBL to allow for flooding.

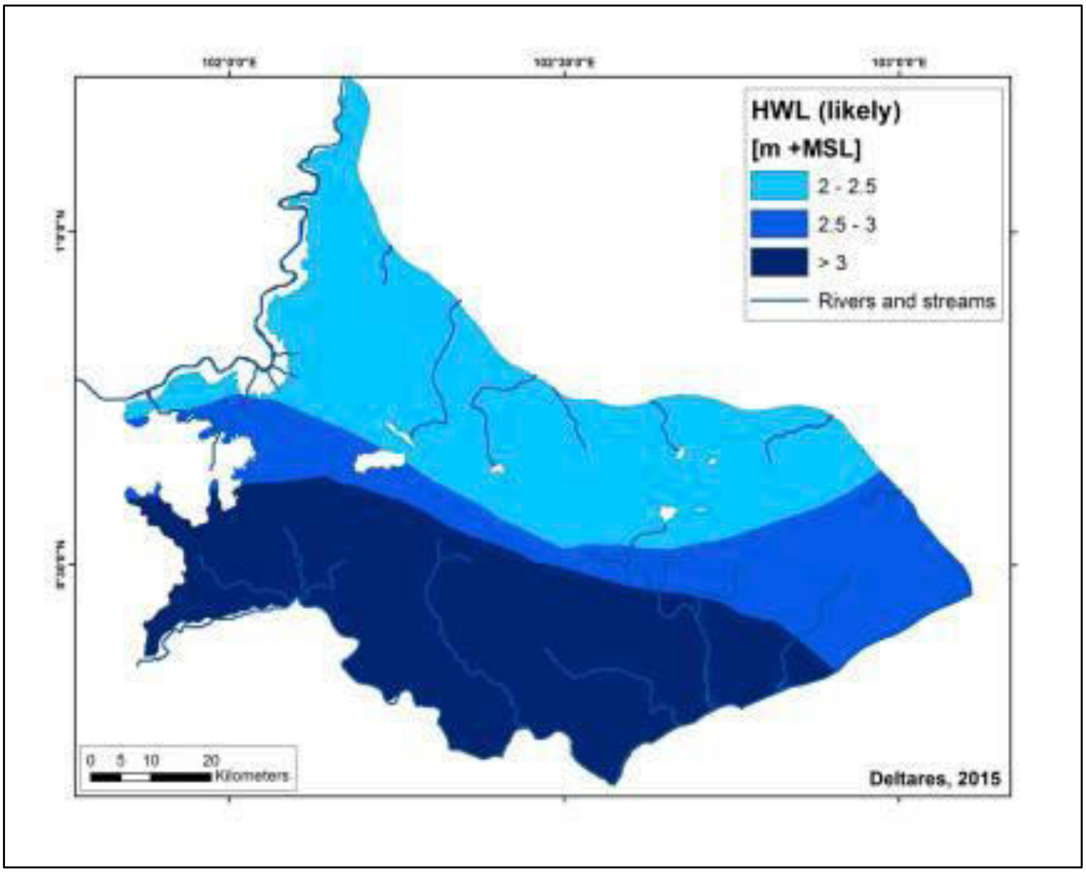

Figure 42 Likely High Water Level (see text for definition) in the study area.

2. Establishing the Free Drainage Limit, FDL

Impaired drainability starts when the peat surface approaches the local Free Drainage Limit (FDL), defined by adding a conveyance gradient of 0.2 m km^{-1} (DID Sarawak, 2001) to High Water Level (HWL), calculated as a function of distance from the coast and River. When land subsidence brings the peat surface below FDL, it becomes increasingly difficult to remove heavy rainfall from the land. The frequency of first waterlogging and later flooding increases as the peat surface subsides further below FDL, and sustained crop cultivation will require increased water management efforts. A soil depth of 0.5 m above the water table is added to FDL levels, which is the minimum required to grow most crops on peatland (DID Sarawak, 2001). The Free Drainage Limit for the Kampar peatland study area is visualized in Figure 21.

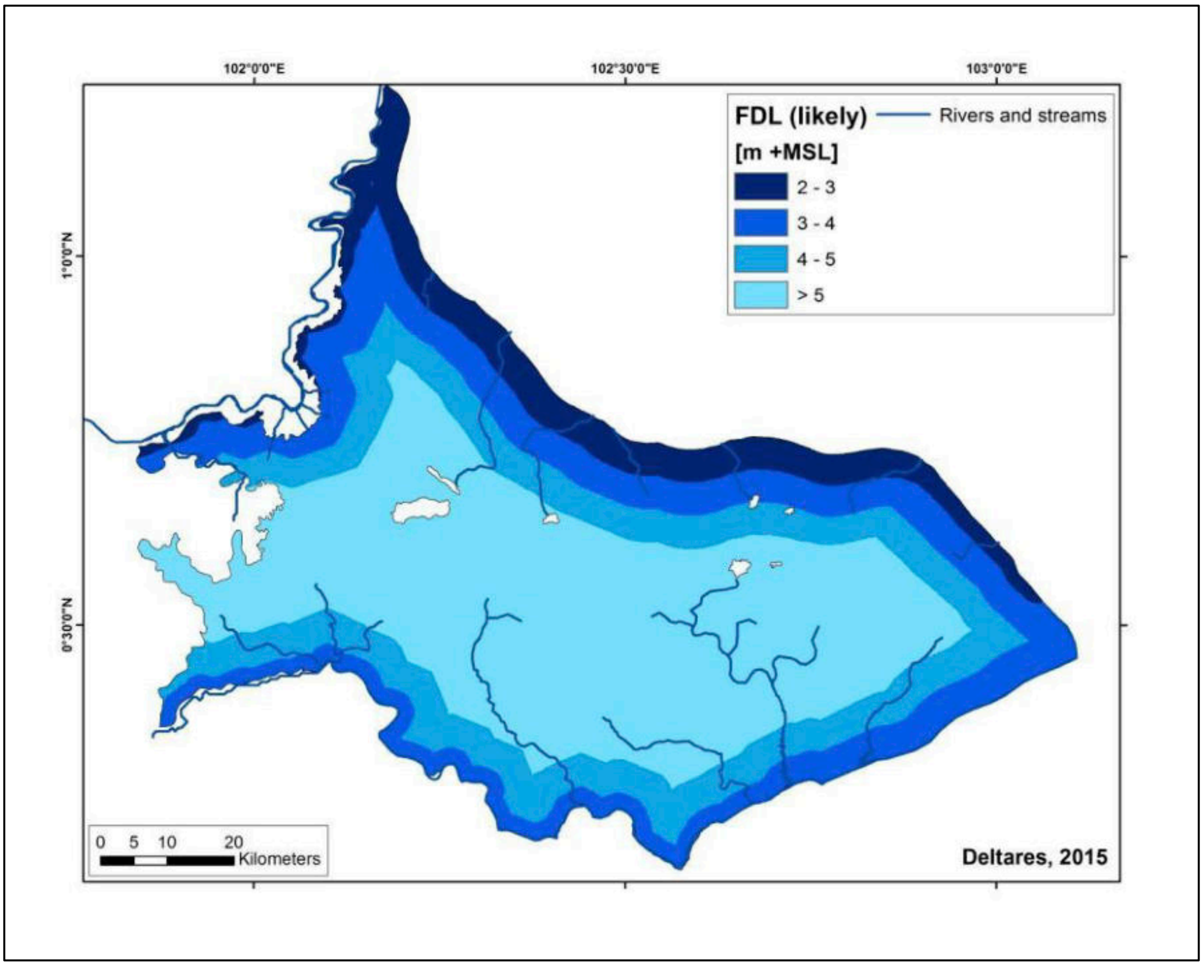

Figure 43 Likely Free Drainage Limit, as determined from HWL (Figure 42) and applying a conveyance gradient of 0.2 m km^{-1} from the coast and Siak and Kampar Rivers.

Calculation and presentation of flood risk

A conservative subsidence rate of 3.5 cm yr^{-1} is applied, which is in accordance with the conservative emission rate of 15 t ha^{-1} yr^{-1} applied for emission calculations (IPCC, 2013; FAO, 2014), and at the lower end of actual subsidence rates measured in plantations on the Kampar Peninsula (Hooijer *et al.*, 2012; Couwenberg and Hooijer, 2013). This rate is applied to the elevation model in areas where plantations were already developed in 2014 (Figure 14), or where concessions exist (Figure 16), over a period of 150 years. After each 25 year time step, we test for each cell whether it is above or below the flooding thresholds. The result is a series of maps showing flooding and drainability conditions after 25, 50, 75, 100, and 150 years. We do not account for the reduction in subsidence rate that is likely to occur as an area gets more frequently flooded, as this relation is as yet unknown and we assume that no substantial reduction in subsidence rate will occur until an area has become flooded for a period of months each year, which is many years after agricultural production is likely to be seriously affected.

The different flooding and drainability risks are presented in a single map, as shown in Figure 44. In these maps, only the condition that is considered to have the greatest impact on land use is shown, with the surface being below HWL being more impacted by flooding than being below FDL. In some areas, peat surface levels are or will be below both thresholds, but only HWL is shown there.

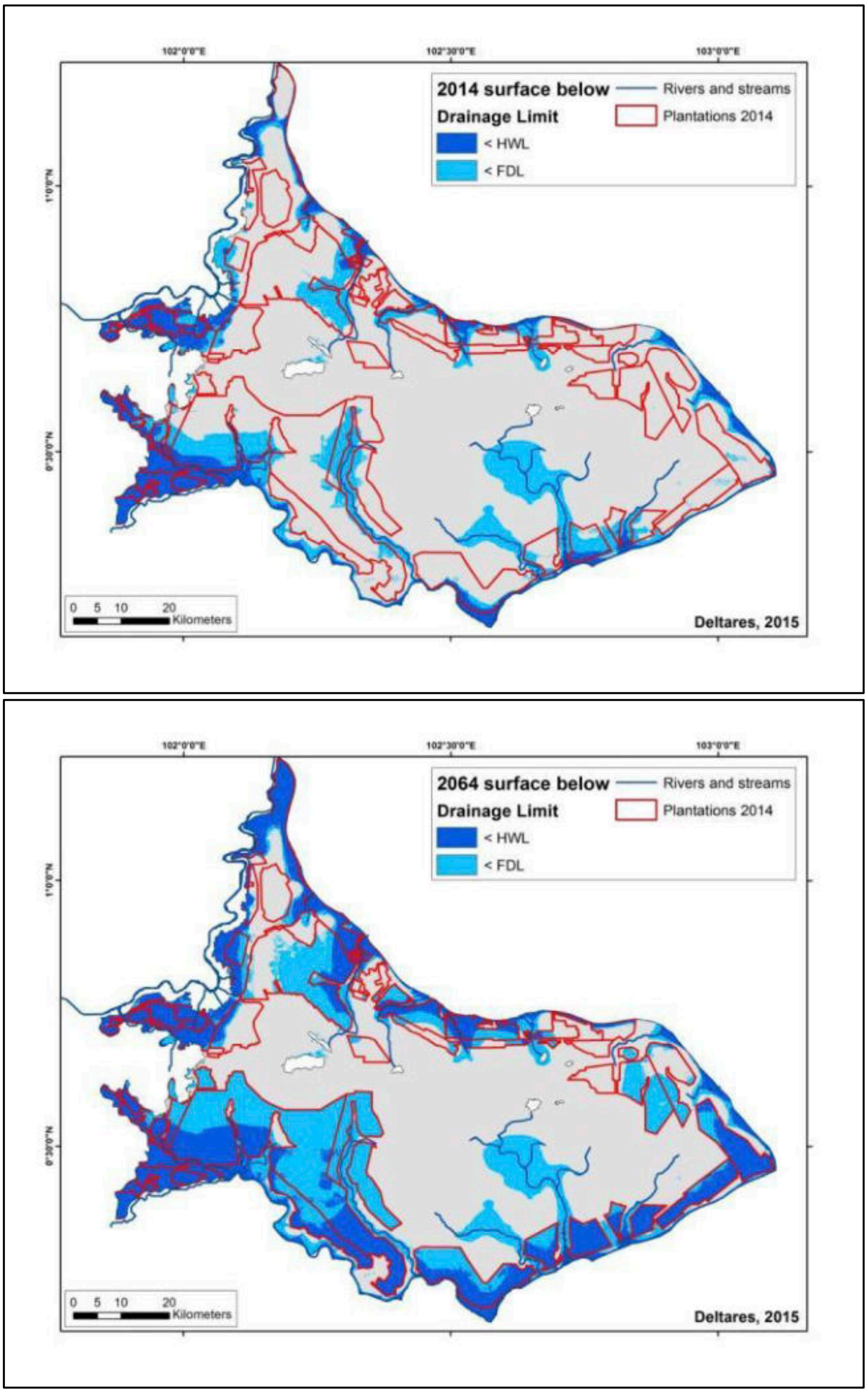

Figure 44 Modelled likely flood extent (HWL) and drainability (FDL) for (top) 2014 and for (bottom) 50 years after 2014.

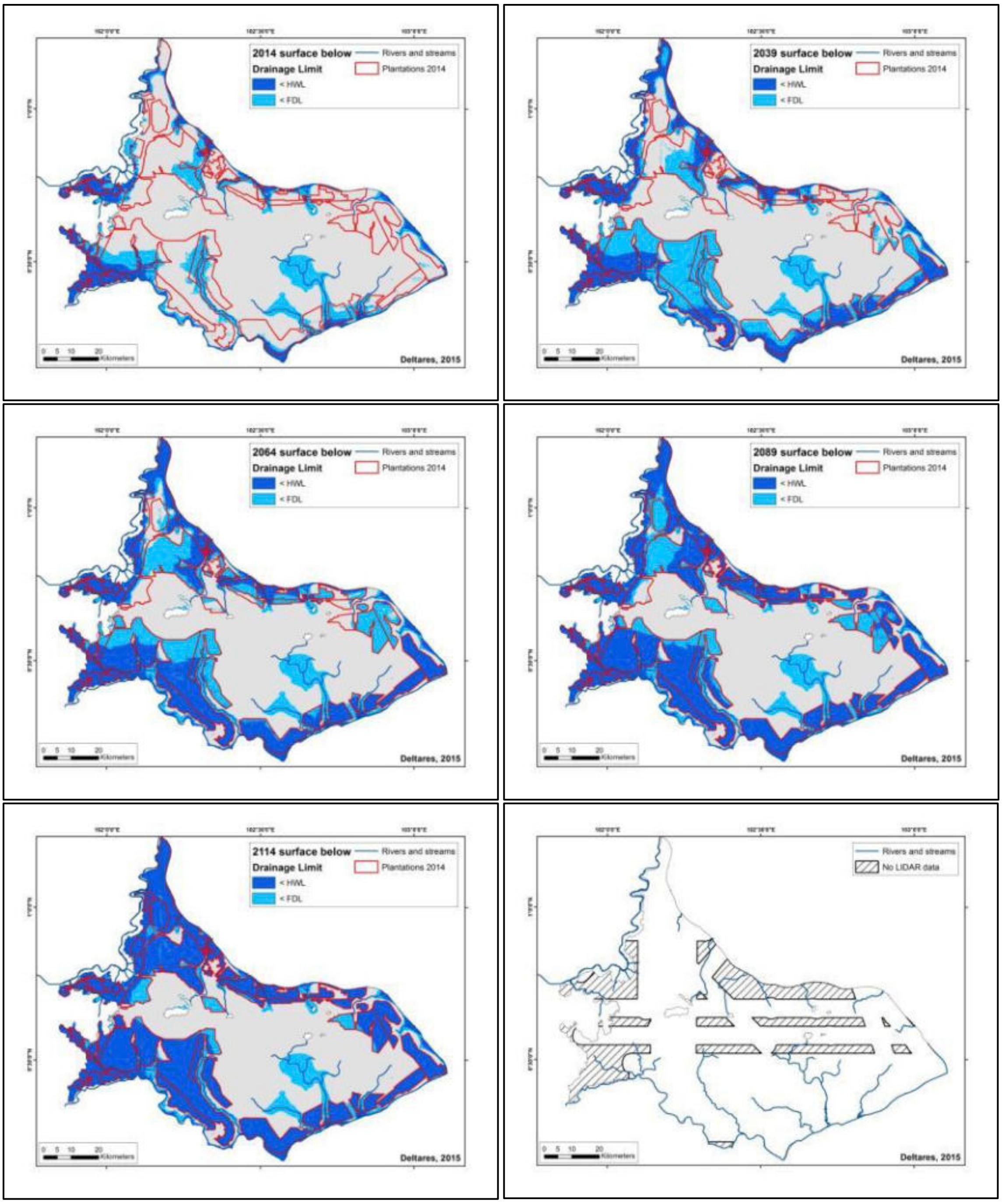

Figure 45 Flood extent projection for 0, 25, 50, 75 and 100 applying a 'Business As Usual' subsidence rate of 5 cm yr^{-1} to existing plantations (Figure 14) and flooding thresholds after 2014 (the date for which the DTM was created using LiDAR data). The associated areas are presented in Table 12. The flood extent projections applying a 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} are shown in Figure 18. The right bottom map shows the area where the Flood extent projection will be less accurate since for those areas no LiDAR data is available. See also the confidence map shown in Figure 35.

Table 12 Areas that are frequently flooded (below HWL) or have impeded drainability (below FDL), in ha and as % of total area, for the different type of plantations which are already developed in 2014 within the Kampar Peninsula study area, in the 'Business As Usual' scenario applying a subsidence rate of 5 cm yr^{-1}. Note 1: FDL presents the area that is ONLY below the FDL level but not below the HWL level. Note 2: total areas as presented here differ from other tables since calculations are done on a grid of 100 x 100 m and do not exactly cover the vector boundary lines. The areas for the 'Best Management Practice' scenario are provided in Table 5.

Year	Time in future (yrs)	Area below the following drainage limit:					
		High Water Level (HWL)		Free Drainage Limit (FDL)		HWL+FDL	
		ha	% of total area	ha	% of total area	ha	% of total area
All existing industrial and smallholder drainage							
2014	0	39742	13.5%	51079	17.4%	90821	30.9%
2039	25	113117	38.5%	107858	36.7%	220975	75.3%
2064	50	170133	57.9%	98354	33.5%	268487	91.4%
2089	75	228951	78.0%	60319	20.5%	289270	98.5%
2114	100	274920	93.6%	18714	6.4%	293634	100.0%
2139	150	293533	100.0%	101	0.0%	293634	100.0%
2189	200	293542	100.0%	92	0.0%	293634	100.0%
Industrial Acacia plantation (APRIL & affiliated)							
2014	0	10208	6.5%	28098	17.8%	38306	24.3%
2039	25	47343	30.0%	78026	49.5%	125369	79.5%
2064	50	84411	53.5%	60291	38.2%	144702	91.7%
2089	75	118614	75.2%	35478	22.5%	154092	97.7%
2114	100	141424	89.7%	16311	10.3%	157735	100.0%
2139	150	157670	100.0%	65	0.0%	157735	100.0%
2189	200	157679	100.0%	56	0.0%	157735	100.0%
Industrial Acacia plantation (APP & affiliated)							
2014	0	587	1.1%	8825	16.7%	9412	17.8%
2039	25	14696	27.9%	19337	36.6%	34033	64.5%
2064	50	26640	50.5%	20616	39.1%	47256	89.6%
2089	75	35131	66.6%	17627	33.4%	52758	100.0%
2114	100	51576	97.7%	1189	2.3%	52765	100.0%
2139	150	52759	100.0%	6	0.0%	52765	100.0%
2189	200	52759	100.0%	6	0.0%	52765	100.0%
Large scale Oil Palm Plantations							
2014	0	9999	28.7%	5602	16.1%	15601	44.9%
2039	25	17907	51.5%	5465	15.7%	23372	67.2%
2064	50	20956	60.2%	12583	36.2%	33539	96.4%
2089	75	32202	92.6%	2565	7.4%	34767	100.0%
2114	100	34748	99.9%	34	0.1%	34782	100.0%
2139	150	34763	99.9%	19	0.1%	34782	100.0%
2189	200	34763	99.9%	19	0.1%	34782	100.0%
Smallholder Oil Palm Plantations							
2014	0	18948	39.2%	8554	17.7%	27502	56.9%
2039	25	33171	68.6%	5030	10.4%	38201	79.0%
2064	50	38126	78.9%	4864	10.1%	42990	88.9%
2089	75	43004	88.9%	4649	9.6%	47653	98.6%
2114	100	47172	97.6%	1180	2.4%	48352	100.0%
2139	150	48341	100.0%	11	0.0%	48352	100.0%
2189	200	48341	100.0%	11	0.0%	48352	100.0%

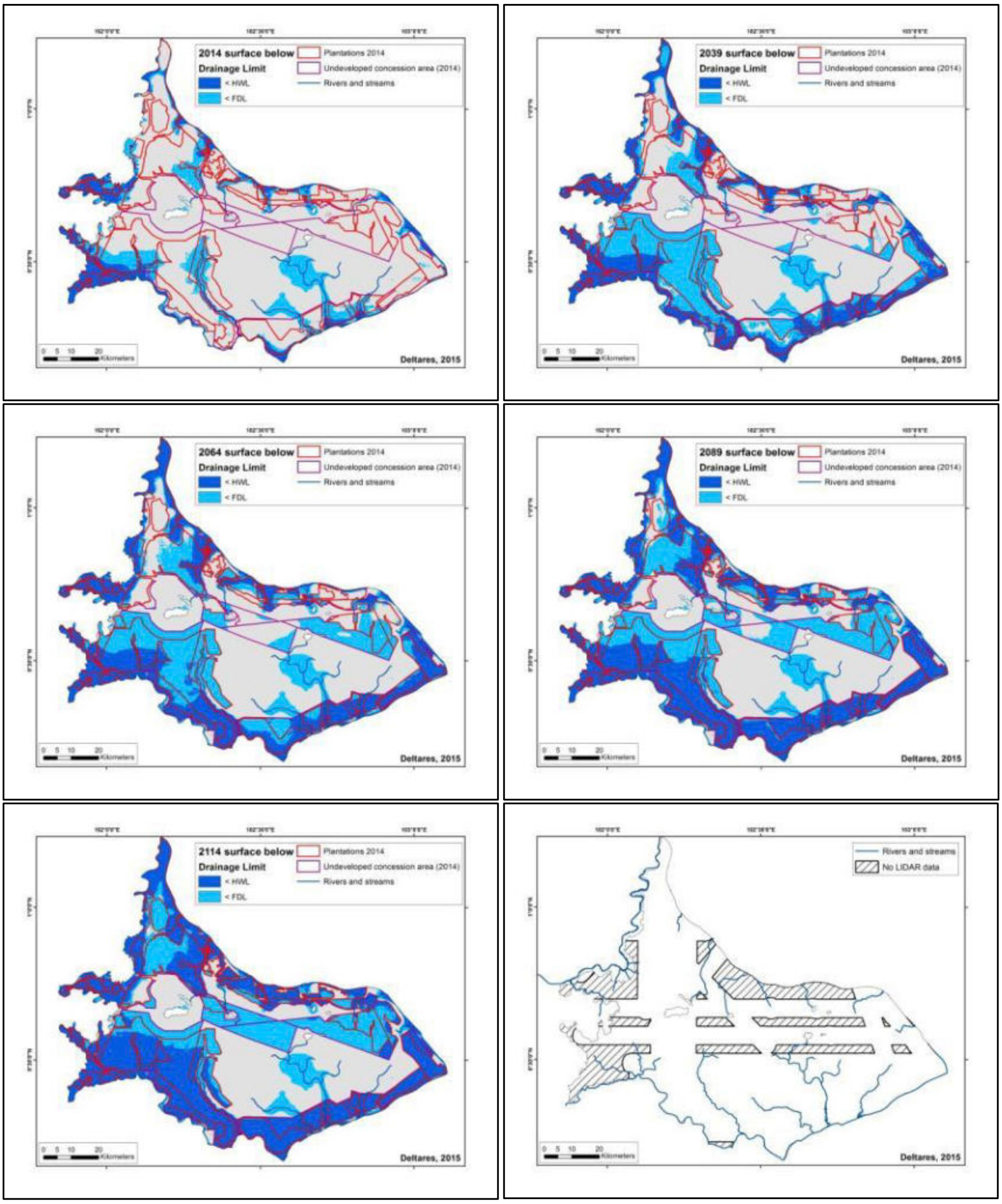

Figure 46 Flood extent projection for 0, 25, 50, 75 and 100 applying a 'Best Management Practice' subsidence rate of 3.5 cm yr^{-1} to existing plantations and undeveloped concession areas (Figure 16) and flooding thresholds after 2014 (the date for which the DTM was created using LiDAR data). The associated areas are presented in Table 7. The right bottom map shows the area where the Flood extent projection will be less accurate since for those areas no LiDAR data is available. See also the confidence map shown in Figure 35.

Annex E – Additional sources of official HTI concessions

In this Annex, maps showing location of official recent HTI concessions are presented which include concessions which were not included in the MoF 2010 GIS vector shape file. These maps were used to identify the location and owners of these 'additional' HTI concessions.

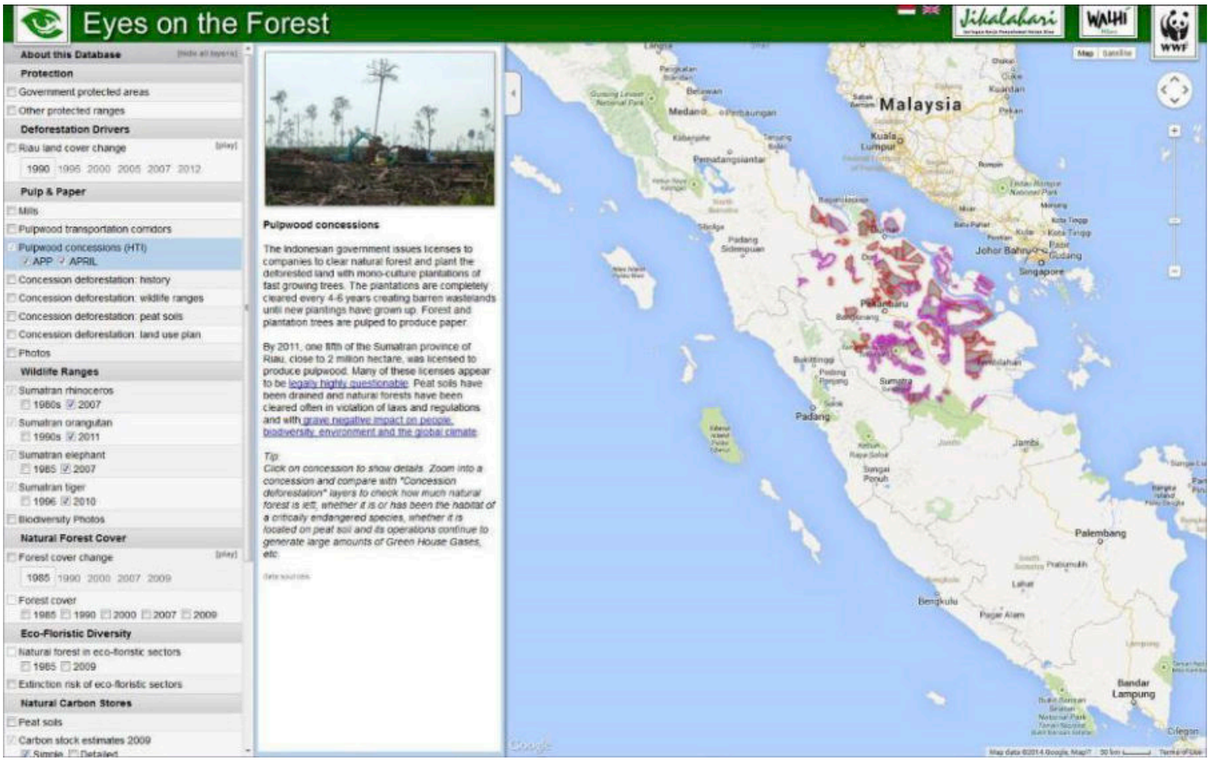

Figure 47 Paper and Pulp plantation concessions from Eyes on the Forest (http://maps.eyesontheforest.or.id/; accessed 19 August 2014).

Figure 48 Wood fiber plantations available from the Global Forest Watch fires platform (http://http://fires.globalforestwatch.org; last accessed 19 August 2014).

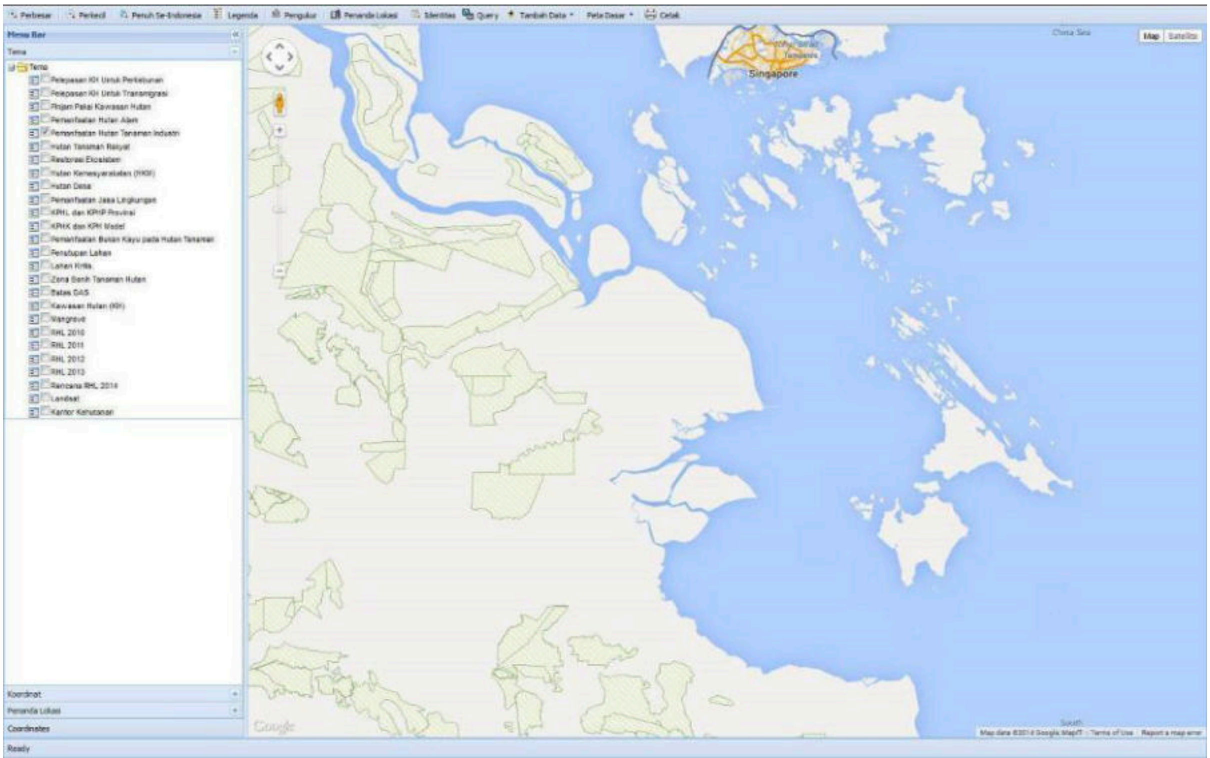

Figure 49 Web application of the Ministry of Forestry showing HTI concession areas (http://webgis.dephut.go.id/ditplanjs/index.html; last accessed 19 August 2014).

Figure 50 Ministry of Forestry landcover map 2012 (downloaded from http://appgis.dephut.go.id/appgis/petapl2012.html; last accessed 19 August 2014).

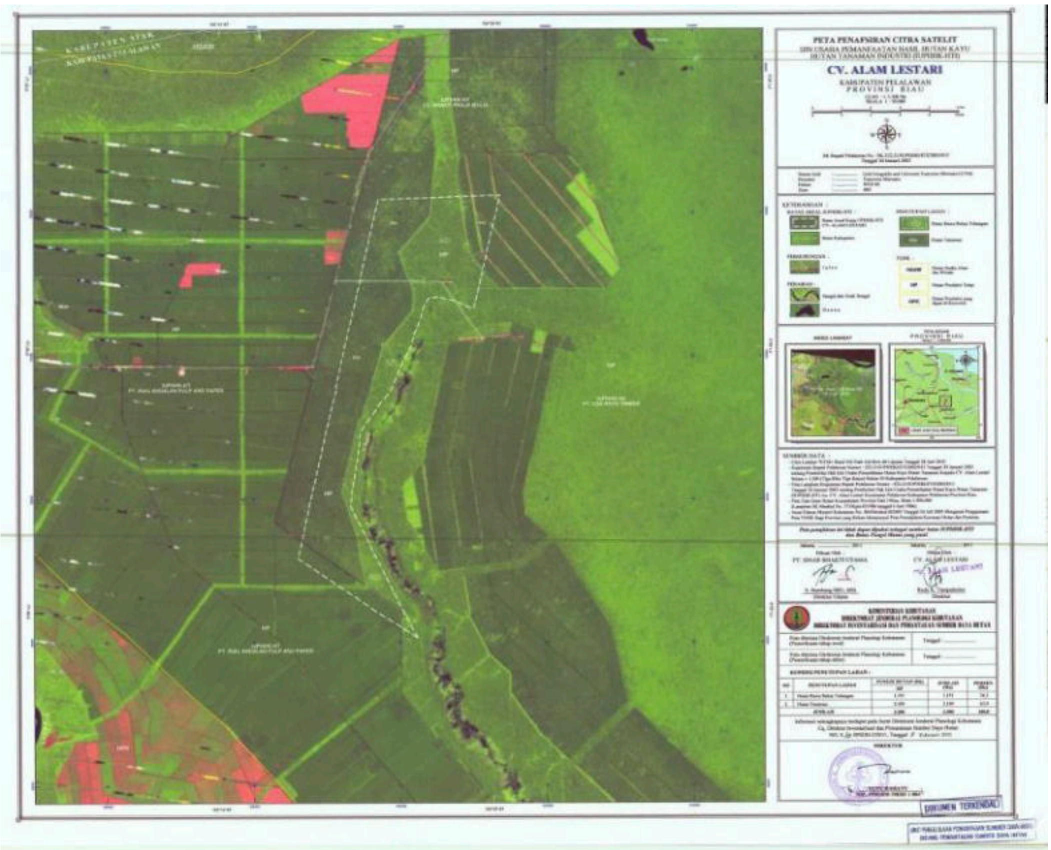

Figure 51 Ministry of Forestry Landsat interpretation of status of HTI concessions in 2011. Available for download from http://appgis.dephut.go.id/appgis/iuphhk.aspx; last accessed 19 August 2014. Example shown here status of CV. Alam Lestari concession in 2011. 2009 maps are available as well.

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