


Quick Assessment and Nationwide Screening (QANS) of Peat and Lowland Resources and Action Planning for the Implementation of a National Lowland Strategy

PVW3A10002
Agentschap NL 6201068 QANS Lowland Development

BAPPENAS & Ditjen Sumber Daya Air, PU
Government of Indonesia
&
Partners for Water Programme
The Netherlands

Peatland maps for Indonesia

Report on QANS Component 4

February 2013

Quick Assessment and Nationwide Screening (QANS) of Peat and Lowland Resources and Action Planning for the Implementation of a National Lowland Strategy

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Peatland maps for Indonesia

- Accuracy assessment
- Recommendations for improvement
- Elevation mapping
- Evaluation of future flood risk

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Abbreviations and Glossary

BAPPENAS	*Badan Perencanaan dan Pembangunan Nasional* (National Development Planning Agency)
BBSDLP	*Balai Besar Sumber Daya Lahan Pertanian* (Ministry of Agriculture)
BIG	*Badan Informasi Geospasial* *(Geospatial Information Agency, formerly BAKOSURTANAL)*
BWR	Black Water River
CKPP	Central Kalimantan Peatland Project
CRISP	Centre for Remote Imaging, Sensing and Processing (National University of Singapore)
DSM	Digital Surface Model
DTM	Digital Terrain Model
EMM	Euroconsult Mott MacDonald
EMRP-MP	Ex Mega Rice Project (in Central Kalimantan); abbreviation for Master Plan for the EMRP, funded by EKN, Jakarta
ERO	Estuary River with erosive features
ETM+	Enhanced Thematic Mapper (part of the Landsat Programme)
FAO	Food & Agriculture Organisation (of the United Nations)
GIS	Geographic Information System
GLAS	Geoscience Laser Altimeter System (an integral part of the NASA Earth Science Enterprise)
ICCC	Indonesian Climate Change Center
ICESat	Ice, Cloud, and land Elevation satellite
IFSAR	Interferometric synthetic aperture radar
KFCP	Kalimantan Forest Carbon Partnership (part of IAFCP)
KP	Kampar Peninsula
LiDAR	Light Detection And Ranging (is an optical remote sensing technology that can measure the distance to, or other properties of a target by illuminating the target with light, often using pulses from a laser)
Mha	Million hectares
MSL	Mean Sea Level
NP	National Park
PU	*Pekerjaan Umum* (Ministry of Public Works)
QANS	Quick Assessment and Nationwide Screening (of Peat and Lowland Resources and Action Planning for the Implementation of a National Lowland Strategy)
REDD	Reduced Emissions from Deforestation and Degradation
REDD+	Reducing Emissions from Deforestation and Degradation, the sustainable management of forests and the enhancement of forest carbon stocks
RMSE	root-mean-square error
RSS	Remote Sensing Solutions (a German firm)
SD	Standard Deviation
SED	Sedimentary River

SRTM	Shuttle Radar Topography Mission
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement) is the name of TerraSAR-X's twin satellite, a German Earth observation satellite using SAR
UGM	University Gadjah Mada (in Yogyakarta)
UKP4	*Unit Kerja Presiden Bidang Pengawasan dan Pengendalian Pembangunan* (the Presidential Working Unit for Development Supervision and Control)
WACLIMAD	Water Management for Climate Change Mitigation and Adaptive Development in Lowlands (in Indonesia)
WI	Wetlands International

Foreword

The peatland mapping activity described in this report is part of the QANS (Quick Assessment and Nationwide Screening of peat and lowland resources and action planning for the implementation of a national lowland strategy) project, funded by Netherlands Government (through Partners for Water) as Technical Assistance to PU and BAPPENAS (the Ministries of Public Works and Planning) in Indonesia. The QANS project, which started in March 2012 and ended in February 2013, is coordinated by Euroconsult Mott MacDonald (EMM). In this Peatland Mapping component we assessed the accuracy of existing peat maps in Indonesia, demonstrate and recommend methods for improvement in the short to medium term, and apply peat thickness data to evaluate future flood risk in selected areas.

The technical analysis and reporting was conducted by Deltares, supported by EMM, but valuable inputs were received from a large number of people and organizations, without which the work would not have been possible. Field measurement data of peat thickness were shared by no less than 23 organizations that saw the urgency of supporting peat map improvements, resulting in a dataset of over 7,000 measurements, which was well above expectations. Through ICCC and UKP4, we received SRTM-30 elevation data and the GIS version of the BBSDLP peat map, as well as valuable feedback in discussions, which much enhanced the quality and relevance of the work. The Kalimantan Forest and Carbon Partnership (KFCP) project has allowed us to use its very accurate LiDAR elevation dataset. From PU staff, we received encouragement and questions that allowed us to make the assessment as focussed as possible. The universities of Gadjah Mada (UGM) and Pekanbaru have carried out field surveys in Riau in support of the project. Remote Sensing Solutions (RSS) have prepared the ICESat/GLAS LiDAR data that were used in creation of elevation models. Finally, there have been discussions with Wetlands International staff and many others that have been very helpful.

We hope the result of the project will make a valuable contribution to improving Indonesia's peatland maps and, ultimately, peatland management. We remain available for clarifications and follow-up actions.

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Deltares
Netherlands / Indonesia

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Summary and recommendations

Accuracy of existing peat maps in Indonesia

Existing peat maps for Sumatra and Kalimantan, by Wetlands International and BBSDLP (the earlier being widely used since 2004, and latter being used as input to the Moratorium map in 2012), were compared with 4,460 field measurements of peat thickness in all Provinces in Sumatra and Kalimantan that have peat. These data were collected from 23 organizations and projects specifically for this purpose (see Table 2). Most of this QANS peat thickness database can be shared with other organizations and projects that wish to improve or study peat maps. The data used in the current analysis are those that represent peat measurements over 0.5 m in thickness, and that were measured after 2000.

It was found that both existing maps consistently underestimate peat thickness when compared with field measurements, for each Province and for each peat thickness class in the maps (Table 6, Figure 5, Figure 6). According to the field data available, actual average peat thickness in Sumatra and Kalimantan is 6.0 m and 5.4 m respectively, with an average of 5.6 m. In comparison with field measurements the WI map underestimates peat thickness by 1.5 m on average, or 27 % of the average peat thickness of 5.6 m determined from field measurements, and the BBSDLP map by 2.0 m or 36%. Peat extent also appears to be underestimated: by 13% of measurement points (possibly 1.7 Mha of area) for the WI map and by a further 1.7 Mha for the BBSDLP map.

Peat thickness of less than 3 m appears to be relatively rare, according to the available field measurements. A thickness of over 3 m was found in 83% of measurements that fall within the peat boundaries of the WI map, and still in 60% of measurements that fall outside those boundaries (Table 8). For peat that was forested in the year 2000, peat was over 3 m in 86% of cases and over 2 m in 92% of cases (Table 8). In other words: nearly all remaining forested peatlands have deep peat. It should be noted however that large forested peat domes may be somewhat overrepresented in the field data available (Table 7), and that it is possible that peat thickness below 3 m is somewhat more common than the data suggest, especially in smaller deforested peat areas.

It appears that the BBSDLP map is largely derived from the WI map, in general showing the same boundaries but lowering WI class values (e.g. a 2 m contour becomes a 1 m contour, and a 0.5 m contour the 0 m contour), so it is similar in many ways except that it suggests a lower average peat depth and smaller peat area (Figure 3, Table 6). Our analysis confirms the widely shared understanding that neither of the existing peat maps may be considered suitable for spatial planning or policy making.

Until improved maps of sufficient accuracy exist, we recommend using the original WI map as the starting point, as it shows a smaller underestimation of peat thickness and peat extent than the BBSDLP map. However to further reduce the underestimation, we propose to apply a different legend to the WI map that is presented in this report (Figure 40), as calculated from field measurements of peat thickness. This tentatively revised WI map ensures that peat thickness and volume estimates become more accurate over large areas (e.g. Provinces), however this hardly

makes the WI map more suitable for land use zoning and policy making because it will still be very inaccurate for most specific locations.

Evaluation of methods for improving peat maps

Ideas and examples are demonstrated on how to further improve existing maps to a level that they can be used for practical spatial planning. It proves to be well possible to create peat thickness maps of reasonable quality, using Digital Terrain Models (DTMs).

We investigated and demonstrated several methods to use existing elevation data (SRTM-30, ICESat/GLAS satellite LiDAR, and airborne LiDAR) for determining peat thickness in coastal peatlands (tentatively defined as peatlands closer than 135 km from the coast), with good results for areas in Riau and Central Kalimantan where sufficient data were available for creation of DTMs. From the elevation data a peat thickness model was created by subtracting an average elevation of the peat bottom that was derived from peat thickness measurements in combination with the DTMs. This elevation is on average 0.72 m above MSL (Table 9) and is explained by the development history of these peatlands that started just above Sea level after Sea level rise stagnated in the mid-Holocene, some 5,500 years BP.

The resulting peat thickness maps for coastal peatlands match reasonably well with the individual field measurements of peat thickness, and certainly much better than existing maps (Figure 48, Figure 50, Figure 51). We conclude that the most effective and cost efficient investment in improving peat maps in the short term would be to invest in accurate elevation data for coastal peatland areas, which are now largely lacking.

Recommendations for map improvement actions in the near future

As large-scale field surveys are very time consuming, and better maps are needed in the short term for actual land use zoning and policy making, additional data sources are needed beyond peat thickness field measurements. We therefore recommend some actions that could quickly improve peat maps to the point where it will at least be clear where the priority areas are for A) peatland conservation / rehabilitation and B) for improved peatland mapping. Following that, we also present recommendations for further map improvements in the medium to long term.

In the **short term** (2013), the following policy-related actions are advised:

1. As a first step, it is advised to recognize that the problem of peat mapping is not equally urgent for all peatlands. Most peatland areas in Sumatra and Kalimantan have already been deforested and drained, with 64% being fully deforested by 2010 (Table 1). In some of these areas, rehabilitation efforts may still be feasible, especially where forest is left on the same peat dome complex. **Creation of improved peat maps for such areas with high conservation / rehabilitation potential should be the highest priority.**

2. Secondly, it is recognized that recent modifications of the WI peat map in Indonesia, resulting in the BBSDLP map, have not resulted in improvements but rather in deterioration of map accuracy. **It is advised to recognize that the WI map for Sumatra and Kalimantan, is currently (early 2013) the most accurate peat map available.** Even though this map is not accurate enough to be used in spatial planning at the scale of individual peat domes or Districts, it is useful for planning at the National (RTRWN) and

possibly Provincial scale. However we recommend use of an improved map legend as presented in Figure 40, which better reflects actual peat thickness.

3. Parallel to recognizing that existing maps are not accurate for spatial planning, it would be easy to **produce a simple first map of the minimum area of peatland over 3 m in depth that needs to be protected and conserved, by identifying all peatland that is still forested** in Sumatra and Kalimantan. This approach would be highly accurate as only 9% of peat thickness measurements in peatland areas that were forested by 2010 indicate peat of less than 2 m in thickness, and 15% less than 3 m (Table 8). Such a map can be provided by the QANS team on request, based on the WI map for peat extent and on the CRISP land cover map for 2010, which is an accurate and up-to-date source to be used for forest identification.

4. As a next step in the short term, we recommend using filtered SRTM-30 elevation data, as are now available for most of Indonesia, outside forested areas (and any other elevation data that is readily available) to identify any other areas of deep peat. Such maps are demonstrated for Riau (Kerumutan), South Sumatra and West Kalimantan in the current assessment (Figure 29 and Figure 30), but can be refined and expanded. This data would **identify the parts of larger peat domes that still exist outside the areas that remain forested**.

5. Furthermore, it is recommended to continue to maintain and expand the database of peat thickness measurement locations that was set up in QANS and made available to the Indonesian Government by early 2013.

In the **medium term** (with results in 2013-2014) we recommend:

6. Collect more accurate elevation data, and generate more accurate elevation models from those, as the basis for much improved but still tentative peat thickness maps. This includes the SRTM-30 data that were not yet available for Northwest Sumatra and new datasets from BIG and TanDEM-X that may soon become available.

7. Collect field data on peat thickness in selected areas where urgent spatial planning questions exist that require accurate information, to improve the map for such areas. Use this activity to establish protocols and develop capacity for accurate field surveys, and to further validate peat thickness maps as derived from elevation models.

In the **longer term** (with results mostly beyond 2014), we recommend:

8. Collect peat thickness data in the field at the large scale. While this can start in the short term, it will take several or even many years before substantial areas have been covered with new high-quality data.

Recommendations for planning of sustainable peatland use

It is demonstrated that improved data on peat thickness, and on the position of the peat bottom relative to Sea level, allows quantification of the moment at which land subsidence, that historically has often followed drainage of peatlands around the World, will cause flooding by River or Sea water (Chapter 5).

It is found that in around 39% of locations in three demonstration areas in Riau (Kampar Peninsula and Kerumutan) and Central Kalimantan (EMRP Blocks A, B and E); the bottom of the peat is below Sea level (plus an unsaturated zone of 0.5 m that is needed for agricultural land use). In over 88% of locations, the peat bottom is below the drainage limit as defined by a conveyance gradient of 0.2 m/km that is needed to transport excess water from agricultural lands to Rivers and Sea (Table 13). Depending on assumptions on subsidence rate, and on peat thickness in agricultural areas, the moment at which gravity drainage becomes impossible may vary from 25 to 200 years. However, based on the data available the most likely projection is that most drained peatlands will become undrainable within 100 years, and possibly within 50 years. These are conservative estimates as Sea level rise and the impact of fires on peat loss are not accounted for.

This risk of land loss due to drainage, and the associated loss of agricultural/silvicultural production and livelihood, in our view may present the most urgent reason to improve peat maps, as it will have major economic impacts.

1 Introduction

1.1 Brief background to peatland-related issues in Indonesia

Much has been written in recent years about the rates and consequences of peatland deforestation, drainage and degradation. We will not discuss those aspects in detail here, but present some key numbers as context for the peat mapping discussions.

A range of ongoing initiatives and projects in Indonesia focuses on improving land use planning and management of lowland peatlands. Although there are differences in focus and interpretation, most stakeholders agree that the ongoing major and rapid loss of forest and carbon resources should be reduced, that subsidence and associated flooding of drained peatlands is likely to become an economic problem in many areas, and that the deeper the peat is, the greater the need to protect it. Despite this general consensus, developments to achieve better planning and management are slow at best, while deforestation and drainage of peatlands continue apace.

From Table 1 it is evident that, based on the peat extent and land cover data used in our analysis, peatland forest cover in Sumatra and Kalimantan decreased from 51% in 2000 to 36% in 2010, a loss of 15% or ±2 Mha out of a total area of 13 Mha (this report will show that peatland extent is actually greater). Over the same period, the loss of forest cover on mineral soils was 5%.

Clearly, the pressure to deforest peatlands has been intense, even greater than on non-peatland areas, and this is only increasing in recent and coming years (Miettinen *et al.,* 2012a). The policy decisions required to lead such development into sustainable pathways, at least for the remaining 36% of 4.7 Mha of peatland that could potentially be conserved or rehabilitated (only around 11% has a nearly-intact forest cover according to estimates of Miettinen and Liew, 2010), require sound data. The concern that data for peatland thickness and extent, are of insufficient quality and coverage for sound policy making, has lead to the current analysis in the QANS project.

Table 1 Forest cover as percentage of peatland and non-peatland area, 2000-2010

Province	Non-peatland area km^2	Forest cover 2000 %	Forest cover 2010 %	Forest cover loss 2000-2010 %	Peatland area* km^2	Forest cover 2000 %	Forest cover 2010 %	Forest cover loss 2000-2010 %
Aceh	55,104	52.9	48.9	4.0	2,790	59.7	39.5	20.2
Bangka Belitung	16,137	17.7	13.9	3.8	598	44.1	30.9	13.2
Bengkulu	19,678	42.6	36.0	6.6	486	1.8	1.5	0.3
Jambi	42,029	33.1	25.0	8.1	7,124	41.6	25.2	16.4
Lampung	32,671	10.9	6.3	4.6	836	8.0	3.7	4.3
North Sumatra	69,706	28.1	24.8	3.4	3,475	29.3	7.6	21.7
Riau	50,113	29.7	18.6	11.1	40,077	59.4	35.5	23.8
South Sumatra	72,481	14.3	10.0	4.3	14,147	15.6	8.1	7.5
West Sumatra	39,875	40.4	35.7	4.7	2,113	24.2	7.9	16.3
Sumatra total	***397,794***	***29.9***	***24.3***	***5.5***	***71,647***	***45.4***	***26.4***	***18.9***
Central Kalimantan	123,658	56.9	50.9	6.0	30,125	56.8	48.2	8.5
East Kalimantan	191,420	65.6	60.7	4.9	6,931	42.6	36.0	6.6
South Kalimantan	34,168	25.3	18.7	6.6	3,316	1.7	1.2	0.5
West Kalimantan	129,295	44.8	38.9	5.9	17,641	76.3	61.7	14.6
Kalimantan total	***478,541***	***54.9***	***49.3***	***5.6***	***58,012***	***57.9***	***48.2***	***9.7***
Total	***876,334***	***43.5***	***38.0***	***5.6***	***129,659***	***51.0***	***36.2***	***14.8***

Note: Data provided for all provinces in Sumatra and Kalimantan, for both 2000 and 2010, based on the CRISP land cover maps of 2000 and 2010 (Miettinen *et al.*, 2012b). *according to the WI peat map (Wahyunto *et al.*, 2003, 2004).

1.2 The need for accurate peat maps to improve planning and policy making

One of the main impediments to better planning of peatland use is the lack of reliable peat thickness maps. The map that is most widely used and accepted is the Peatland Atlas for Sumatra and Kalimantan, produced by Puslitanak with Wetlands International (WI) (Wahyunto *et al.*, 2003; 2004). This was a 'best guess' effort some 10 years ago, and it has contributed greatly to raising awareness of the extent and thickness of peatlands in Indonesia, as well as providing a basis for numerous peatland-related studies. However it lacks the accuracy and detail that is required for application in actual land use zoning and policy making: it is known to underestimates peat thickness in many areas, and also peat extent in some areas (these shortcomings are indicated in the Atlases, which present the maps as a first step not a definitive product). Moreover, it lacks the link to land elevation that is needed to assess which peat areas will be affected by future flooding due to subsidence, and when. Finally, the peat thickness patterns presented by existing maps are often impossible from a scientific perspective, ignoring basic relations with the current landscape and historical developments, as discussed later on in this analysis (Section 3, Figure 9).

A recent (2011) attempt at peatland map improvement based on the Puslitanak/WI map, by the Ministry of Agriculture (BBSDLP), has apparently re-interpreted existing WI peat thickness contours on the assumption that they systematically overestimated peat thickness. The resulting map has substantially reduced overall peat thickness and extent relative to the Wetlands International map, as the analysis in this report will show (Section 2).

To help fill the knowledge gap on peat thickness in the shortest possible term, as a basis for spatial planning and policy making, Deltares and partners have in the (Netherlands-funded) QANS quick assessment project evaluated existing peat thickness maps for Indonesia against field data, and demonstrated rapid methods for improvement.
We hope that this rapid assessment will help develop other activities to improve peatland maps, at a larger scale and to a higher level of accuracy and detail than is possible in QANS. One of the initiatives that aim to do this is the One Peatland Map initiative initiated by the Indonesian Council for Climate Change (ICCC), which was supported by QANS through advice and data.

1.3 This analysis

The QANS approach, already partly developed in WACLIMAD[1], KFCP[2] and other projects, aimed to first assess and quantify the accuracy of existing peat maps, and their usefulness for spatial planning and policy making. As a second step, we aimed to provide guidance and examples on how to improve peat thickness (and elevation) maps in the short term, by reducing the need for further field data collection and research as much as possible. This is done by using mostly available data and knowledge, as follows:

- Optimum use of existing peat thickness data (that is mostly not used to date).
- Use of elevation data, as well as thickness patterns dictated by peatland landscape and development history, to augment and interpolate peat thickness data.
- Quick and targeted ('surgical') peat thickness field surveys in Riau.

[1] http://www.nedeco.nl/projects/waclimad

[2] http://www.ausaid.gov.au/Publications/Pages/7610_8464_9778_3906_689.aspx

The peatland mapping approach demonstrated here will yield maps that are a substantial improvement over existing ones and that, while not perfectly accurate by 2013, can be further improved if more data become available beyond QANS. We acknowledge that large-scale additional surveys will be needed in future to produce maps that are accurate enough for detailed land use planning, but think that aiming for 'perfection' at this stage would take too much time and resources to support improved planning and management in the short and medium term; from our experience a detailed full-coverage nationwide survey project may well take over 5 or even 10 years. Through our analysis, our aim is to support the rapid map improvement that is required for improved land use zoning and policy making.

In brief, the analysis steps were as follows:

1. Identify and collect existing peat maps.
2. Identify and collect existing peat thickness and elevation data.
3. Identify clear data gaps and fill some of these with rapid field surveys where possible (only possible in Riau, one of two provinces targeted by QANS).
4. Compare existing peat thickness maps with peat thickness measurements; derive statistics for differences.
5. Use peat thickness and surface elevation data to determine typical profiles for peat thickness, peat surface elevation and peat bottom elevation as a function of distance to rivers and other landscape variables in coastal peatlands.
6. Select areas with sufficient data availability for mapping and validation.
7. Apply derived typical profiles to selected areas, to derive a 'peat thickness model' and a tentative map.
8. Compare the 'peat thickness model' against field data.
9. Apply subsidence rules to the 'peat thickness model' for selected areas; derive projections of drainability and flooding.
10. Interpret and report the results of the above, in terms of tentative estimates of peat thickness and future flood risk.
11. Help develop other peatland mapping activities where possible, if the QANS approach is seen as a useful starting point.

2 Accuracy assessment of existing maps of peat thickness and extent

2.1 Field peat thickness measurements used in assessment

Peat thickness data were collected from organizations that have collected peat thickness data over the years for various purposes, including agricultural land suitability assessments, research, conservation and REDD project development. Other data are from public domain reports and already existing datasets. Furthermore, data are derived from various literature sources that present locations where peat thickness was measured for scientific purposes. The list of organizations, projects and literature sources is provided in Table 2. The location of the peat thickness measurements is shown in Figure 1.

Two categories of peat thickness data were excluded from much of the analysis (unless indicated otherwise):

- Measurements indicating a peat thickness of less than 0.5 m, the minimum thickness of peat according to ICCC (Purnomo *et al.*, 2012).
- Measurements that were done before 2000, at locations that were deforested by the year 2000 according to the 2000 land cover map produced by CRISP (Miettinen *et al.*, 2012b). Such points were excluded because it is expected that in deforested peatlands (that are usually also burnt and drained) these pre-2000 measurement locations may have experienced considerable subsidence and may in some cases no longer be valid in comparison with existing peat maps that were produced after 2000.

Of the 7,030 available measurements with an organic horizon >0.1 m, 5,718 locations (or 81%) had a peat thickness greater than 0.5 m. Slightly less than a third of the collected measurements with peat thickness greater than 0.5 m (1,753 locations or 31%) were measured before the year 2000, going as far back as the early 1980's. Of these, 495 locations (28% of the pre-2000 data) were still forested by 2000. The total number of peat thickness data points included in the analysis was therefore 4,460 (or 63% of collected peat thickness measurements).

Most peat thickness measurements included in the analysis were from Kalimantan (3,016 or 68%) compared to Sumatra (1,444 or 32%) (Table 3). Most data in Kalimantan were from Central Kalimantan (2,312 locations or 52% of the total used in the analysis), of which 2,103 (91%) are in the Ex-Mega Rice Project area and Sebangau NP. Only 18 peat thickness measurements were available for West Sumatra.

The organizations that agreed to share data, did so because they have an interest in seeing accurate peat maps become available for Indonesia. However some organizations did not want their data to be distributed beyond Deltares, and a few wanted to remain anonymous. To prevent having many sets of different data user conditions, three 'data handling categories' were distinguished:

A. Open data use and open distribution: we fully credit the organization for any use of data, can show detailed point values on maps, and can distribute data to other organizations.
B. Open data use and no distribution: as above, but no data distribution outside Deltares.
C. Restricted data use and no distribution: the organization will remain anonymous, limited data values are shown on maps, and no data distribution outside Deltares.

Data that are for further distribution have been shared with ICCC, and can be shared with others upon request, for purposes of map improvement and research.

Table 2 Organizations, projects and peer-reviewed literature sources of peat thickness data

Data provider	Number of data points	Province
non-public data		
Anonymous	427	West Kalimantan
Gadjah Mada University	187	Riau
Infinite Earth	24	Central Kalimantan
Kalimantan Forest and Carbon Partnership (KFCP)	876	Central Kalimantan
PusAir (PU)	40	Central Kalimantan
Wetlands International (WI)	285	Central Kalimantan, South Kalimantan, South Sumatra, Riau, Jambi
Zoological Society of London (ZSL)	175	Jambi
Subtotal	***2,014***	
public data		
Air Hitam Laut Project	24	Jambi
BOS-Mawas	111	Central Kalimantan
BPKEL	64	Aceh
Central Kalimantan Peatland Project (CKPP)	282	Central Kalimantan
CIMTROP	74	Central Kalimantan
EMRP Master Plan Project	63	Central Kalimantan
Jack Rieley	171	Central Kalimantan
Nationwide Study on Coastal Swampland (1980-84)	422	all peatland provinces Kalimantan, Sumatra
Other	473	Riau, South Sumatra
PanEco	15	Aceh
Puslitanak	1,987	Central Kalimantan
Restorpeat	286	Central Kalimantan
Singapore Delft Water Alliance (SDWA)	86	Jambi
South Sumatra Forest Fire Management Project (SSFFMP)	236	South Sumatra
South Sumatra Mining Services [1]	248	South Sumatra
Starling Resources / PT. RMU	119	Central Kalimantan
WWF	52	Central Kalimantan
Subtotal	***4,713***	
literature		
Esterle and Ferm, 1994	18	Jambi
Hope et al., 2005 [2]	84	East Kalimantan
Manuri et al., 2011	125	South Sumatra
Maswar et al., 2011	17	Aceh
Morley, 1981	6	Central Kalimantan
Neuzil, 1997	19	Central Kalimantan, West Kalimantan, Riau
Shimada et al., 2001	24	Central Kalimantan
Supardi et al., 1993	10	Riau
Subtotal	***303***	
Total	***7,030***	

Notes: Sources (in alphabetical order) from which peat thickness measurements were obtained. A distinction has been made in non-publicly and publicly available datasets and area and number of measurements (excluding 318 measurements of 0 m and an additional 90 measurements <0.1 m) are provided. [1]provided by S. Manuri; [2]raw data provided by G. Hope.

Table 3 Overview of available peat thickness measurements (>0.5 m) per Province

Province	Number of data points	after 2000	pre-2000 but forested	used in analysis
Aceh	105	92	8	100
Jambi	338	298	15	313
Riau	677	620	29	649
South Sumatra	638	373	1	374
West Sumatra	18	0	8	8
Sumatra total	***1,776***	***1,383***	***61***	***1,444***
Central Kalimantan	3,197	1,980	332	2,312
East Kalimantan	98	73	22	95
South Kalimantan	131	116	1	117
West Kalimantan	516	413	79	492
Kalimantan total	***3,942***	***2,582***	***434***	***3,016***
Kalimantan (excl. EMRP and Sebangau)	***1,839***	***767***	***146***	***913***
Total	***5,718***	***3,965***	***495***	***4,460***

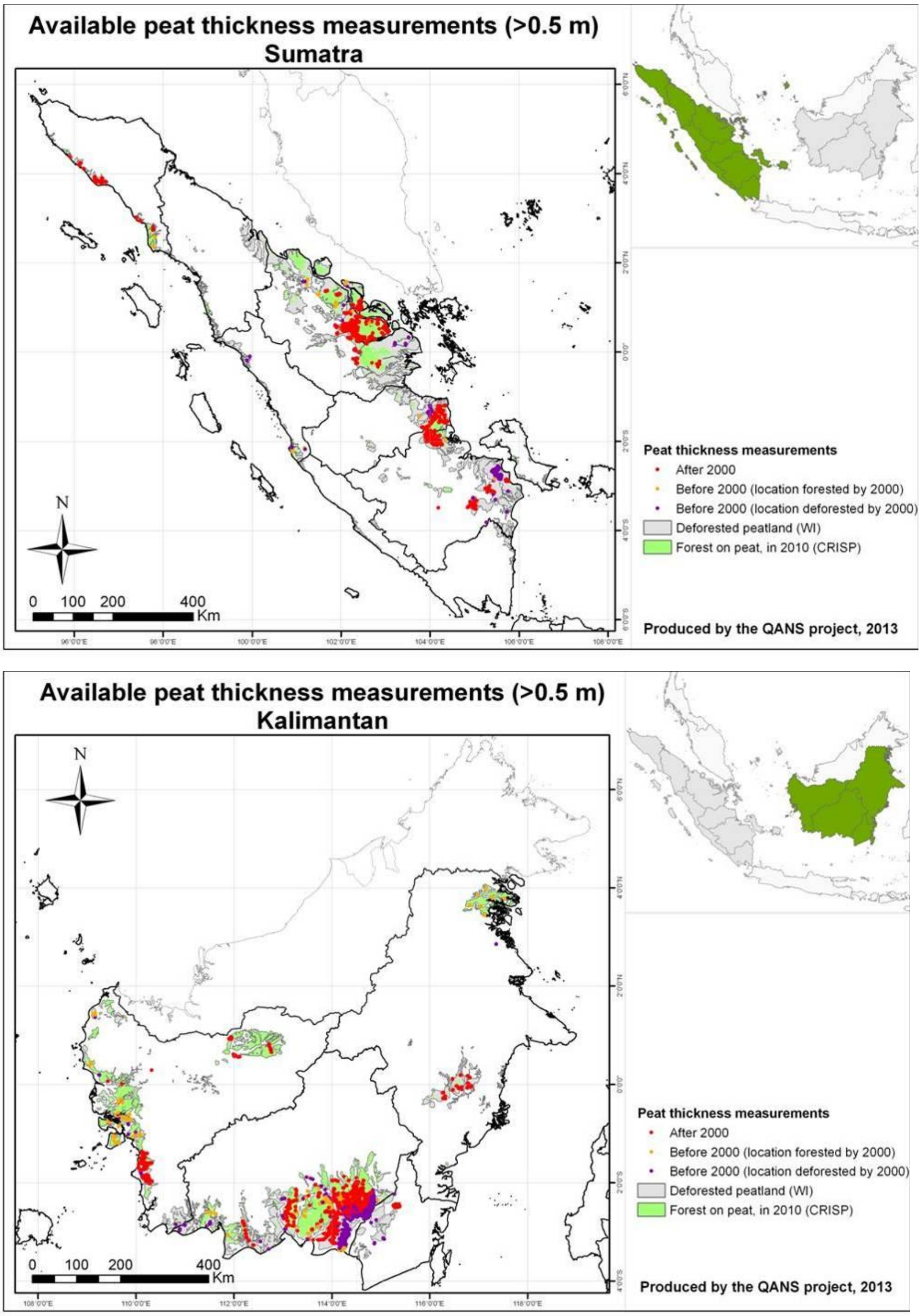


Figure 1 Peatland and forest cover in Sumatra and Kalimantan

Notes: Map showing peatland extent in Sumatra and Kalimantan (Wahyunto *et al.*, 2003, 2004) as well as 2010 forest cover (from CRISP; Miettinen *et al.*, 2012b) and available peat thickness data points (excluding <0.5 m). Dots of different colour show peat thickness measurements before and after 2000, at locations that were forested or deforested in 2000. Note that, due to the scale of this map, measurement transects of less than 10 km in length show as individual points.

2.2 Existing maps and analyses of peat thickness and extent

2.2.1 Wetlands International peat atlas

The Wetlands International (WI) peat atlas (Wahyunto *et al.*, 2003; Wahyunto *et al.*, 2004) was developed under the *'Climate Change, Forest and Peatlands in Indonesia'* (CCFPI) project with the aim of making an inventory of the extent and distribution of peatlands in Indonesia available in the public domain. Data used in the construction of the peat maps included existing historical maps, field surveys and satellite imagery. It was explicitly recognized by the authors that the maps were far from perfect and needed further improvement based on field data.

Although numerous obvious mapping errors were already observed in the WI Atlas maps during the earlier WACLIMAD project, mostly including shifts in the vector file that caused peatland areas to overlap with rivers and coastlines, these were not corrected here with one exception: the Ketapang peat dome in West Kalimantan which in the Atlas has a large hole in the middle where a vector remained unlabeled (Figure 2). As this is an obvious GIS error that affects a large area and is easily fixed, we have attributed the value 4-8 m to this area.

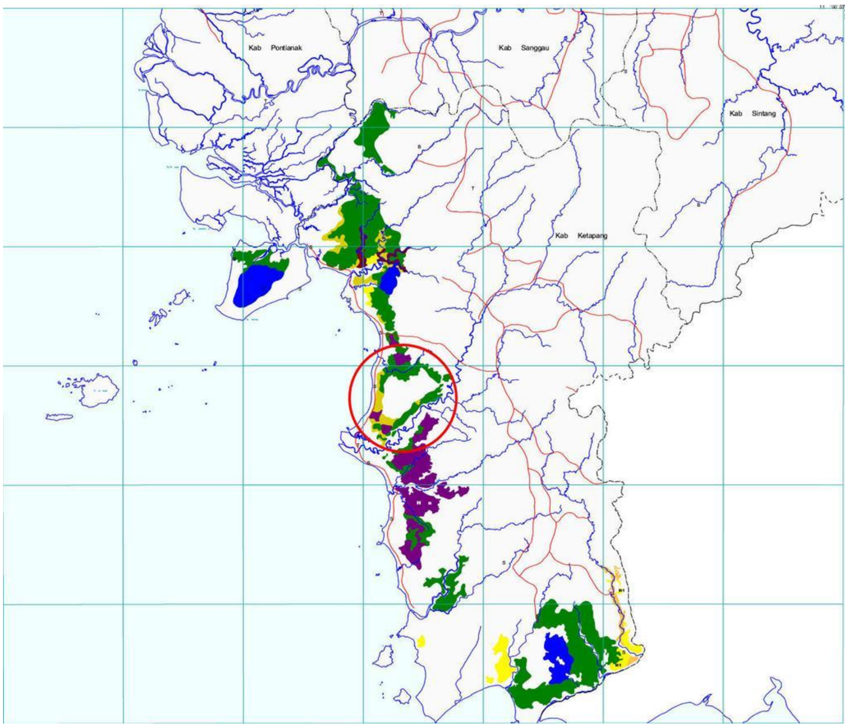


Figure 2 Wetlands International peat atlas for Ketapang District, West Kalimantan

Notes: Indicated with the red circle an obvious unlabeled peatland area ('vector') which was corrected for further QANS analysis.

The Wetlands International peat extent area per peat thickness class for the individual provinces is provided in Table 4. Combining the results of both Sumatra and Kalimantan, a total of 13.0 Mha of peatland were mapped, of which 12.1 Mha would be over 0.5 m in thickness according to the WI map. The Provinces of Riau and Central Kalimantan have the most peat according to the WI map, at 31% and 23% of the total peatland area, respectively.

Both the areas published in the WI Atlas and the areas calculated in QANS based on the GIS file provided by WI are shown in Table 4. Differences between the two may be attributed to using slightly different province boundaries. For West Kalimantan the large difference between the published and QANS calculated area of 341 km^2 is due to the fix of the Ketapang peat dome (see above; Figure 2). When considering the differences in other provinces were between -359 and +222 km^2, the differences are considered negligible with an only 77 km^2 lower peat extent for all provinces together calculated in QANS than was published in the WI Atlases.

It should be noted that the WI Atlas provides contours for 0-2 and 2-4 m peat thickness, but not for 3 m. This is inconvenient, because the 3 m contour has legal and planning significance: only peat less than 3 m thick may legally be developed for agriculture according to most interpretations. However, it is understood that the 3 m peat thickness may not have been shown in the WI Atlas precisely because the map was deemed too inaccurate to be used in policy making and planning.

Table 4 Peat extent per peat thickness class as determined from the WI Peat Atlas for Sumatra and Kalimantan

Province		0-0.5 m km^2	0.5-1 m km^2	1-2 m km^2	2-4 m km^2	4-8 m km^2	8-12 m km^2	Total km^2	>2 m %	Volume* km^3
Aceh	published	383	198	1,448	713	0	0	2,741	26	5
	QANS	391	203	1,471	726	0	0	2,790	26	5
Bangka Belitung	published	0	90	480	66	0	0	636	10	1
	QANS	0	64	468	65	0	0	598	11	1
Bengkulu	published	497	81	24	24	4	0	631	5	0
	QANS	378	72	8	22	7	0	486	6	0
Jambi	published	1,537	1,279	1,054	2,786	512	0	7,168	46	14
	QANS	1,528	1,264	1,041	2,782	510	0	7,124	46	14
Lampung	published	604	67	204	0	0	0	876	0	1
	QANS	578	63	196	0	0	0	836	0	0
North Sumatra	published	440	1,632	957	224	0	0	3,253	7	3
	QANS	445	1,644	1,146	239	0	0	3,475	7	4
Riau	published	856	5,734	9,521	8,274	16,051	0	40,436	60	140
	QANS	836	5,635	9,193	8,294	16,119	0	40,077	61	140
South Sumatra	published	1,590	3,043	9,340	226	0	0	14,200	2	17
	QANS	1,681	3,011	9,233	223	0	0	14,147	2	17
West Sumatra	published	921	293	248	151	489	0	2,102	30	4
	QANS	931	285	219	189	488	0	2,113	32	4
Sumatra total	published	**6,829**	**12,417**	**23,276**	**12,464**	**17,057**	**0**	**72,043**	**41**	**186**
	QANS	**6,767**	**12,241**	**22,975**	**12,540**	**17,124**	**0**	**71,647**	**41**	**186**
Central Kalimantan	published	760	9,585	4,624	5,750	6,611	2,777	30,106	50	99
	QANS	760	9,578	4,624	5,775	6,611	2,777	30,125	50	99
East Kalimantan	published	0	2,646	1,125	2,197	1,002	0	6,970	46	16
	QANS	0	2,610	1,125	2,194	1,002	0	6,931	46	16
South Kalimantan	published	768	794	788	967	0	0	3,316	29	5
	QANS	769	797	788	961	0	0	3,316	29	5
West Kalimantan	published	367	4,382	7,371	2,137	3,043	0	17,300	30	39
	QANS	321	4,428	7,368	2,137	3,387	0	17,641	31	41
Kalimantan total	published	**1,894**	**17,406**	**13,908**	**11,051**	**10,656**	**2,777**	**57,692**	**42**	**159**
	QANS	**1,850**	**17,413**	**13,905**	**11,067**	**11,000**	**2,777**	**58,012**	**43**	**161**
Total	published	**8,724**	**29,823**	**37,184**	**23,515**	**27,713**	**2,777**	**129,735**	**42**	**345**
	QANS	**8,617**	**29,654**	**36,880**	**23,607**	**28,124**	**2,777**	**129,659**	**42**	**347**

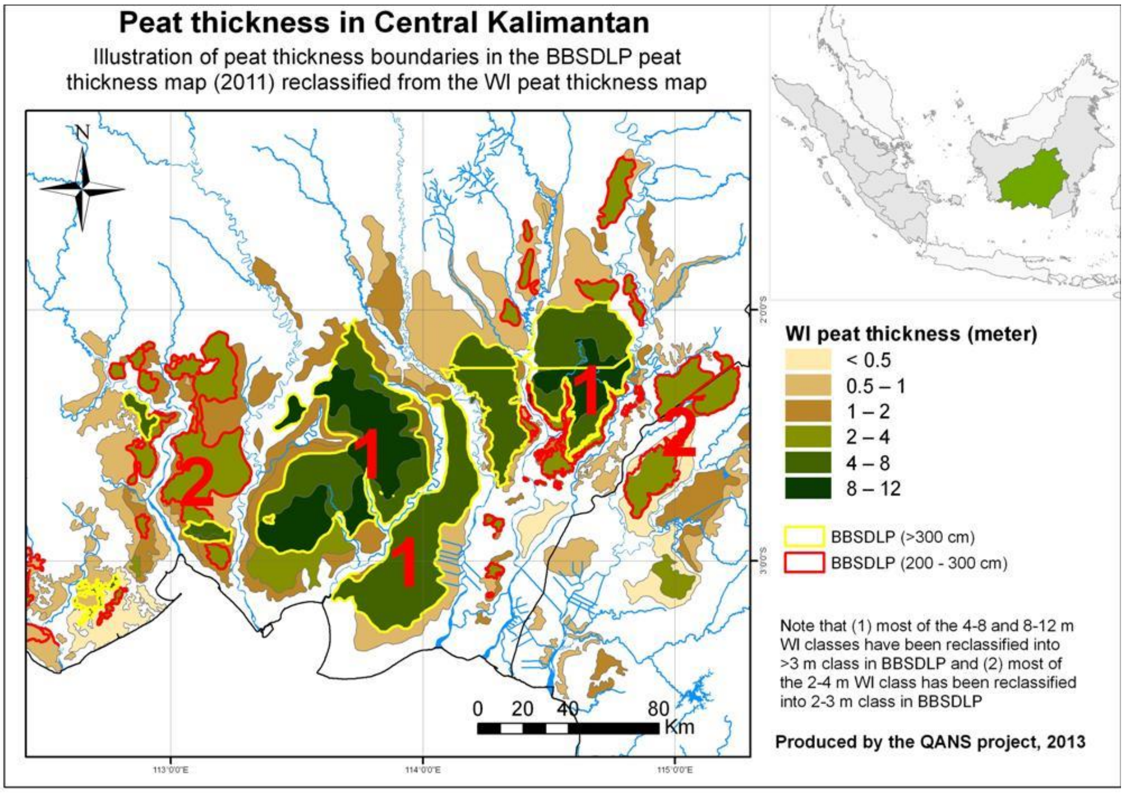
Notes: Peat extent based on the Wetlands International Peat Atlas (2003-2004) for individual provinces of Sumatra and Kalimantan. For Sumatra no 8-12 m peat thickness class is present in the peat map. *Peat volume is determined by applying the mid value of ranges, e.g. '1-2 m' becomes 1.5 m. QANS peat extent areas were calculated using the UTM48N and UTM49S projection for Sumatra and Kalimantan respectively, using province boundaries available from http://www.gadm.org/.

2.2.2 BBSDLP map

The recently published BBSDLP peat map (Ritung *et al.*, 2011; available in pdf from http://bbsdlp.litbang.deptan.go.id/) was produced by the Ministry of Agriculture and is tentatively used in the development of the two-year Moratorium map (PIPIB; Peta Indikatif Penundaan Ijin Baru) issued by the Ministry of Forestry in May 2011 as part of Indonesia's pledge to reduce CO_2 emissions from deforestation and degradation (REDD+) with 26% from a projected 2020 baseline (Presidential Instruction No.10/2011). The moratorium map, which is revised every six-months including the peat map, serves as a guideline for local administrations when issuing new forestry licences.

The BBSDLP peat extent area per peat thickness class for the individual provinces is provided in Table 5. Both the published areas as well as the areas calculated based on the GIS file available to the QANS project are provided. Combining the results of both Sumatra and Kalimantan, a total of 11.2 Mha of peatlands were identified and mapped.

From comparison of the maps, it appears that in most areas the BBSDLP map was derived from the Wetlands International map by reclassifying contour lines downward (although other changes based on different sources were also made). Thus, the 2 m line became the 1 m line and the 1 m line the 0.5 m line. One consequence of doing this was that the WI 0.5 m line was effectively lost, and with it almost a million hectare of peat. To obtain the 3 m peat thickness contour, which was required for the Moratorium, the BBSDLP map has simply reclassified the WI >4 m contours. No peat depth contours greater than 3 m are provided by the BBSDLP map, which complicates comparison with other sources or quantification of peat volume. The reclassification of contour lines is further illustrated for Central Kalimantan in Figure 3.



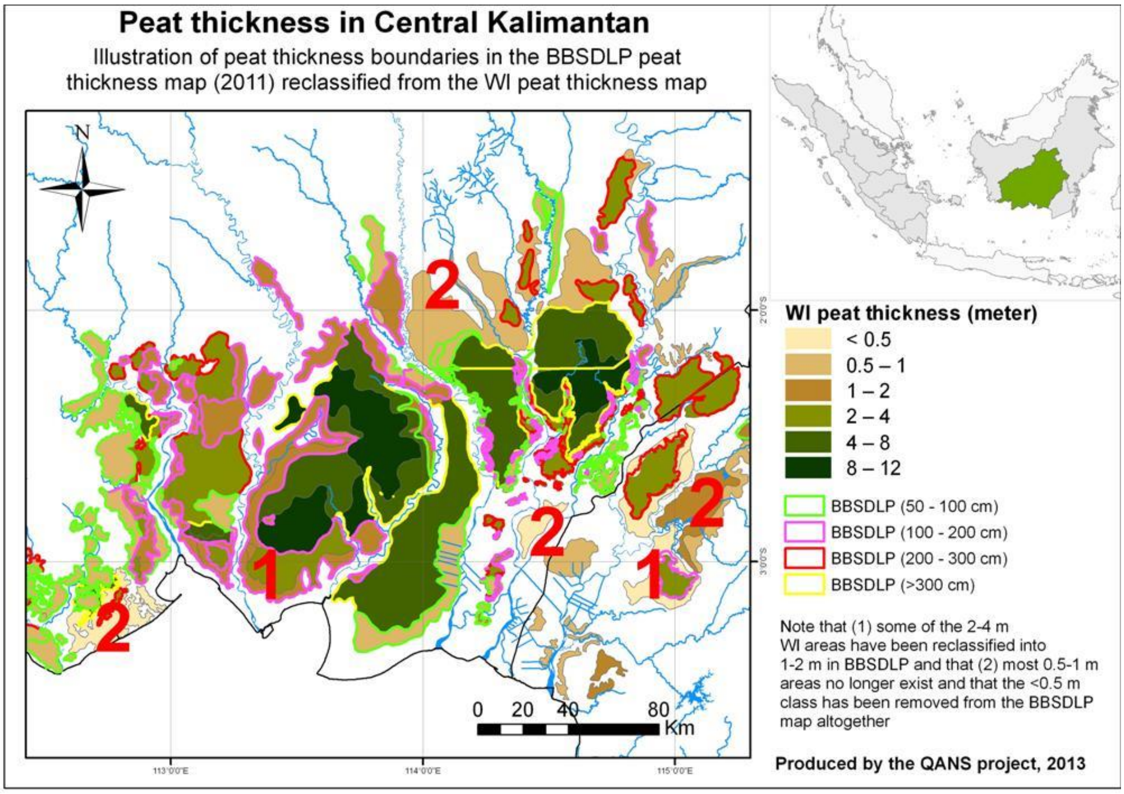


Figure 3 BBSDLP peat thickness map reclassified from WI Peat Atlas

Note: Figure 3 (top and bottom) provide an example of how peat thickness boundaries in the BBSDLP peat thickness map have been reclassified from the WI peat thickness map (i.e. the Peat Atlas).

Table 5 Area per peat thickness class as determined from the BBSDLP peat map for Sumatra and Kalimantan

Province		0.5-1 m km²	1-2 m km²	2-3 m km²	>3 m km²	Total km²	>2 m %	>3 m %	Volume* km³
Aceh	*published*	1,443	714	0	0	2,157	0	0	2
	QANS	1,471	726	0	0	2,197	0	0	2
Bangka Belitung	*published*	426	0	0	0	426	0	0	0
	QANS	448	0	0	0	448	0	0	0
Bengkulu	*published*	39	8	25	9	81	42	12	0
	QANS	39	8	22	7	75	38	9	0
Jambi	*published*	918	1,427	3,458	407	6,211	62	7	14
	QANS	917	1,385	3,438	407	6,146	63	7	14
Lampung	*published*	493	0	0	0	493	0	0	0
	QANS	490	0	0	0	490	0	0	0
Riau	*published*	5,092	9,086	8,385	16,111	38,674	63	42	135
	QANS	5,078	9,105	8,405	16,135	38,724	63	42	135
South Sumatra	*published*	7,054	5,154	416	0	12,624	3	0	14
	QANS	7,026	5,181	426	0	12,633	3	0	14
West Sumatra	*published*	115	244	145	503	1,007	64	50	4
	QANS	115	245	149	507	1,016	65	50	4
North Sumatra	*published*	2,093	365	0	154	2,612	6	6	3
	QANS	2,120	367	0	156	2,643	6	6	3
Sumatra total	***published***	***17,672***	***16,997***	***12,430***	***17,186***	***64,285***	***46***	***27***	***173***
	QANS	***17,705***	***17,016***	***12,439***	***17,213***	***64,373***	***46***	***27***	***173***
Central Kalimantan	*published*	5,724	5,086	6,330	9,452	26,592	59	36	84
	QANS	5,714	5,081	6,328	9,452	26,575	59	36	84
East Kalimantan	*published*	444	416	1,718	746	3,324	74	22	10
	QANS	450	419	1,732	751	3,352	74	22	10
South Kalimantan	*published*	102	211	750	0	1,063	71	0	2
	QANS	105	217	764	0	1,086	70	0	2
West Kalimantan	*published*	4,217	8,185	1,930	2,470	16,801	26	15	35
	QANS	4,257	8,239	1,945	2,493	16,934	26	15	35
Kalimantan total	*published*	***10,486***	***13,898***	***10,728***	***12,668***	***47,780***	***49***	***27***	***132***
	QANS	***10,526***	***13,956***	***10,769***	***12,696***	***47,947***	***49***	***26***	***132***
Total	*published*	***28,158***	***30,896***	***23,157***	***29,854***	***112,065***	***47***	***27***	***304***
	QANS	***28,231***	***30,972***	***23,208***	***29,908***	***112,320***	***47***	***27***	***305***

Notes: Peat extent per peat thickness class as determined from the BBSDLP peat map for individual provinces of Sumatra and Kalimantan. Note that no <0.5 m peat thickness class is present in the BBSDLP peat map. *Peat volume is determined by applying the mid value of ranges, e.g. the class range '1-2 m' becomes 1.5 m. An average value of 6 m was arbitrarily assigned to the BBDSLP class '>3 m', for calculation of peat volume. QANS peat extent areas were calculated using the UTM48N and UTM49S projection for Sumatra and Kalimantan respectively, using province boundaries available from http://www.gadm.org/.

2.3 Map comparison and accuracy assessment

2.3.1 Accuracy of peat thickness in existing maps

The accuracy of the widely used WI peat atlas and recently published BBSDLP peat map was assessed by comparing the maps with collected peat thickness measurements. In Table 6 field peat thickness measurements per Province are compared with the peat thickness at the same locations according to the two different peat maps.

Average measured peat thickness ranges from 3.8 m in the provinces of Aceh and South Sumatra to 7.9 m in Riau. The average measured peat thickness is 6 m and 5.4 m for Sumatra and Kalimantan, respectively. Combined average peat thickness for all 4,460 locations is 5.6 m. This is close to the 5.5 m reported by Page *et al.* (2011) who came to this best estimate of peat thickness for Indonesia using 4 literature sources (Neuzil, 1997; Page *et al.*, 1999; Jaya, 2007; Jaenicke *et al.*, 2008) that are included in the current database as well.

From comparing the field measurements with the existing peat maps it is apparent that the measurements are consistently higher than the map values, with average differences ranging from +0.5 to +4 m compared to the WI map and from +0.9 to +4.6 m compared to the BBSDLP map (Table 6). For Sumatra and Kalimantan together, the average difference with field measurements is +1.5 and +2 m for the WI and BBSDLP map, respectively.

Table 6 Average peat thickness per Province for field measurements >0.5 m

	Average thickness (m)			% >2 m			% >3 m	
Province	Data	WI	BBSDLP*	Data	WI	BBSDLP	Data	BBSDLP
Aceh	3.8	1.3	0.6	77	20	0	63	0
Jambi	5.7	2.3	2.1	84	71	78	77	0
Riau	7.9	5.1	4.2	96	83	81	95	55
South Sumatra	3.8	1.4	1.0	79	0	0	62	0
West Sumatra	4.6	3.0	3.0	100	50	50	100	50
Sumatra total	***6.0***	***3.2***	***2.7***	***88***	***54***	***54***	***80***	***25***
Central Kalimantan	5.6	5.0	4.6	86	73	78	78	72
East Kalimantan	5.7	1.7	1.1	92	37	32	73	8
South Kalimantan	4.5	0.7	0.5	84	0	0	74	0
West Kalimantan	4.7	3.7	2.8	79	58	41	66	39
Kalimantan total	***5.4***	***4.6***	***4.1***	***85***	***67***	***67***	***75***	***62***
Kalimantan (excl. EMRP and Sebangau)	***4.7***	***2.8***	***2.2***	***80***	***42***	***34***	***66***	***24***
Total	***5.6***	***4.1***	***3.6***	***86***	***63***	***63***	***77***	***50***

Notes: Average peat thickness per Province for field measurements >0.5 m, after 2000 (or measured before 2000 but in areas still forested in 2000; see Table 3) compared with values for the same field locations according to the WI and BBSDLP peat maps. Average peat thickness for the peat maps is determined by applying the mid value of ranges, e.g. the range class '1-2 m' becomes 1.5 m. *A peat thickness of 6 m was arbitrarily assumed for the BBSDLP peat thickness class '>3 m', to allow comparison.

The differences are also reflected in an underreporting of peat thickness less than 2 and 3 m. Of the total of 4,460 field measurements used in analyses (Table 3)) 86% is over 2 m in thickness, and 77% is over 3 m in thickness. According to the WI and BBSDLP maps only 63% of points are over 2 m at the same locations, a difference of 23%.

In Table 7 the distribution of the available peat thickness measurements per WI class is shown. From this table it is clear that the available measurements are not evenly distributed among WI thickness classes, with most measurements (51.5%) collected in the 4-8 m WI thickness class that accounts for 21.7% of the peat area in the WI map, a relative overrepresentation by 2.4 times. This observation may easily be explained by the fact that projects, organizations and publications from which the measurements were collected often focused on the deep peat deposits. This skewed distribution of available measurements does however not affect the validity of the comparison with the WI and BBSDLP map, since the peat thickness measurements were compared with values for the same field locations according to the WI and BBSDLP peat maps. Moreover, while measurements in deeper peat deposits may be somewhat overrepresented, a large number of 1513 measurements were nevertheless located in peat of less than 4 m thickness according to the WI map, and 1082 measurements in peat of less than 2 m thickness, ensuring that shallow peat deposits were well represented in the analysis.

Table 7 Distribution of available peat thickness measurements over the different WI classes

WI class	Area (km^2)	% of total area	No. peat thickness measurements	% / WI class
no peat	-	-	579	-
<0.5	8,617	6.6	17	0.4
0.5-1	29,654	22.9	227	5.8
1-2	36,880	28.4	838	21.6
2-4	23,607	18.2	431	11.1
4-8	28,124	21.7	1,998	51.5
8-12	2,777	2.1	370	9.5
Total	**129,659**	**-**	**4,460**	**-**

Peat thickness of less than 3 m is relatively rare. A thickness of over 3 m was found in 83% of measurements that fall within the peat boundaries of the WI map, and still in 60% of measurements outside those boundaries (Table 8). For peat that was still forested in the year 2000, peat was over 3 m in 86% of cases and over 2 m in no less than 92% of cases. In other words: nearly all remaining forested peatlands have deep peat. It should be noted however that large forested peat domes may be somewhat overrepresented in the field data available (Table 7), and that it is possible that peat thickness below 3 m is somewhat more common than the data suggest, especially in smaller deforested peat areas.

Table 8 Average peat thickness for field measurements inside/outside WI peat boundary

Area	Peat thickness (m)	2000				2010				All	
		Forest		Non-forest		Forest		Non-forest			
		inside WI boundary	outside WI boundary	inside WI boundary	outside WI boundary	inside WI boundary	outside WI boundary	inside WI boundary	outside WI boundary	inside WI boundary	outside WI boundary
Sumatra	**average**	**6.99**	**3.61**	**4.55**	**4.14**	**6.36**	**3.50**	**6.23**	**4.11**	**6.28**	**3.82**
	std	3.15	1.89	2.42	3.46	3.20	2.00	3.14	3.08	3.16	2.63
	n	*911*	*59*	*374*	*39*	*449*	*47*	*836*	*51*	*1285*	*98*
	% >2 m	***92.2***	***81.4***	***80.2***	***61.5***	***88.4***	***78.7***	***88.9***	***68.6***	***88.7***	***73.5***
	% >3 m	***87.3***	***50.8***	***71.1***	***53.8***	***81.3***	***48.9***	***83.3***	***54.9***	***82.6***	***52.0***
Kalimantan (excl. EMRP + Sebangau NP)	**average**	**5.73**	**2.74**	**5.25**	**4.42**	**5.84**	**2.51**	**5.05**	**4.01**	**5.60**	**3.84**
	std	2.85	1.68	2.56	2.85	2.85	2.27	2.56	2.63	2.78	2.63
	n	*443*	*57*	*159*	*108*	*418*	*19*	*184*	*146*	*602*	*165*
	% >2 m	***89.6***	***57.9***	***91.2***	***76.9***	***90.9***	***47.4***	***88.0***	***73.3***	***90.0***	***70.3***
	% >3 m	***81.3***	***35.1***	***81.8***	***66.7***	***83.3***	***21.1***	***77.2***	***60.3***	***81.4***	***55.8***
EMRP + Sebangau NP	**average**	**6.87**	**3.22**	**5.46**	**3.50**	**7.18**	**2.70**	**5.52**	**3.55**	**6.18**	**3.40**
	std	2.83	1.62	2.37	1.60	2.86	1.60	2.38	1.57	2.71	1.61
	n	*842*	*65*	*798*	*110*	*660*	*32*	*980*	*143*	*1640*	*175*
	% >2 m	***92.9***	***69.2***	***98.0***	***80.9***	***93.3***	***53.1***	***88.9***	***81.8***	***90.7***	***76.6***
	% >3 m	***87.3***	***60.0***	***80.6***	***72.7***	***88.3***	***46.9***	***81.1***	***72.7***	***84.0***	***68.0***
All	**average**	**6.69**	**3.19**	**5.18**	**3.99**	**6.57**	**3.05**	**5.77**	**3.83**	**6.12**	**3.66**
	std	3.01	1.75	2.44	2.54	3.01	1.97	2.77	2.34	2.90	2.28
	n	*2196*	*181*	*1331*	*257*	*1527*	*98*	*2000*	*340*	*3527*	*438*
	% >2 m	***91.9***	***69.6***	***86.4***	***76.3***	***91.2***	***64.3***	***88.8***	***76.2***	***89.8***	***73.5***
	% >3 m	***86.1***	***49.2***	***78.1***	***67.3***	***84.9***	***42.9***	***81.7***	***64.7***	***83.0***	***59.8***

Notes: Average peat thickness for field measurements (>0.5 m, after 2000) falling inside and outside the WI peat extent boundary for forested and non-forested areas in 2000 and 2010 according to Miettinen *et al.* (2012b).

The large differences between the field measurements and the peat maps are further illustrated in Figure 4, Figure 5 and Figure 6 where the difference between field measurements and the peat maps are illustrated for the two QANS focus Provinces, Riau and West Kalimantan, respectively. Apart from the general underestimation of peat thickness in both maps, compared with field measurements, there are also apparent differences in thickness when the WI and BBSDLP peat thickness maps are compared with each other. This is illustrated in peat thickness difference maps presented in Figure 7 for Riau and West Kalimantan. These difference maps show in most areas a decrease in peat thickness in the BBSDLP map compared to the Wetlands International peat thickness map. Most differences are 0 m to 1 m, which is partly due to the fact that the BBSDLP map is largely derived from reducing the WI contour values by one step, which is 0.5 m or 1 m (cf. Figure 3). However the larger differences, where the BBSDLP map provides values that are 2 m or more than WI values, often appear to coincide with boundaries of oil palm or Acacia plantation concessions. It may be that the makers of the BBSDLP map have reasoned that because there were plantation concessions, peat thickness must be limited and earlier maps must be wrong.

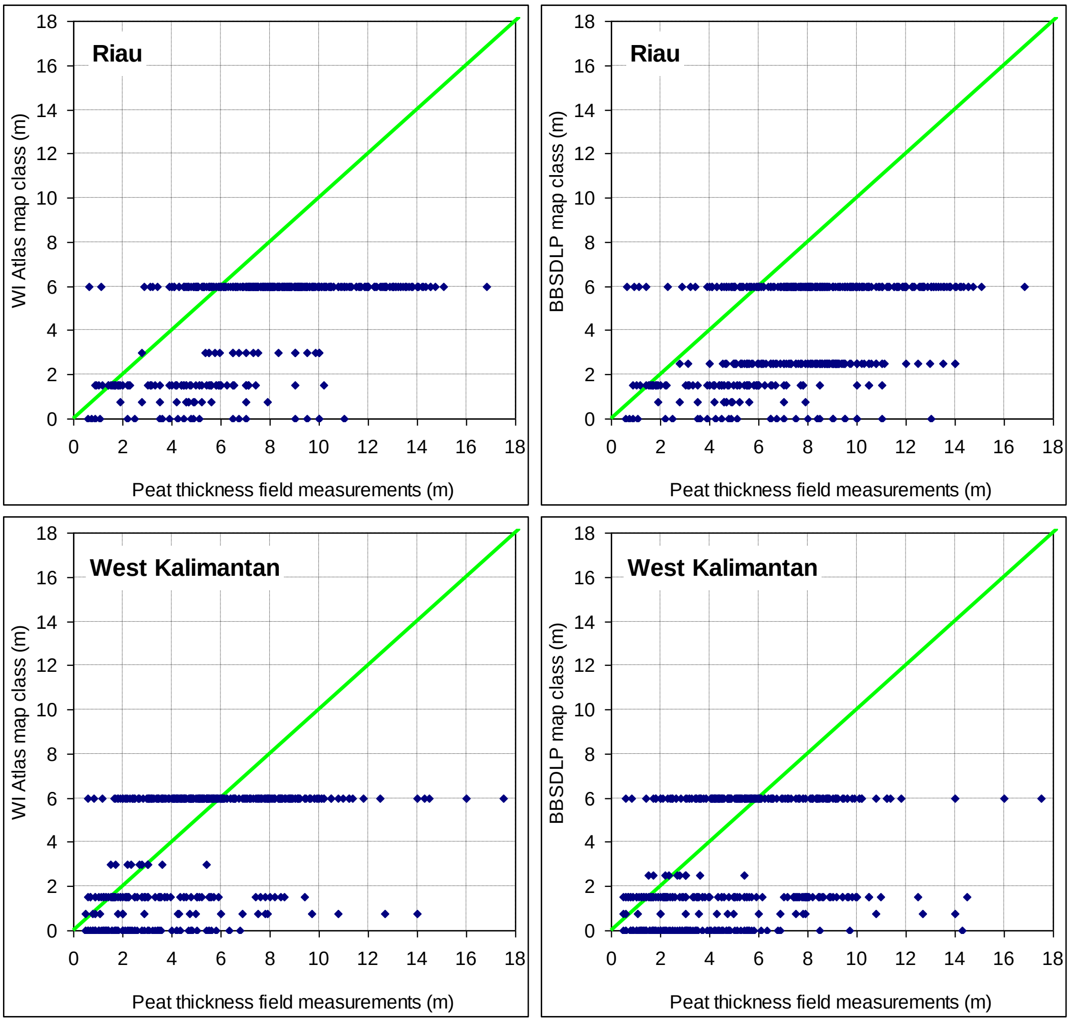
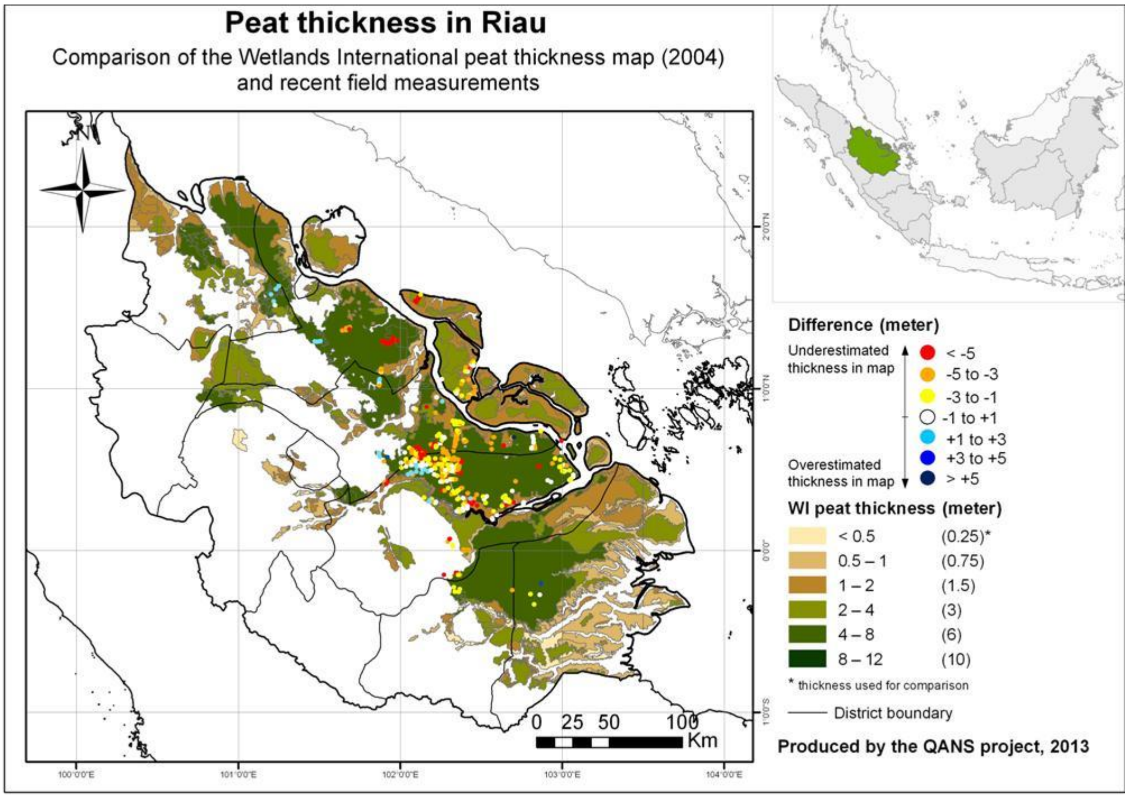


Figure 4 Comparison of WI (left) and BBSDLP (right) peat maps and field measurements >0.5 m

Notes: Comparison of the Wetlands International (left) and BBSDLP (right) peat map and field measurements >0.5 m, after 2000 (or measured before 2000 but still forested in 2000; see Table 3), for Riau (top) and West Kalimantan (bottom). A peat thickness of 6 m was arbitrarily assumed for the BBSDLP peat thickness class '>3 m', to allow comparison. Note that all points to the right of the green line present an underreporting of actual peat thickness by the peat maps. Comparison graphs for other provinces are provided in Annex 1.



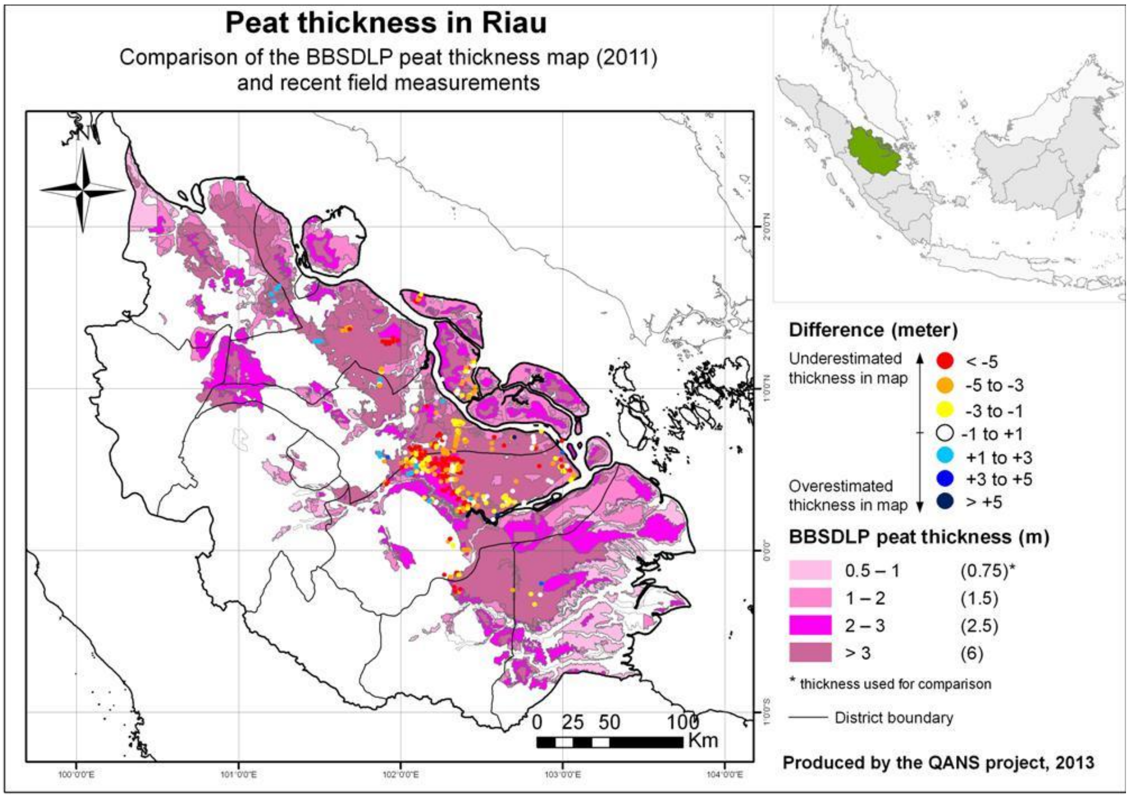
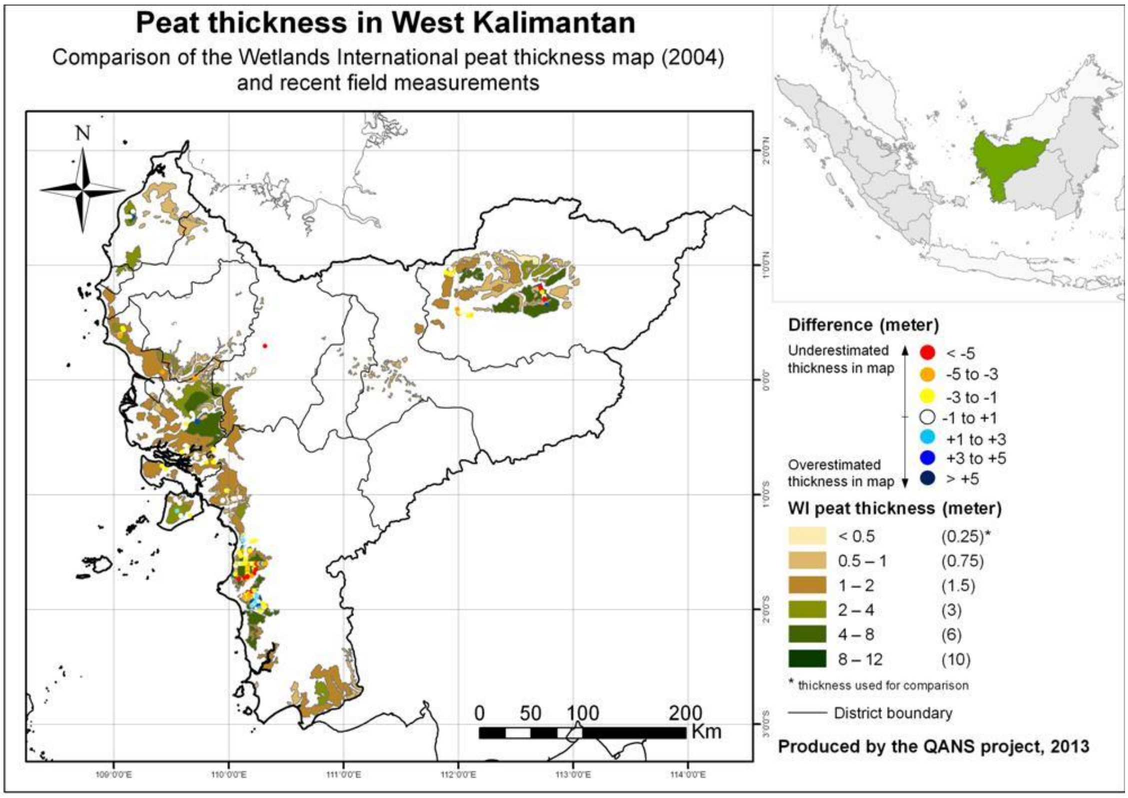


Figure 5 Comparison of the WI (top) and BBSDLP (bottom) peat thickness map and field measurements for Riau

Notes: Comparison of the Wetlands International (top) and BBSDLP (bottom) peat thickness map and field measurements >0.5 m, after 2000 (or measured before 2000 but in areas still forested in 2000; see Table 3) for Riau. Difference maps for other provinces are provided in Annex 2. A peat thickness of 6 m was arbitrarily assumed for the BBSDLP peat thickness class '>3 m', to allow comparison.



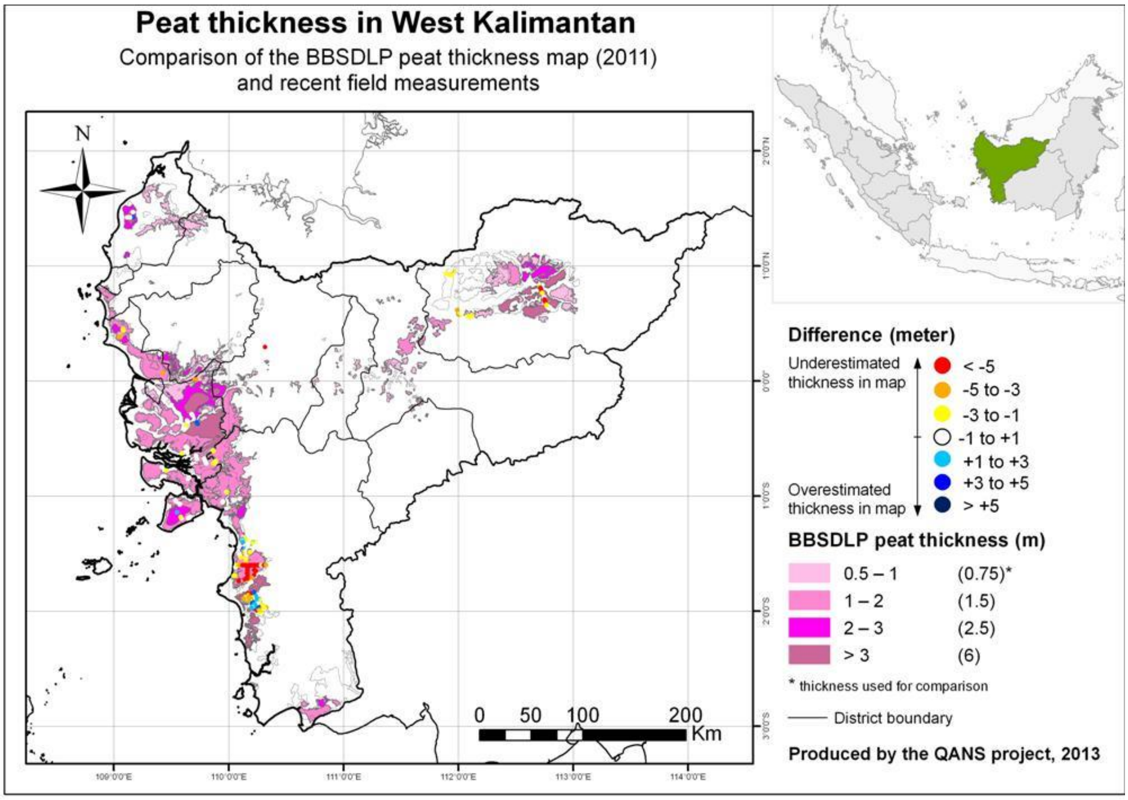
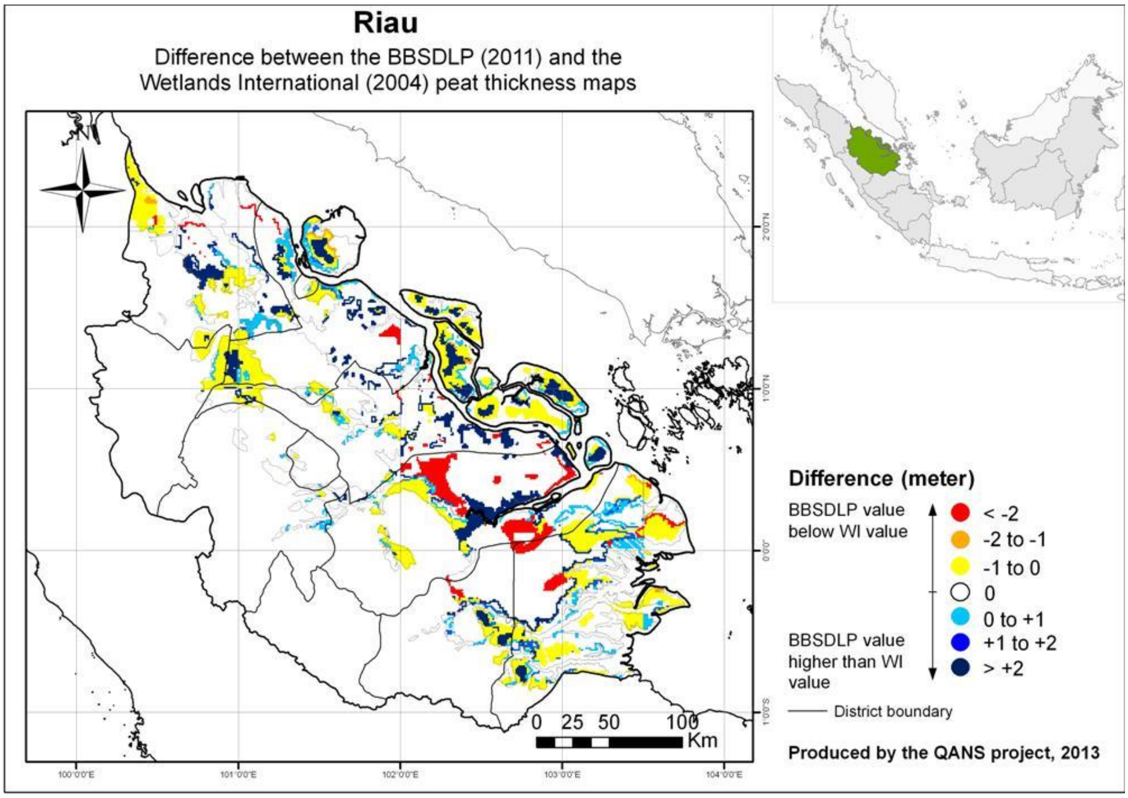


Figure 6 Comparison of the WI (top) and BBSDLP (bottom) peat thickness map and field measurements for West Kalimantan

Notes: Comparison of the Wetlands International (top) and BBSDLP (bottom) peat thickness map and field measurements >0.5 m, after 2000 (or measured before 2000 but in areas still forested in 2000; see Table 3) for West Kalimantan. Difference maps for other provinces are provided in Annex 2. A peat thickness of 6 m was arbitrarily assumed for the BBSDLP peat thickness class '>3 m', to allow comparison.



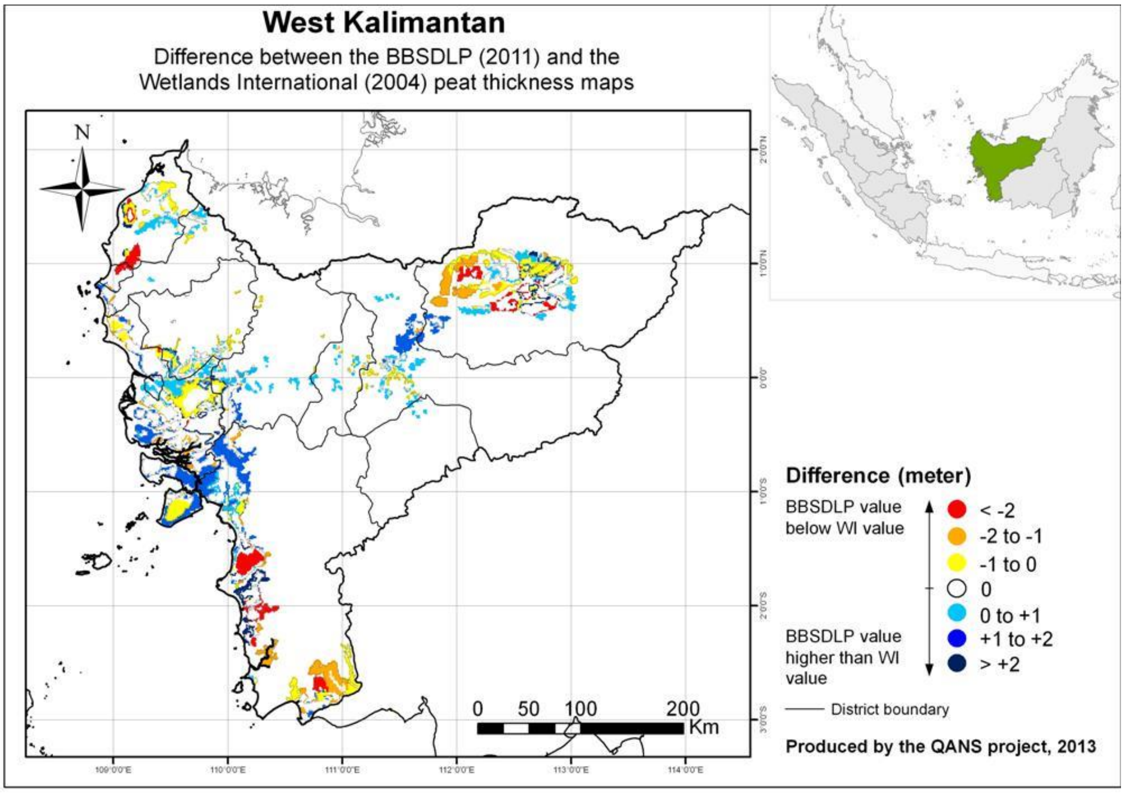


Figure 7 Difference between the BBSDLP and Wetlands International peat thickness map for Riau (top) and West Kalimantan (bottom)

Notes: To allow for an objective comparison the 0-0.5 m class in the WI map has been set to 0, and peat thickness of 6 m was arbitrarily assumed for the BBSDLP peat thickness class '>3 m'. Difference maps for other provinces are provided in Annex 3.

2.3.2 Accuracy of peat extent in existing maps

The peat extent boundary is usually understood to coincide with the 0.5 m peat thickness boundary, and is mapped by applying a combination of field peat thickness measurements and visual interpretation of satellite images. Considering the limited accuracy of the existing peat thickness maps (both WI and BBSDLP), suggesting that only limited peat thickness data were used in producing these maps, it appears that peat extent was mostly mapped from satellite images. The most useful images for this purpose are usually older, pre-1990, when vegetation patterns were still indicative of soil conditions (this relation is largely lost after deforestation, drainage and fires).

When comparing the peat extent of the WI peat map with the available peat thickness measurements, peat extent is generally fairly well mapped. However, 13% of peat thickness measurements fall outside the mapped boundaries (i.e. also outside the 0-0.5 m class), having an average peat thickness of 3.3 m (+/- SD 2.2 m). This corresponds well with the 10% underestimation of the WI peat extent found by Jaenicke *et al.* (2008), who delineated three representative peat domes in Central Kalimantan, South Sumatra and West Papua from Landsat ETM+ and SRTM-90 imagery. We conclude that the WI map probably underestimates peat extent by around 10%, in Sumatra and Kalimantan, and that much of a probable 'missing' peat area of over 1 Mha that is not included in the WI map may in fact have a peat thickness of over 3 metres.

In comparison with the Wetlands International peat map, the peat extent of the BBSDLP peat map reveals a decrease in peat extent of approximately 1.7 Mha (17,339 km^2 or 13.4%) with the greatest decrease in Kalimantan (17.3%) compared to Sumatra (10.2%) (Table 4 and Table 5). Looking in more detail this peat extent reduction was most pronounced in the Lake Sentarum area in West Kalimantan (Figure 8). Major areas in the WI peat map, ranging in peat thickness classes from 1-2 m to 4-8 m, were no longer considered in the peat map of BBSDLP. The peat measurements available to QANS suggest that in at least some of these areas where the BBSDLP map had reduced peat extent relative to the WI map, substantial peat deposits actually exist.

It must be noted that although the boundary of the peat extent in the WI peat map is generally well mapped, peat thickness patterns of individual areas of the same peat thickness class are often impossible from a scientific perspective, ignoring basic relations with the current landscape and historical developments, as discussed later on in Section 3. The same irregularities are also still present in the BBSDLP peat map. For both peat thickness maps this is further illustrated for Central Kalimantan in Figure 9.

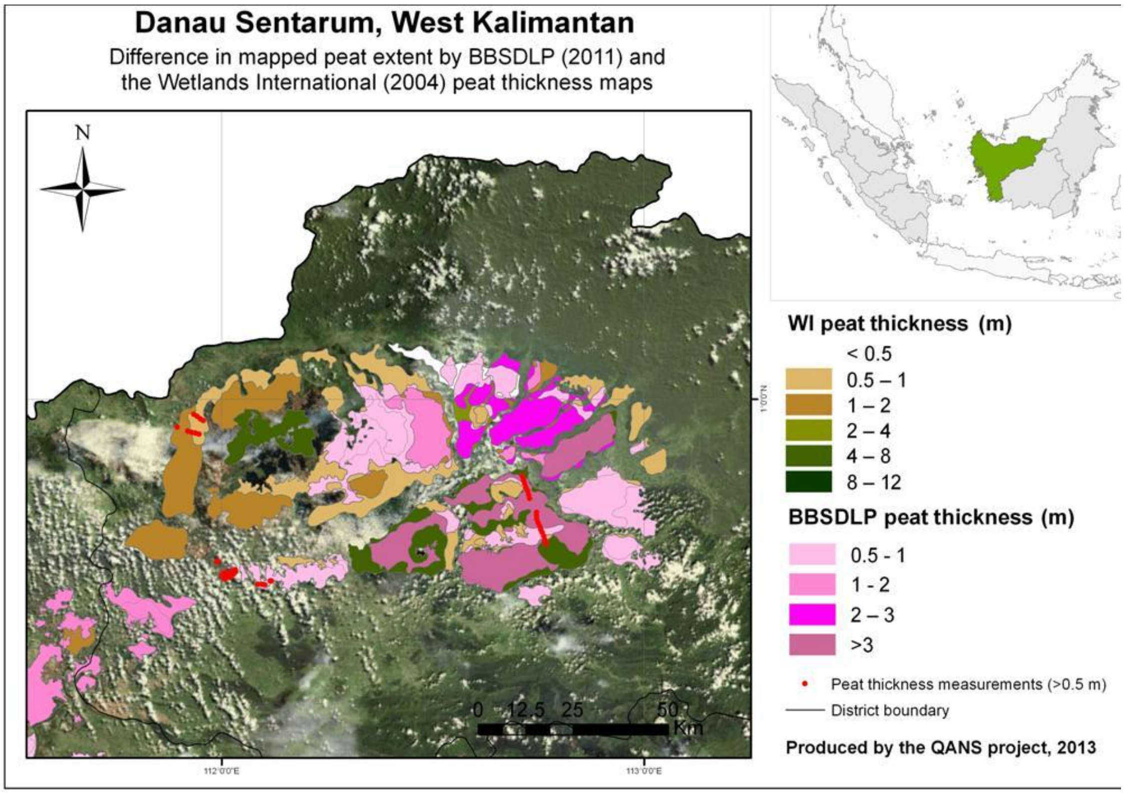
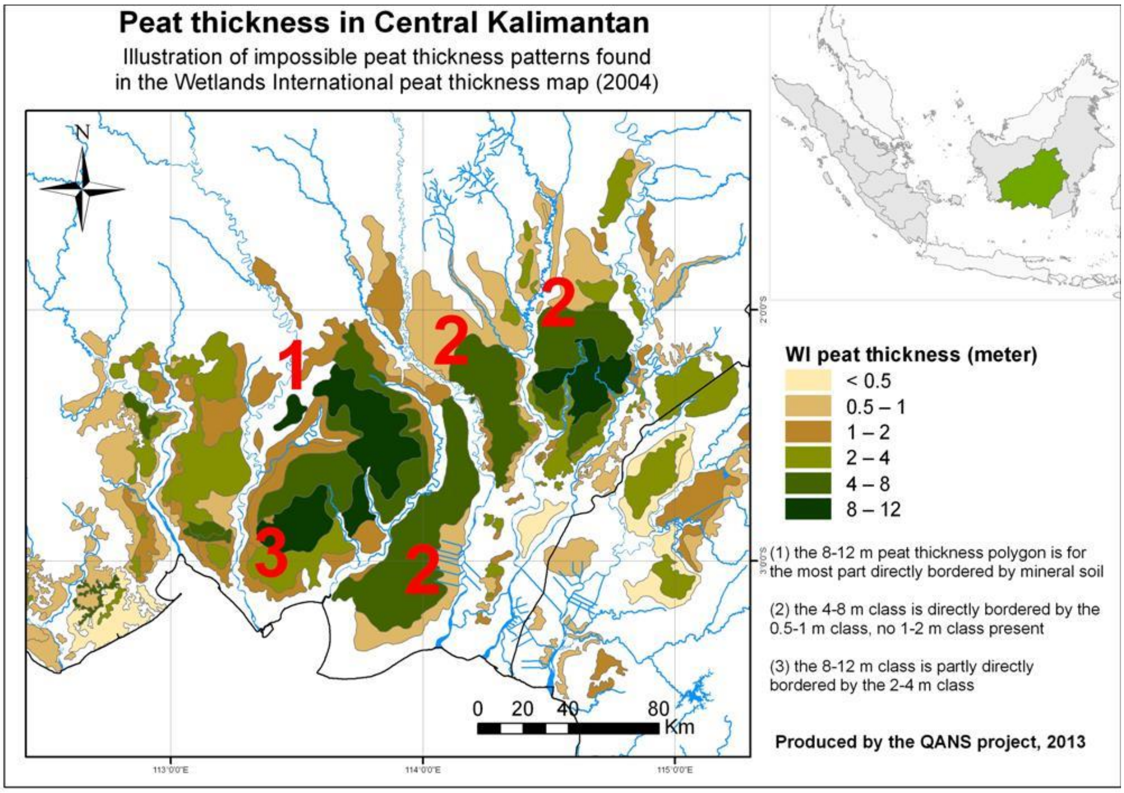


Figure 8 Illustration of difference in mapped peat extent for Lake Sentarum, West Kalimantan

Notes: The Wetlands International peat extent is overlaid by BBSDLP peat extent. Available peat thickness measurements (>0.5 m) are shown as well.



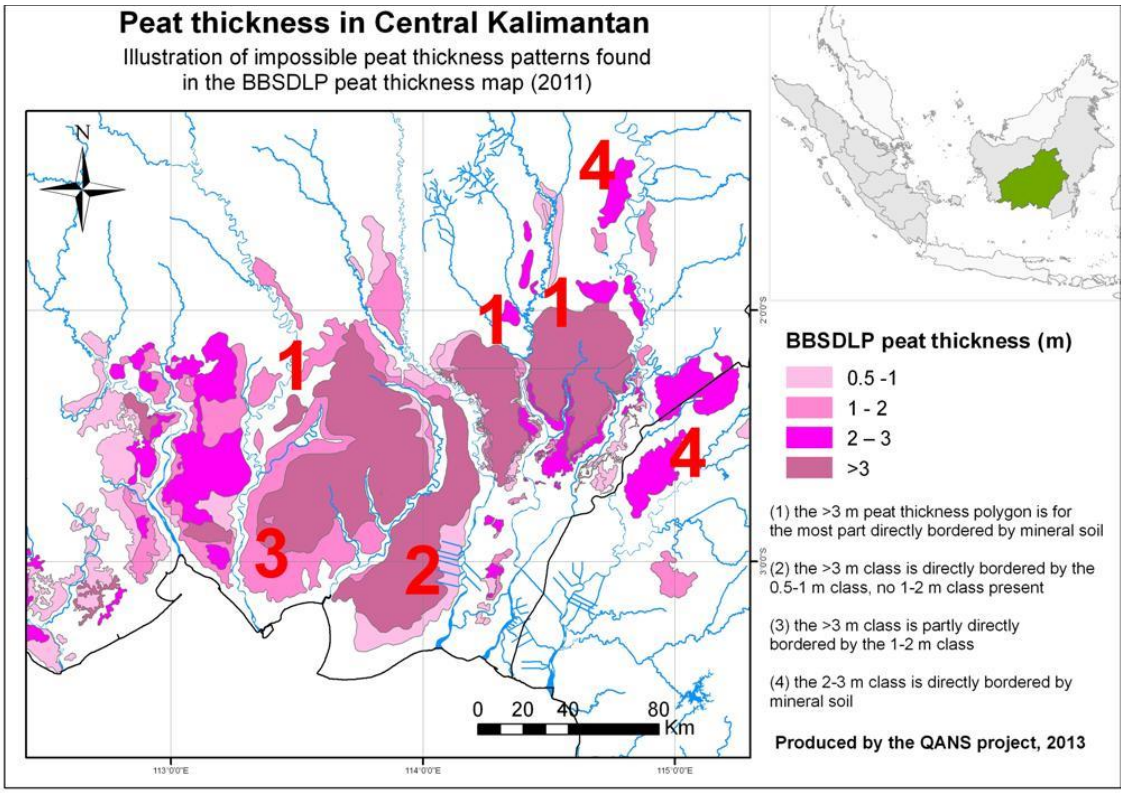


Figure 9 Impossible peat thickness patterns for Central Kalimantan in both WI (top) and BBSDLP (bottom) peat maps

2.4 Conclusion

Compared with peat thickness measurements peat maps, both WI and BBSDLP, systematically underrepresent actual peat thickness, by 1.5 m and 2 m on average, respectively (Table 6). In some areas, underestimations by over 5 m occur over large areas. For instance the BBSDLP map presents no peat over 2 m at all in the Province of Aceh (including Tripa) (Table 6), whereas field data indicate that the majority of the peat area in this Province is over 4 m and depths over 6 metres are common (the few measurements available for the large Singkil peat dome, that accounts for half of Aceh's peat and is still nearly intact, indicate depths over 10 metres).

In the EMRP area in Central Kalimantan, where abundant field data have been available for a longer time (collected in the aftermath of the PLG / Mega Rice Project failure), both maps appear to be more accurate than in other areas, but even there it does not have the accuracy required for detailed analysis or spatial planning.

Peat extent also appears to be underestimated: by 13% (1.7 Mha) for the WI map and by a further 1.7 Mha for the BBSDLP map. It appears that the BBSDLP map is largely derived from the WI map, by lowering class values (e.g. a 2 m contour would become a 1 m contour, and a 0.5 m contour the 0 m contour), so it is similar in many ways except that it suggests a lower average peat depth and smaller peat area.

It is concluded that the existing peat maps should be considered rough estimates of peat extent, apparently based more on inspection of satellite images than field measurements, rather than actual maps of peat thickness that may be used in research or spatial planning. While there is a relation between actual peat extent and peat extent presented by the maps, it appears that peat thickness classes on the maps are almost random and are hardly based on field evidence. For research, the existing maps may be used as minimum estimates of peat extent and thickness. For spatial planning and policy making however, it appears the existing maps can hardly be used at all, and improved maps are urgently needed.

While both the WI and BBSDLP maps are inadequate for most practical purposes, especially outside Central Kalimantan, the 2003/2004 WI map is consistently more accurate than the 2011 BBSDLP map, considering both peat thickness and peat extent. It appears that the attempt to improve the peat map for the Moratorium has actually caused a deterioration of map quality. It is therefore recommended that the WI map, and not the BBSDLP map, is used as the basis for future map improvements.

As a general rule, we would recommend that all peat thickness and peat extent indications in the WI map are interpreted as minimum values, where land use decisions need to be taken on the basis of peat thickness information. In Section 4.1 and Figure 40 an improved legend for the WI map is presented, that we would recommend to be used until further improved maps are available.

3 Methods to improve peat thickness maps using elevation data and morphological principles

Peatland formation is only possible under favourable environmental conditions, i.e. under waterlogged conditions with low decomposition rates due to acidic and anaerobic conditions, resulting in the accumulation of organic matter. As it accumulates, the peat system holds and slowly releases water, thereby creating wetter conditions around it and allowing the area of wetland to expand. The majority of the peatlands in Southeast Asia are domed, ombrogenous (rain water fed) systems (Rieley *et al.*, 1996) and are close to the coast or to rivers (Page *et al.*, 2006).

The surface of the ombrogenous peatlands is convex, i.e. dome-shaped, and above the limit of wet season river flooding (Anderson, 1964; Page *et al.*, 1999). Knowledge on the shape of the peat surface can be used to map peat thickness when the position of the peat bottom is also known, which relates to the period of formation of the peatland. In Southeast Asia, three major categories of ombrotrophic peatland have been proposed, based upon their location, mode of formation and the maximum age of the peat deposits: coastal peatlands; basin or valley peatlands; and high, interior or watershed peatlands (Rieley *et al.*, 1996; Page *et al.*, 1999). Based on a meta analysis on radiocarbon dated peat profiles, Dommain *et al.* (2011) found that peat domes of the coastal type all started development less than 7700 years BP, with 58% starting between 7000 and 4000 years BP and 29% younger than 3000 years BP. The main driver for coastal peat dome development was the Mid-Holocene sea-level stagnation following a rise in earlier millennia (van der Meene, 1984; Staub and Esterle, 1994; Dommain *et al.,* 2011). Because of this formation history of coastal peatlands, the bottom of the peat is usually expected to have a position around current mean sea level (MSL), as is the case in many parts of the world (Figure 10).

It should be noted that this rule-of-thumb applies only to coastal peatlands, and even there it must be tested for different areas, because some coastal zones may experience tectonic movement that may move the peat base away from the Sea level (upwards or downwards). Also, it should be noted that peatlands may ‘move uphill’ on the inland side, where the peat dome accumulates up pre-existing non-fluvial morphology, resulting in a peat base that can be well above Sea level; the assumption of a peat base near Sea level therefore does not hold for peatlands further away from the coast. In Section 3.1.3 we provide refined criteria for which peatlands may be considered to have a peat bottom near Sea level.

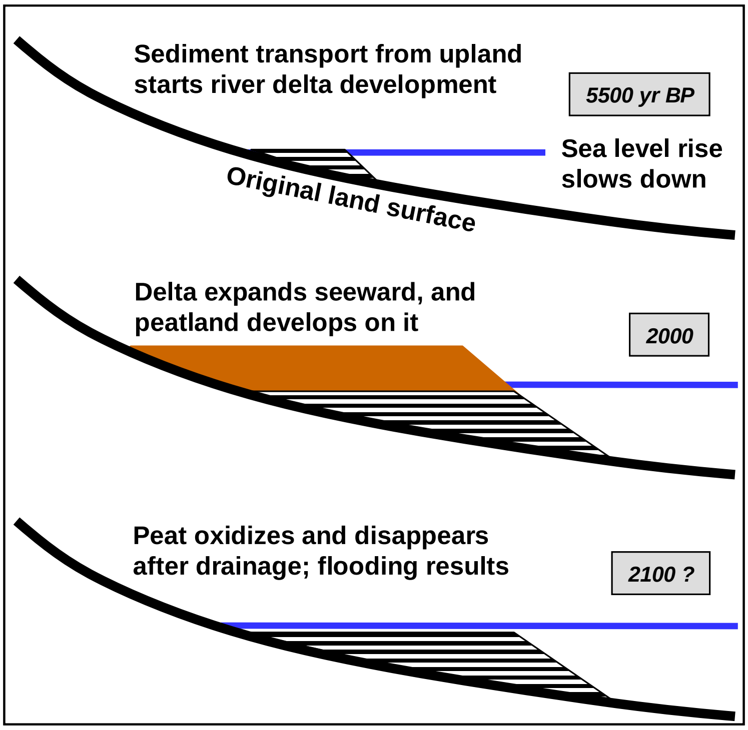


Figure 10 Chronology of peatland development in relation to Mean Sea level

Notes: Chronology of peatland development in relation to Mean Sea level, explaining why the peat bottom is usually near MSL (cross section after van der Meene, 1984).

A number of detailed profiles of peat depth and elevation in SE Asia have been published in past decades that may help derivation of morphological rules describing peat thickness and surface slope as a function of for instance distance to river (e.g. Anderson, 1964; Staub and Esterle, 1994). They all show the peat domes typically have flattened dome shapes (Figure 11 and Figure 12), with relatively steep edges in the first few kilometers from the river where the peat surface goes up by 1 to 2 m per km, whereas slopes are reduced to around or less than 0.5 m per km towards the center of the dome. The corresponding peat thickness usually goes from 0 to over 3 m in less than 3 km from the river, and is over 5 m over most of the peatland extent. The peat bottom is usually below Sea level, or rather below the reference level used to approximate Sea level (see below). These pattern observed in published studies are also observed in the larger and more recent datasets that were analyzed in this study (Section 3.1.3).

While these older publications are helpful in qualitative assessments of peatland morphology, they are mostly in Sarawak and offer no precise measurement coordinates, so they are of limited use for precise peat mapping in Indonesia. Also, older profiles are relative to a local reference level rather than MSL, usually a low-water river level that was estimated to be close to MSL, but may have been somewhat above it.

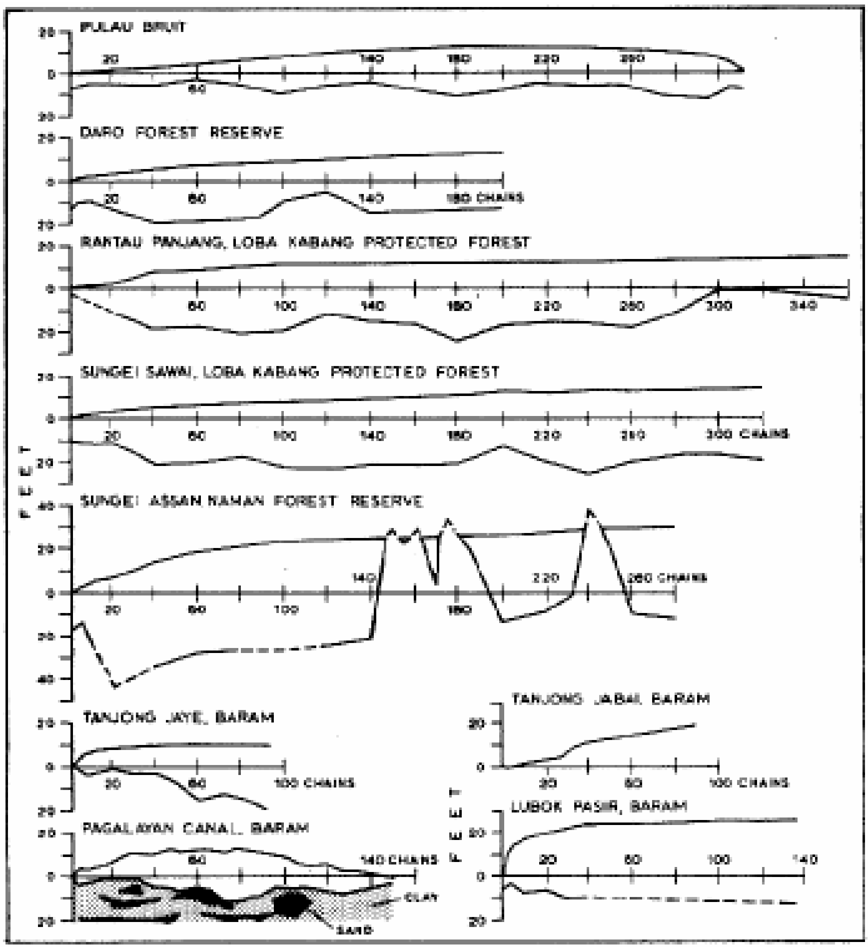


Figure 11 Cross sections through peat domes in Rajang and Baram deltas in Sarawak

Notes: Cross sections through peat domes in the Rajang and Baram river deltas in Sarawak, Malaysia, relative to low-water river level before they were deforested and drained (Anderson, 1964). Note that elevations are in 'feet' (0.3 m) and distances are in 'chains' (20.1 m).

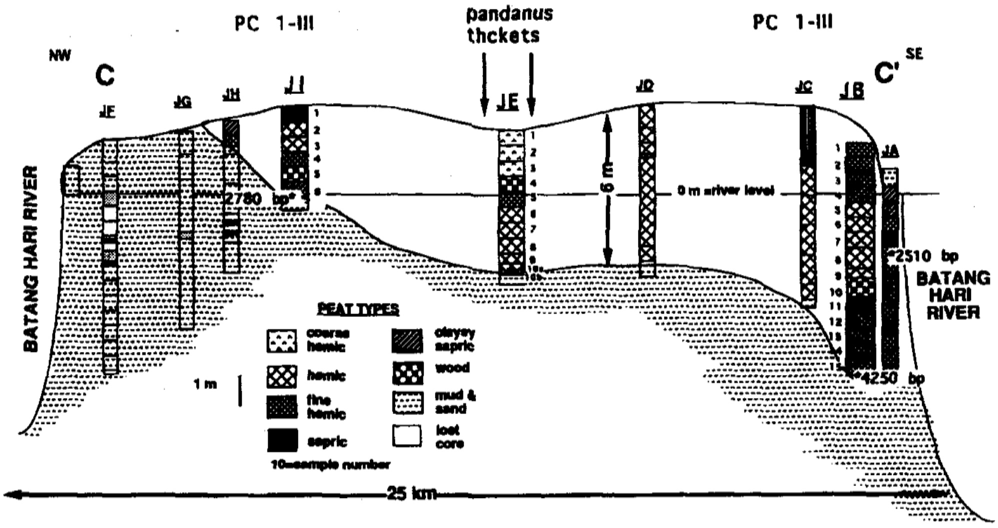


Figure 12 Cross section through a peat dome in Jambi, Sumatra

Notes: Cross section through a peat dome in Jambi (Staub and Esterle, 1994), relative to low-flow river level that was used as a proxy for Sea level).

Now that a lot of recent accurate peat thickness data have become available (Table 2) it is possible to derive quantitative relations across regions that, together with accurate full coverage elevation models for Indonesian lowlands, could greatly contribute to an improved peat thickness map for Indonesia.

In Section 3.1 both the typical dome shape of the peat surface and position of the peat bottom will be demonstrated for part of the EMRP area in Central Kalimantan where a highly detailed and accurate airborne LiDAR elevation model and high-quality peat thickness measurements are abundantly available to demonstrate that this geomorphological approach can be used to map peat thickness. In Section 3.2 the filtering of less accurate available remote sensing elevation datasets will be described which will further be used to derive peat thickness maps based on the analysis of Section 3.1.

3.1 The KFCP area as a pilot area for detailed analysis and concept development, with reference to other areas

Until recently, it was not possible to accurately validate the logical assumption that the position of the peat bottom for coastal peatlands in Indonesia must be around current mean sea level, as it is in other parts of the world, due to the lack of elevation and peat thickness data of sufficient density, detail and quality. In the EMRP area, between the Kahayan and Barito rivers in Central Kalimantan, efforts have been made since 2007 in various projects (CKPP, EMRP-MP, KFCP) to collect accurate peat thickness data. Especially the KFCP project collected highly accurate peat thickness data in the Blok A and E areas between the Kapuas and Mantangai rivers[3], and produced a LiDAR DTM that is accurate to within 25 cm (Siegert *et al.*, 2012).

The availability of a detailed DTM and peat thickness dataset in this area allowed it to be used as a pilot area for testing methods to derive peat thickness maps from elevation data for coastal peatlands.

3.1.1 The relation between peat thickness and distance to river

For the relation between peat thickness and distance to river, we use peat thickness measurements (>0.5 m) in two peat domes for which KFCP LiDAR data are available: Blok A+E and Blok B. We focus initially on forest areas because here we may tentatively assume only limited drainage and subsidence has taken place, i.e. the peat dome shape is likely to be more or less in its original state. For Blok A+E, only those measurements within 12 km distance from the Kapuas river were used, the location of the top of the peat dome. Furthermore, based on an analysis of the levee height along the Kapuas river, determined from the LiDAR DTM, 135 km was found to be the approximate distance from the coast where increase of levee elevation was rather constant, beyond that the rise is much faster (Figure 13). We therefore only considered those peat thickness measurements which were <135 km from the coast. Later on in the analysis (Section 3.1.3) this distance is independently confirmed.

[3] KFCP peat thickness data was collected following strict protocols, which include i) only using well-trained teams, ii) proving with field sheets and photos that the mineral subsoil was actually found in each case, iii) 2 or 3 replicate measurements at each location, and iv) revisiting locations where peat thickness values seem dubious.

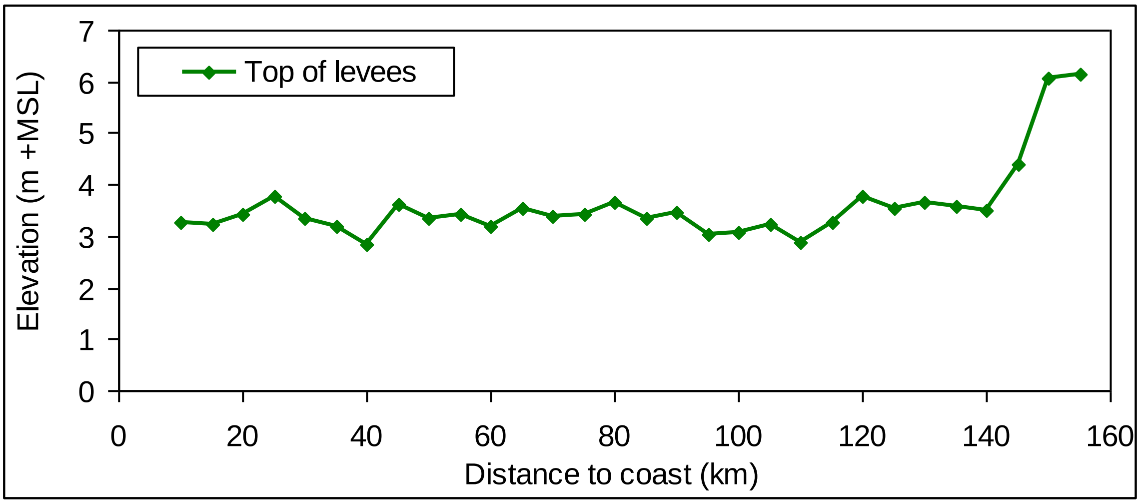


Figure 13 Average elevation of the top of right and left levee along Kapuas River

Notes: Average elevation of the top of the right and left levee along the Kapuas River, Central Kalimantan, determined from the KFCP LiDAR DTM in relation to the distance to the coast.

After a point by point visual analysis with neighbouring points a further 10% of the available measurements (29 out of 304) were removed from the analysis, all from a few individual survey transects, since those measurements differed greatly from values found by a larger number of other surveys along the same transects. The relationship between peat thickness and distance to river is shown in Figure 14.

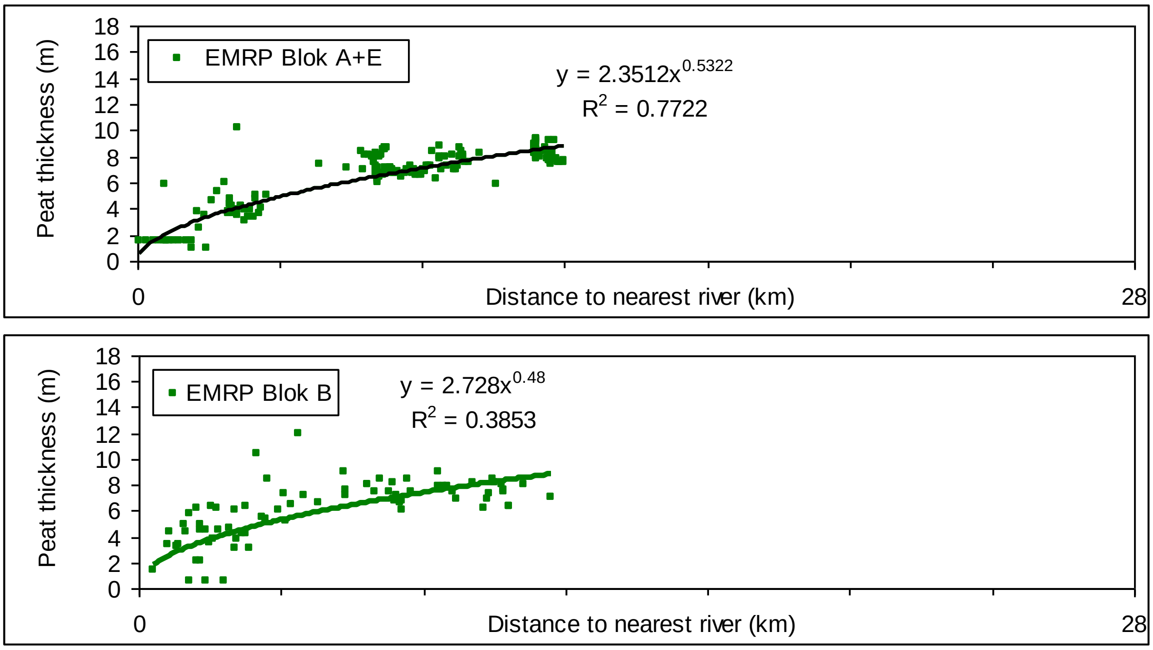


Figure 14 Relation between peat thickness and distance to large rivers (Kahayan and Kapuas)

Notes: Relation for forested peatland (year 2000) between peat thickness (>0.5 m) and distance to large rivers (Kahayan and Kapuas) for the peat domes in Blok A+E and Blok B of the EMRP area, Central Kalimantan, closer than 135 km from the coast.

Despite the inevitable variation in the data, as shown by the scatter around the regression lines, Figure 14 confirms that clear relations exist between peat thickness and distance to river. When allowing a 2 meter margin around the regression lines, 90% of measurements are within that margin when considering the two peat domes (Blok A+E and Blok B) together. Some of the remaining outliers may well be measurement errors.

Similar relations are found for other forested peatland areas in Indonesia where sufficient peat thickness measurements are available: Sebangau NP in Central Kalimantan and the Kampar Peninsula in Riau (Figure 15). Combining the separate relations results in closely corresponding dome shapes (Figure 16), suggesting that such relations may be generally valid. All data analysed confirm the observation from older publications that, at least in larger peat domes that are still forested or were deforested and drained less than 20 years ago, peat thickness is over 3 m along most of the transects, being less than 3 m only over the first few km from the river.

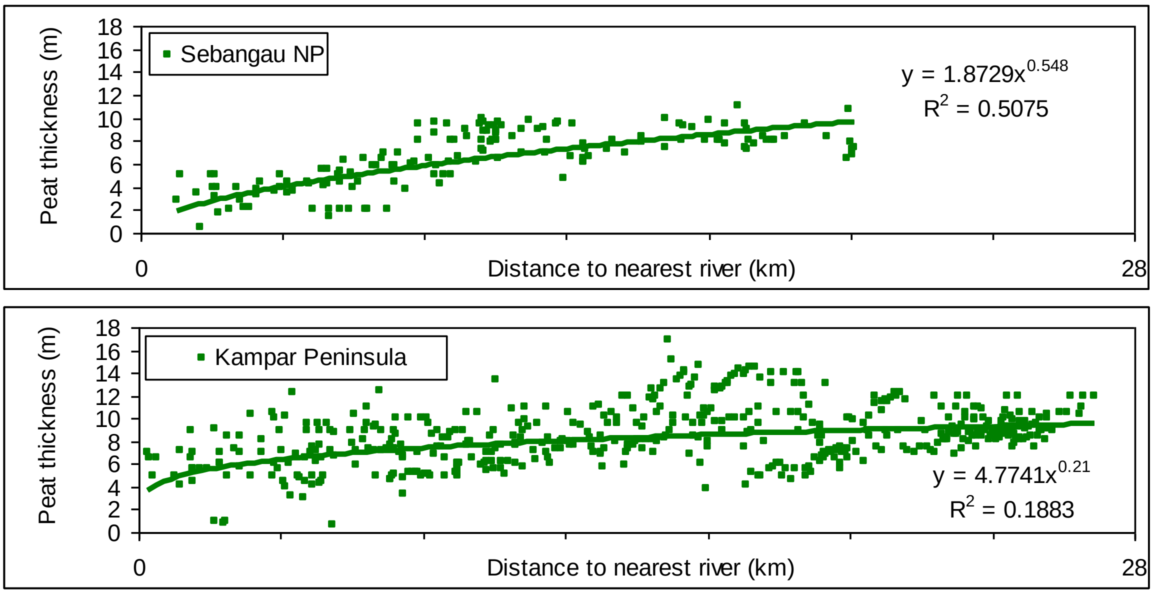


Figure 15 Relation between peat thickness and distance to large rivers for Sebangau NP, Central Kalimantan and Kampar Peninsula, Riau

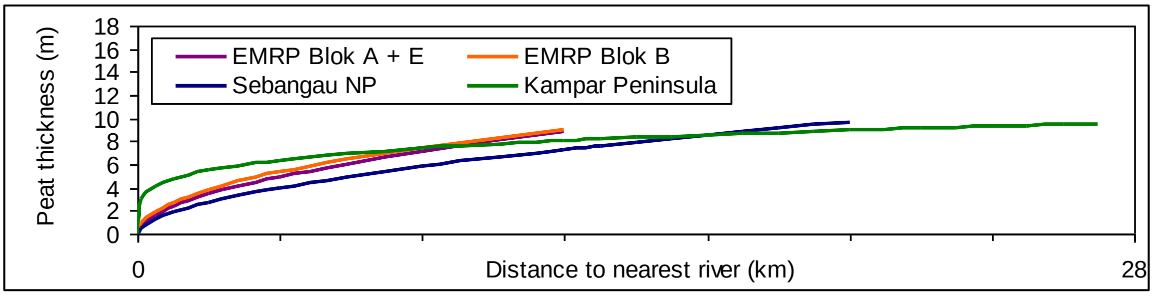


Figure 16 Average relation between peat thickness and distance to large rivers for various largely forested (i.e. relatively intact) peat areas in Central Kalimantan and Riau.

Notes: Based on relations derived from individual peat thickness measurements as shown in Figure 14 and Figure 15.

3.1.2 The relation between elevation and distance to river

For the measurement locations plotted in Figure 14 highly accurate recent elevation measurements from LiDAR are available through the KFCP project (Siegert *et al.*, 2012). When these elevation measurements, for locations where peat thickness data are available, are plotted against the distance to the nearest large river (Figure 17) similar concave shapes are found as for peat thickness (cf. Figure 14).

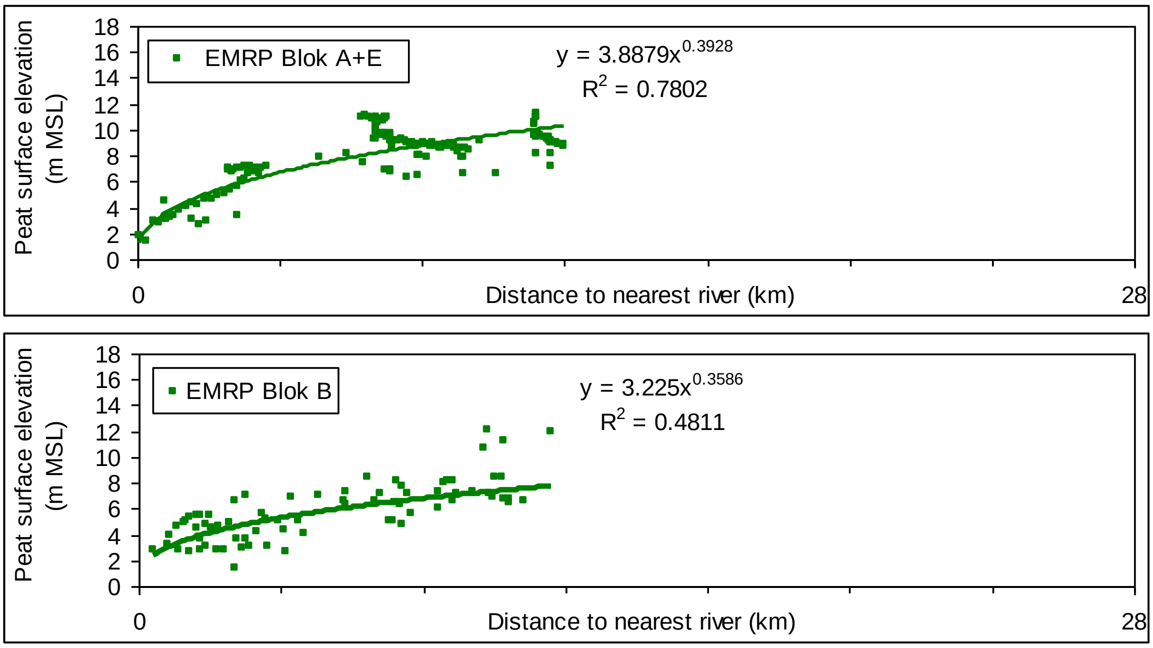


Figure 17 Relation between peat surface elevation and distance to large rivers (Kahayan and Kapuas)

Notes: Relation for forested peatland (year 2000) between peat surface elevation and distance to large rivers (Kahayan and Kapuas) for the peat domes in Blok A+E and Blok B of the EMRP area, Central Kalimantan for the same locations as shown in Figure 14.

In Figure 18 both peat surface elevation and peat thickness relationships are combined for both Blok A+E and B, showing a close relationship between both peat surface elevation and peat thickness.

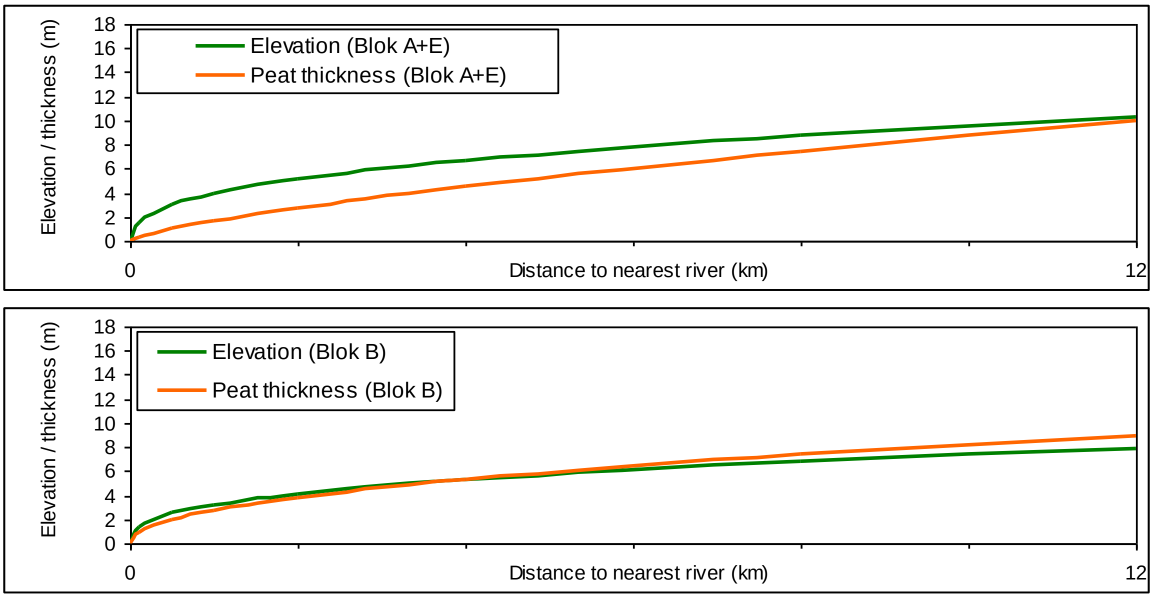


Figure 18 Relation for forested peatland (year 2000) between elevation or peat thickness and distance to large rivers (Kahayan and Kapuas)

Notes: Relation for forested peatland (year 2000) between elevation or peat thickness and distance to large rivers (Kahayan and Kapuas) for the peat domes in Blok A+E and Blok B of the EMRP area, Central Kalimantan. The individual relationships were derived from locations where peat thickness measurements were available, see Figure 14 and Figure 17.

3.1.3 The position of the peat bottom, i.e. relation between peat surface elevation and peat thickness

In order to avoid the effect of subsidence in the time between measurements of peat thickness and elevation (LiDAR DTM of 2011), the analysis on the position of the peat bottom is limited to peat thickness measurement locations which were recently collected by the KFCP project (2010-2011). For each of the selected peat thickness locations (869 in total) LiDAR DTM elevation was determined after which the position of the peat bottom could easily be determined by subtracting the peat thickness from the elevation. From Figure 19 and Figure 20 it is clear that the position of the peat bottom relative to MSL (+/- 2 m) is somewhat dependent on the distance to the coast. When this distance is less than 135 km, the peat bottom is relatively close to MSL (+0.72 m MSL), with 74% of the measurements less than 2 m above current MSL and 33% below it (Table 9). However beyond 135 km from the coast, the peat bottom rises relatively steeply, to over 10 m above MSL more than 150 km from the coast. It appears that this inland peat has not started development on a coastal plan but rather in rising terrain. It is worth noting that Dommain *et al.* (2011) in their meta-analysis on radiocarbon dated peat profiles used a distance of 80 km from the coast as boundary for coastal peatlands. We conclude that beyond some 100 km from the coast, or 135 km in the case of the EMRP area in Central Kalimantan, the assumption of having a peat bottom near MSL does not apply.

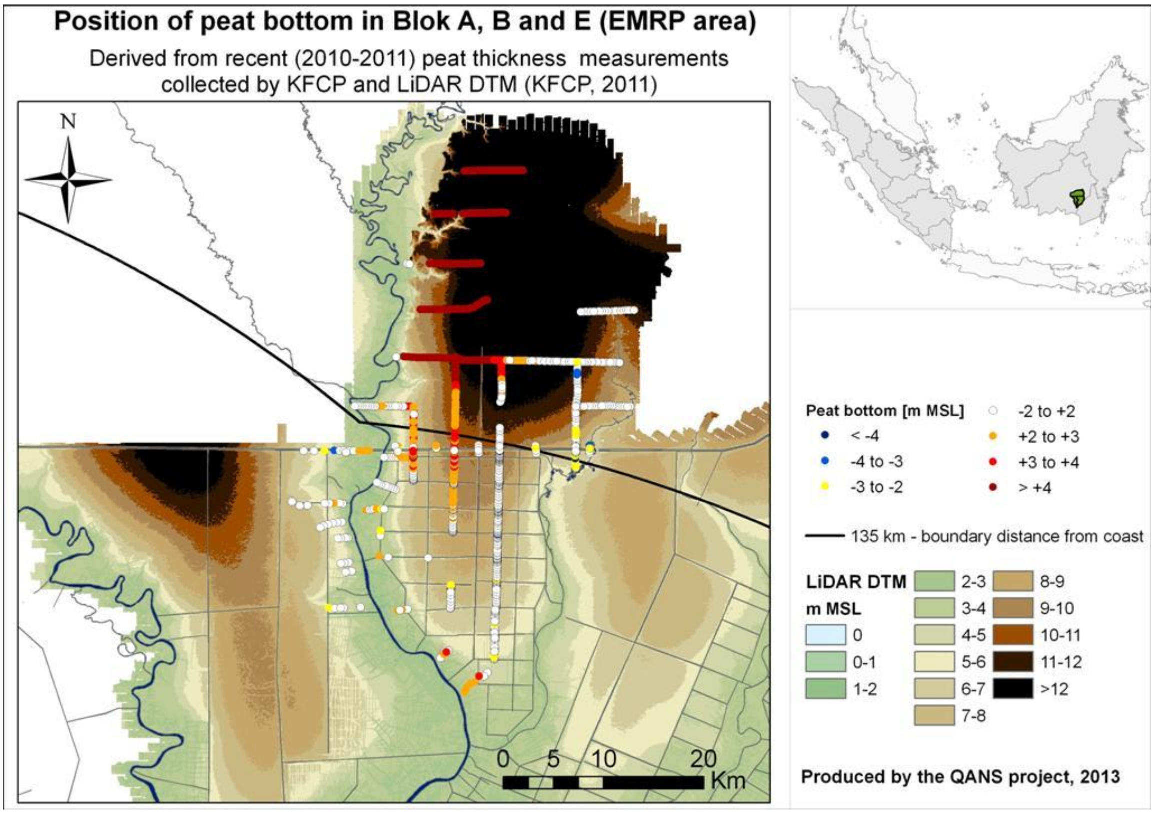


Figure 19 Peat bottom (m MSL) at peat thickness locations measured by KFCP

Notes: Peat bottom (m MSL) at peat thickness locations recently measured by the KFCP project (2010-2011) or were still forested in 2010 in EMRP Bloks A, B and E in Central Kalimantan. See also Figure 20.

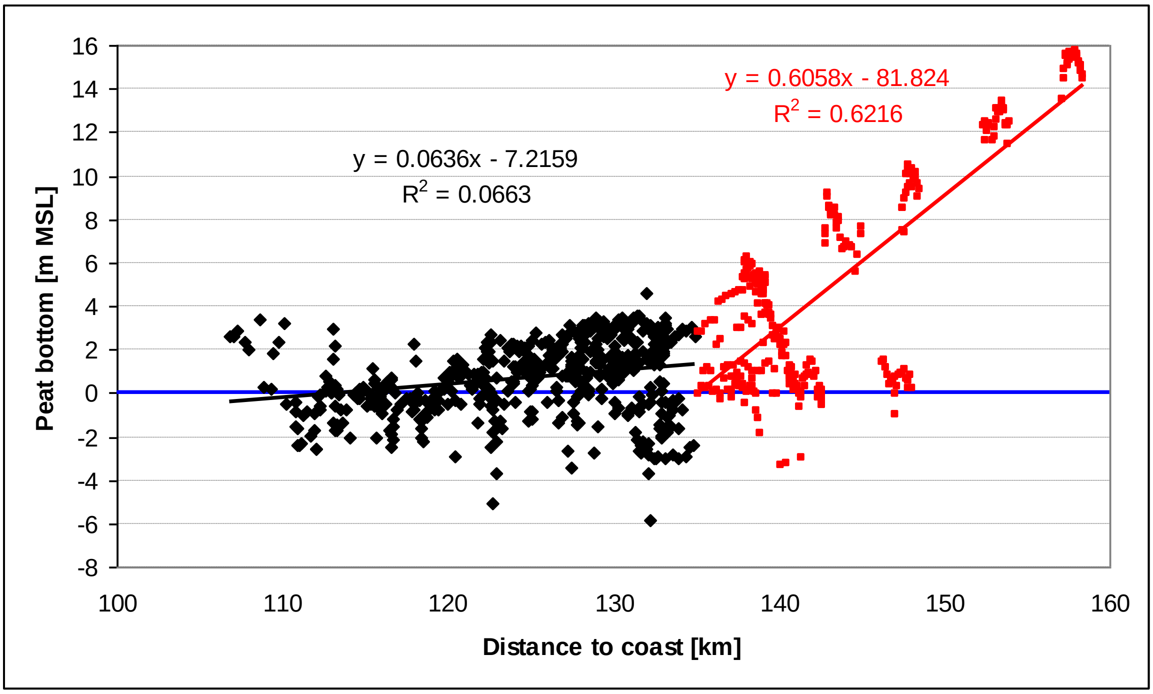


Figure 20 Relation between peat bottom and distance to the coast (Central Kalimantan)

Notes: Relation between peat bottom (m MSL) at locations where peat thickness has recently been measured by the KFCP project (2010-2011) or were still forested in 2010 in EMRP Bloks A, B and E in Central Kalimantan and distance to the coast. See also Figure 19.

Whereas there was a very clear relationship between peat thickness and peat surface elevation with distance to the nearest river (Sections 3.1.1 and 3.1.2) this relationship is less evident for the position of the peat bottom. This is, despite the inherent natural variations due to the presence of a pre-existing morphology at the start of peat development, relatively flat albeit somewhat declining along a very shallow gradient of approximately 10 cm/km away from the river (Figure 21).

Table 9 Position of peat bottom in EMRP Bloks A, B and E in Central Kalimantan

Distance from coast [km]	n	Average peat bottom [m MSL]	Peat bottom < +2 m MSL [%]	Peat bottom < +0 MSL [%]
< 105	0	-	-	-
< 110	10	2.06	30	0
< 115	66	-0.05	85	53
< 120	139	-0.21	92	60
< 125	244	0.12	90	45
< 130	405	0.69	77	32
< 135	558	0.72	74	33
< 140	694	1.15	67	28
< 145	774	1.33	66	27
< 150	819	1.53	65	26
< 155	845	1.87	63	25
< 160	869	2.23	62	24

Notes: Statistics on the position of the peat bottom in EMRP Bloks A, B and E in Central Kalimantan, calculated from elevation derived from a detailed LiDAR DTM (KFCP, 2011) and peat thickness measurements recently collected by the KFCP project (2010-2011) or were still forested in 2010.

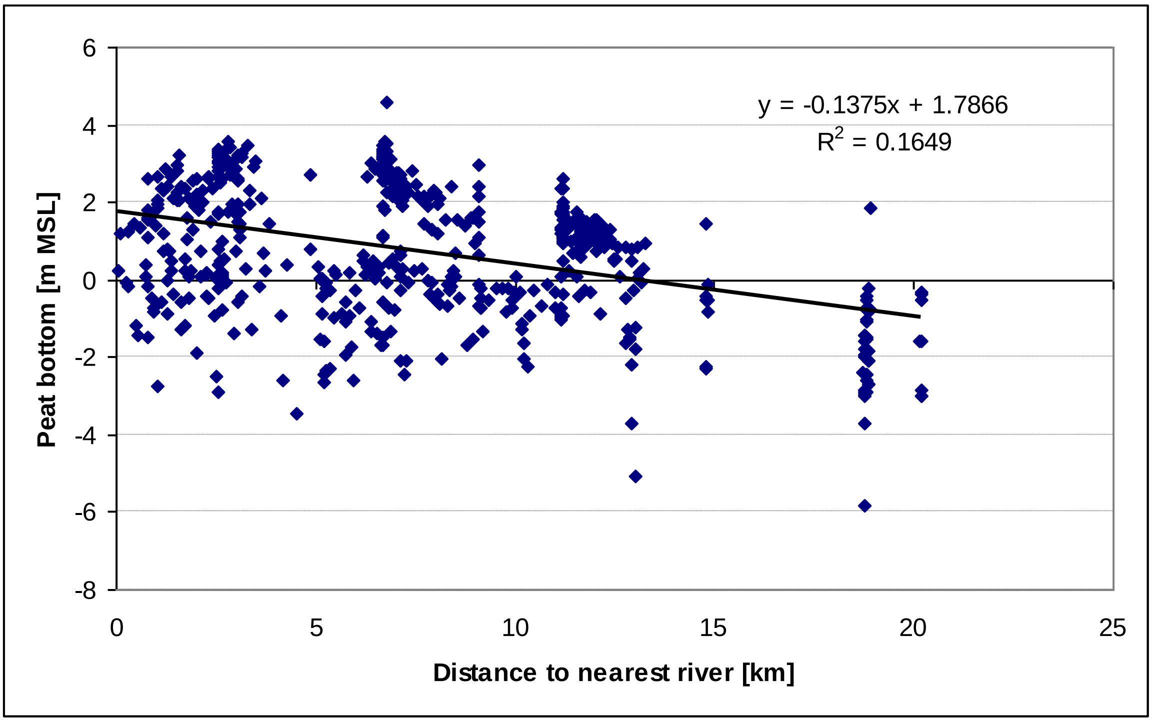


Figure 21 Relation between peat bottom and distance to nearest large river

Note: This is for those peat thickness measurements of Figure 20 <135 km from the coast.

3.1.4 Applicability of peatland geomorphological relations

The analysis of data presented in previous subsections demonstrates that, as the position of the peat bottom is known with relative certainty for peatlands less than ~100 km from the coast, it is over this coastal zone generally possible to estimate peat thickness from elevation data. For peatlands further away from the coast, other methods need to be developed. In coastal peatlands, the method should be used with caution in areas where there is evidence of mineral outcrops in peatlands, as is the case in e.g. Sebangau NP. The better the elevation data are, the more accurate this approach will be. A rough peat thickness map for the KFCP area, derived from this method, is presented in Figure 22. Such a map could be improved with actual measurements of peat thickness, where available, it presents a starting point rather than a final product.

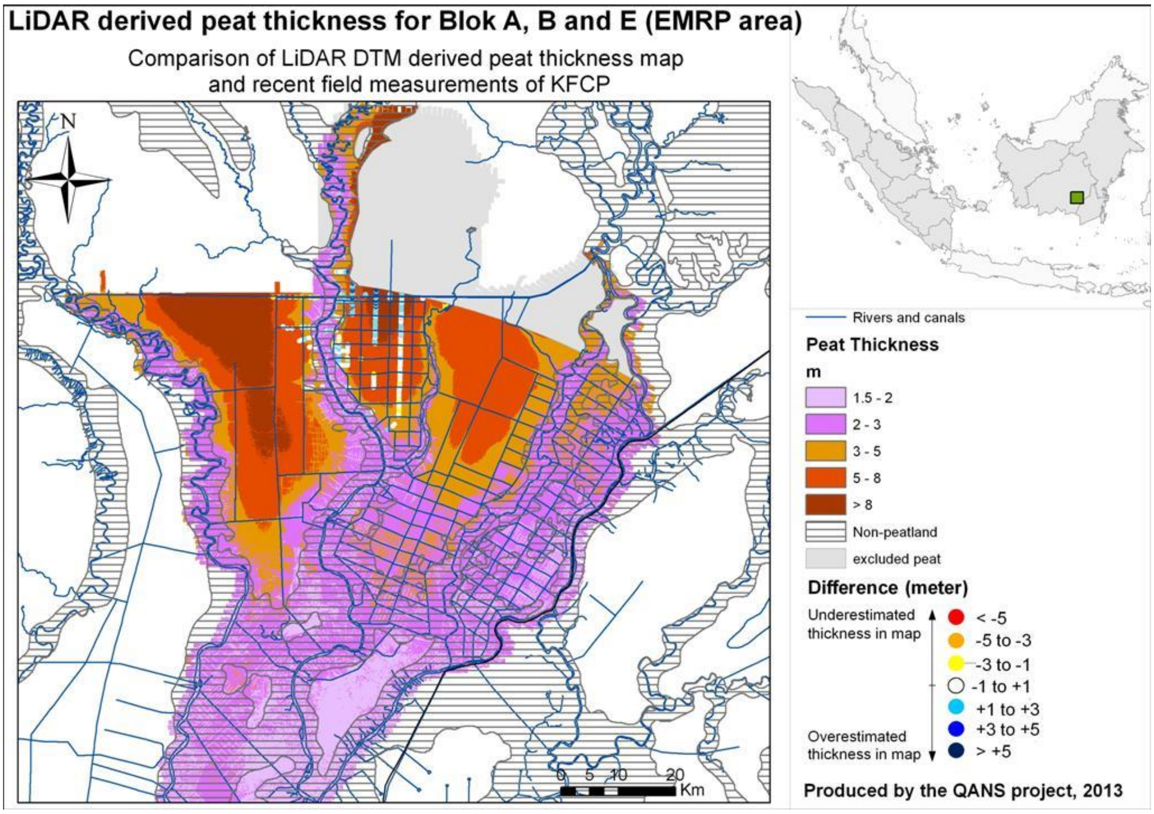


Figure 22 Peat thickness model for Blok A, B and E in the EMRP area, showing difference with actual peat thickness

Notes: Peat thickness model for Blok A, B and E in the EMRP area, Central Kalimantan derived from the elevation of the LiDAR DTM and from it subtracted a fixed position of the peat bottom of 0.72 m from the LiDAR DTM. Shown as well is the difference with actual peat thickness measurements.

3.2 Mapping peat surface elevation using SRTM-30 and GLAS data

In the absence of airborne LiDAR data for most lowland areas in Indonesia, data derived from satellite platforms are usually the only Remote Sensing elevation datasets available. At the moment, there are two existing datasets in the public domain that can be used. The SRTM-30 dataset (Space Shuttle Radar with a 30m lateral resolution; 1m vertical resolution; Farr *et al.* (2007) was recently made available by the US Government to Indonesia, and kindly made available to QANS through UKP4, has nearly full coverage over Indonesian peatlands (albeit currently still missing for the part of Sumatra West of the 102 degrees East Meridian, incl. approximately 50% of the Riau Province and all of North Sumatra and Aceh Province). This radar data allows construction of rough elevation models for deforested or sparsely forested areas after data filtering (see below), but in forested areas it represents the canopy level not the actual ground level. The LiDAR data transects collected ICESat/GLAS satellite (Schutz *et al.*, 2005) are not full coverage, but they do penetrate the canopy in forested areas (after filtering) and could thus be used to validate and complete DTMs for such areas (Ballhorn *et al.*, 2011). The processing of both datasets is explained in the next Sections.

The SRTM-30 data used in this assessment were received from UKP4. The ICESat / GLAS data were prepared by RSS (Remote Sensing Solutions).

3.2.1 Peat surface elevation for deforested areas (in 2000)

The SRTM-30 dataset is not an actual digital terrain model (DTM) but rather a digital surface model (DSM) which includes vegetation height. Before SRTM-30 can be used as a DTM, the vegetation effect needs to be filtered out. Filtering is possible for relatively open and degraded areas with little remaining forest cover, where a sufficient density of data points may be expected where the SRTM data actually represent ground level, albeit with some inaccuracy as SRTM data have a vertical resolution of 1 m.

3.2.1.1 SRTM-30 window filtering

The filtering approach applied here is based on the assumption that within a certain ‘window’ area at least one 30 m grid cell represents the true surface. Moving minimum windows of 4 different sizes (330 m, 660m, 1 km and 2 km, i.e. 11x11, 22x22, 33x33 and 66x66 grid cells) followed by moving average windows of the same size on the minimum results were applied to test which window size yields the best results. The filtering method, illustrated in Figure 23, is tested in open and degraded peatland areas (in year 2000) in 4 different provinces, Riau, Jambi, South Sumatra and Central Kalimantan (Figure 24). The selection of these areas was based on the overall availability of ICESat/GLAS transects which, after filtering, are used to validate the result of the SRTM-30 window filtering.

ORIGINAL GRID											
1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80	81	82	83	84
85	86	87	88	89	90	91	92	93	94	95	96
97	98	99	100	101	102	103	104	105	106	107	108
109	110	111	112	113	114	115	116	117	118	119	120
121	122	123	124	125	126	127	128	129	130	131	132
133	134	135	136	137	138	139	140	141	142	143	144

RESULTING GRID AFTER WINDOW MINIMUM OF 3x3											
1	1	2	3	4	5	6	7	8	9	10	11
1	1	2	3	4	5	6	7	8	9	10	11
13	13	14	15	16	17	18	19	20	21	22	23
25	25	26	27	28	29	30	31	32	33	34	35
37	37	38	39	40	41	42	43	44	45	46	47
49	49	50	51	52	53	54	55	56	57	58	59
61	61	62	63	64	65	66	67	68	69	70	71
73	73	74	75	76	77	78	79	80	81	82	83
85	85	86	87	88	89	90	91	92	93	94	95
97	97	98	99	100	101	102	103	104	105	106	107
109	109	110	111	112	113	114	115	116	117	118	119
121	121	122	123	124	125	126	127	128	129	130	131

Figure 23 Example of the applied window filtering

Notes: Illustration of the applied window filtering. In this example a minimum window of 3x3 cells is applied on a 12 x 12 grid. For each grid cell the minimum in a 3x3 window is selected. So the minimum value for the red cell in the original grid with value 41 (left) has a minimum value of 28 when using a 3x3 window (right).

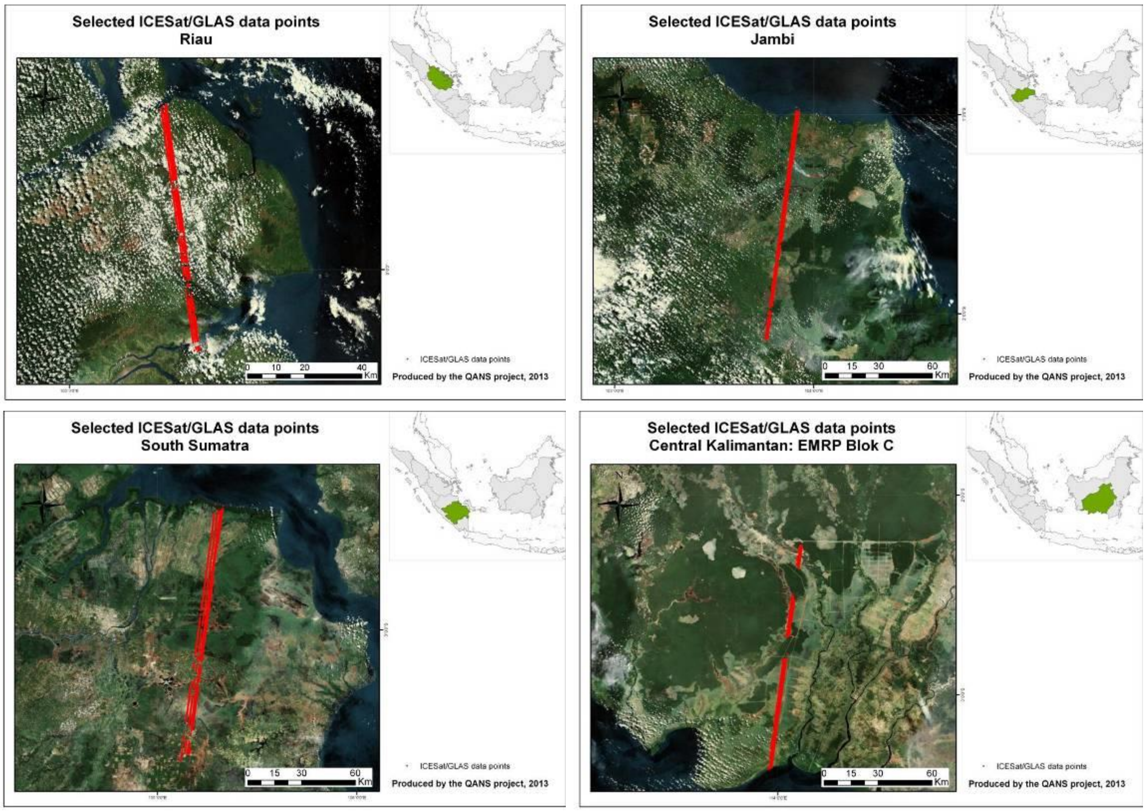


Figure 24 ICESat/GLAS data points in Riau, Jambi, South Sumatra and Central Kalimantan

Notes: Location of ICESat/GLAS data points in open or degraded areas in Riau (Kerumutan), Jambi (Berbak NP), South Sumatra and Central Kalimantan (EMRP Blok C) used to validate the different SRTM-30 window filters.

Prior to application of the window filters the forested areas were masked out from the original SRTM-30 to avoid the vegetation still present in the original SRTM-30 data creating an edge effect introducing higher average elevation in open areas bordering the forested areas. To discern between forested and deforested areas the CRISP 2000 landcover map is used (Miettinen *et al.*, 2012b), which represents the land cover status at the moment the SRTM data were collected (February 2000).

3.2.1.2 ICESat/GLAS additional filtering

ICESat/GLAS data points were available for the period 2003-2009 and were processed and filtered by Remote Sensing Solutions (RSS) for the peatlands (with a 10 km buffer) on Sumatra and Borneo. A detailed explanation of the filtering method is found in Ballhorn *et al.* (2011). Inspection of selected ICESat/GLAS transects however indicated that numerous outlier values were still present in the filtered ICESat/GLAS dataset, both above and below the surface (Figure 25). The outliers above the actual peat surface may be explained by vegetation being hit rather than the peat surface; outliers below the surface may be caused by a phenomenon called ‘multiple pathway reflection’. Whatever the cause, these outliers must be removed before ICESat/GLAS data can be used in DTM construction and validation of the filtered SRTM-30 data.

Additional filtering of the ICESat/GLAS data included the removal of data points which were forested according to the CRISP 2000 landcover map or had an elevation less than 0 or greater than 14 m (based on the initial observation that the near-coastal peat domes studied did not have elevations above +12 m MSL). On the remaining data points a moving median filter was applied using 5 to 11 ICESat/GLAS data points, depending on the window filter with which it was compared (spacing between ICESat/GLAS data points is generally 175 m). All data points deviating +/- 1.5 m from this median value were removed from the dataset. The threshold value of 1.5 m was determined through trial and error, and may be replaced in future method refinement by a value related to the standard deviation. Data points for which no median value could be calculated (i.e. at the start and end of a transect, but also where distance between start and end point of a median calculation was more than 1 or 2 km, due to the removal of forested ICESat/GLAS data points) were removed from the comparison. Only ICESat/GLAS transects with sufficient data points after filtering (always over 230 data points) were considered in the comparison with SRTM-30.

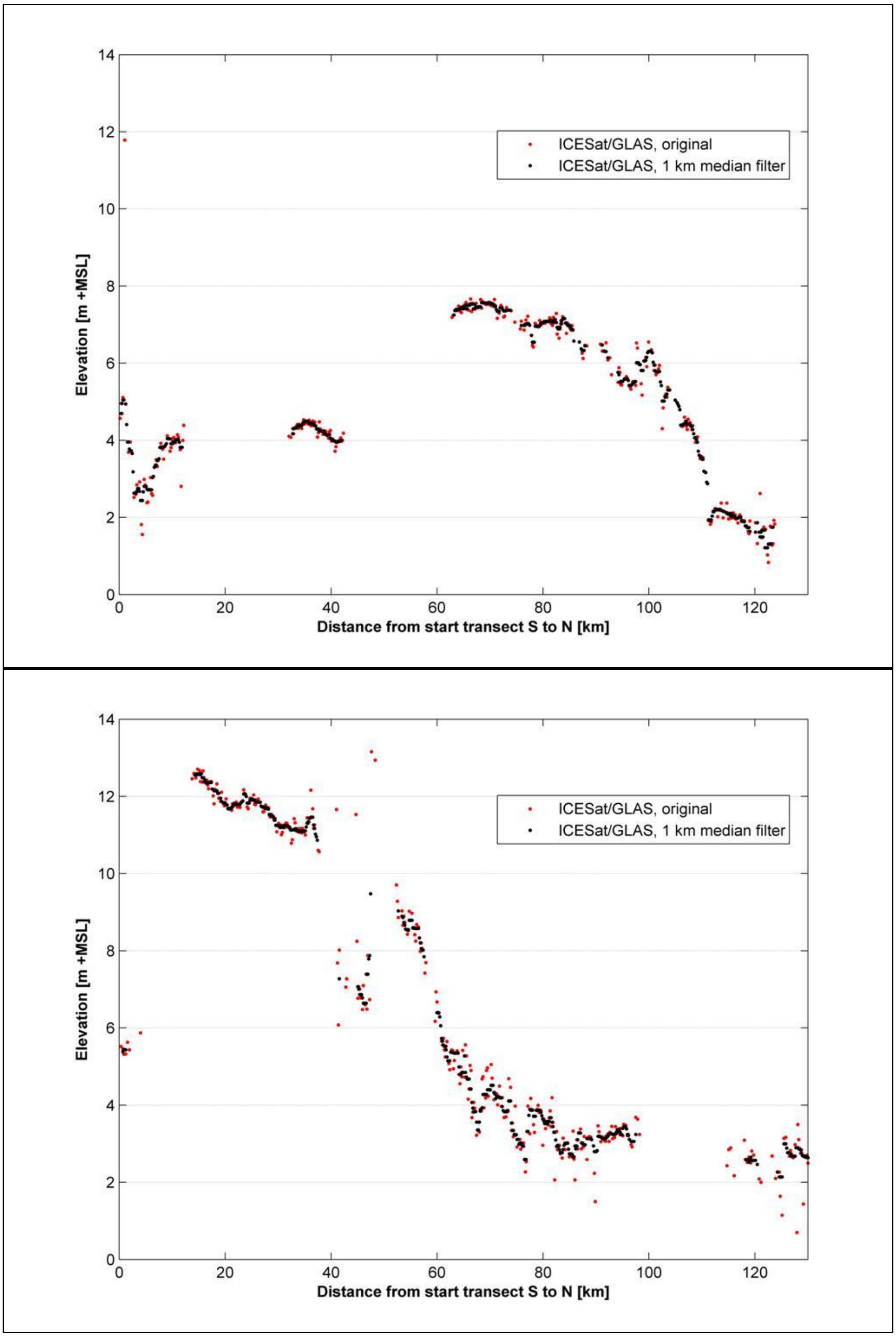


Figure 25 Example of presence of outliers in ICESat/GLAS data

Notes: Example of presence of outliers in ICESat/GLAS data as filtered following Ballhorn et al. (2011) (red dots) and with additional filtering as explained in the text (black dots) for (top) ICESat/GLAS transect (2007-03) located in Blok C of EMRP in Central Kalimantan and (bottom) ICESat/GLAS transect (2007-03) in South Sumatra. Densely forested data points, as indicated by the CRISP 2000 landcover map, and outliers below the surface are not shown here.

3.2.1.3 Comparison of window filtered SRTM-30 and ICESat/GLAS

Comparing the ICESat/GLAS transects with original and window filtered SRTM-30 revealed that the 330 and 660 m window filters still included too much vegetation, whereas the 1 and 2 km window filters resulted in a much more natural representation of the surface and looked most similar to the GLAS filtered transects (Figure 26). Further comparison therefore only focused on the 1 and 2 km window filters.

In each of the 4 areas (Figure 24) a total of 7 to 10 transects ranging in length from 71 to 144 km were available to carry out the comparison. In general, the 2 km window filtered SRTM-30 had a slightly higher correlation with the filtered ICESat/GLAS data set compared to the 1 km window, with the majority (70%) of the individual transects having a coefficient of determination (R^2) > 0.70 (57% had an R^2 >0.80 and for 30% R^2 was >0.90), whereas for the remainder the R^2 was greater than 0.44. R^2 for the 1 km window ranged between 0.39 and 0.97, with 73% having a R^2 > 0.70 (52% had an R^2 > 0.80 and for 21% R^2 was >0.90). Combining all data pairs per area resulted in a R^2 ranging from 0.61 to 0.94 for the 1 km window and from 0.65 to 0.96 for the 2 km window (Table 9 and Figure 28).

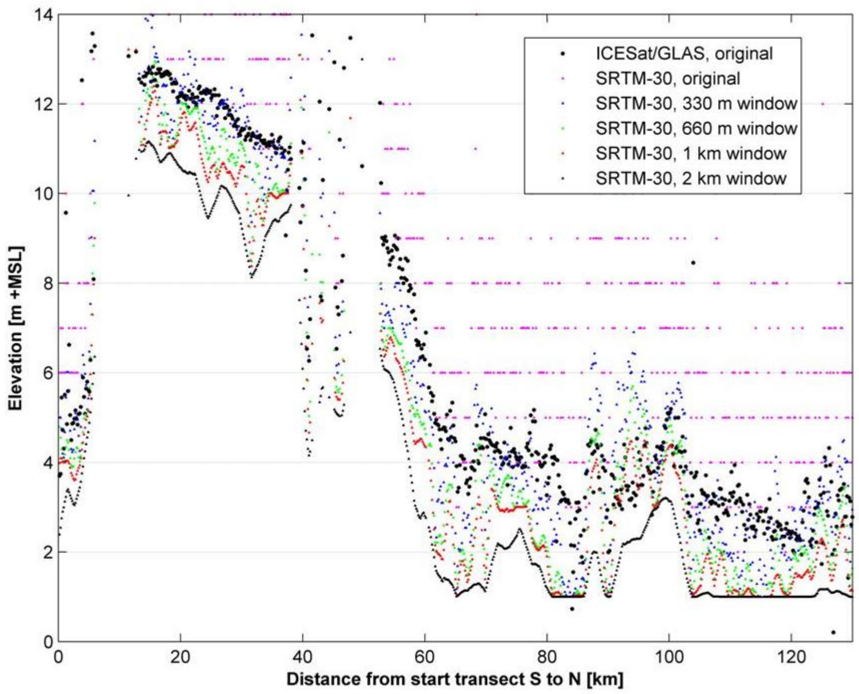


Figure 26 Example of ICESat/GLAS transect (2004-05) in South Sumatra

Notes: Example of ICESat/GLAS transect (2004-05) in South Sumatra showing the result of the different applied window filters on SRTM-30 to remove the vegetation signal. Areas that have closed forest canopy according to CRISP 2000 data are not included.

Table 10 Summary statistics for comparison between 1 and 2 km window filtered SRTM-30 and ICESat/GLAS data

Area	Number of transects	Range transect length [km]	total GLAS data points	total 1 km median GLAS data points	1 km R^2	1 km avg. difference (+/- stdev)	total 2 km median GLAS data points	2 km R^2	2 km avg. difference (+/- stdev)
Jambi (Berbak)	10	72 - 128	4,962	4,298	0.78	1.79 (0.33)	3,144	0.67	2.48 (0.61)
Riau (Keramutan)	9	71 - 87	3,027	2,697	0.61	1.64 (0.26)	2,015	0.65	2.16 (0.27)
South Sumatra	7	83 - 144	3,584	3,256	0.94	1.40 (0.20)	2,579	0.96	2.14 (0.14)
Central Kalimantan (EMRP Blok C)	7	123 - 125	3,168	2,931	0.86	1.20 (0.13)	2,353	0.87	1.78 (0.14)

Notes: Summary statistics for the comparison between 1 and 2 km window filtered SRTM-30 and ICESat/GLAS data for open and degraded areas in 4 different Provinces as shown in Figure 24.

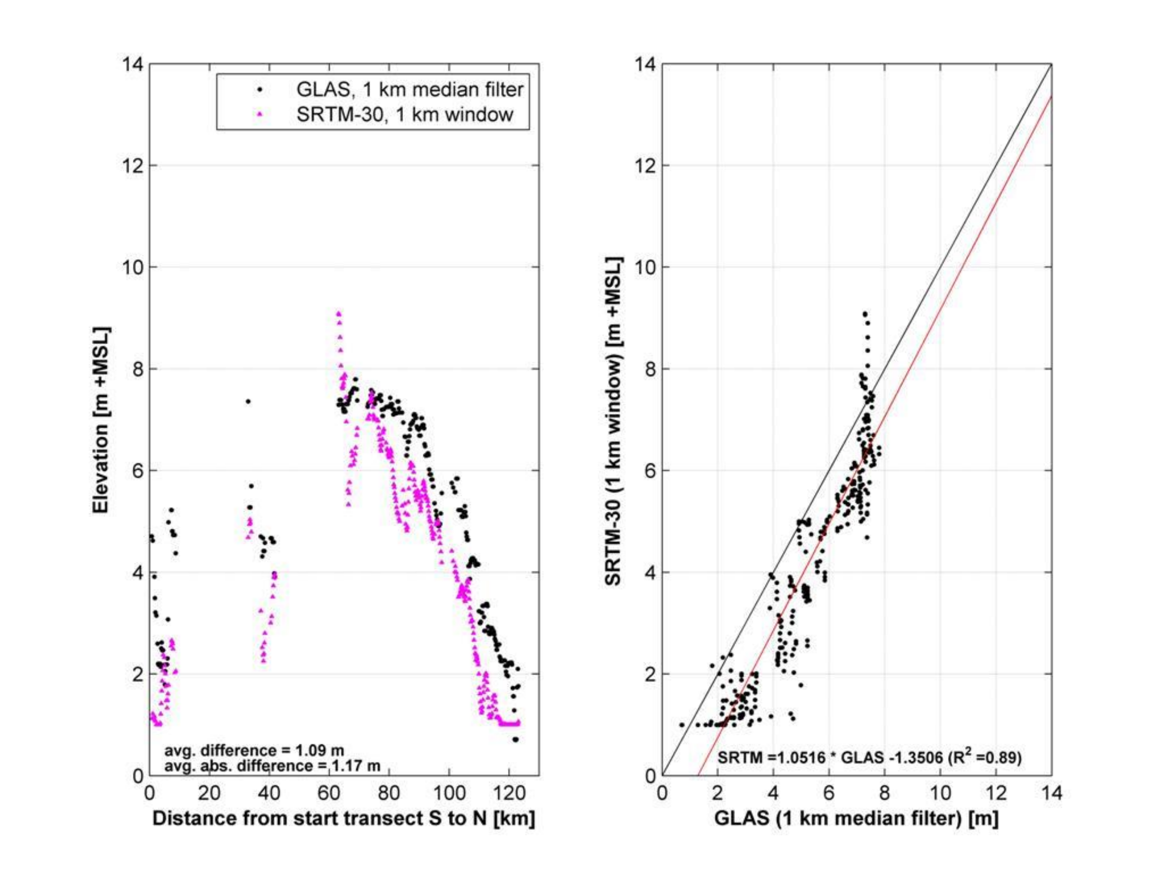


Figure 27 Correlation between 1 km window filtered SRTM-30 and ICESat/GLAS data points

Notes: Example of correlation between 1 km window filtered SRTM-30 and ICESat/GLAS data points for ICESat/GLAS transect 2005-05 in Blok C, Central Kalimantan.

From Figure 27 and Figure 28 it is clear that SRTM-30 window filtered data need to be shifted to match the elevation of the ICESat/GLAS data. Average vertical offset ranged from 1.20 to 1.79 m for the 1 km window and from 1.78 to 2.48 m for the 2 km window (Table 10). Overall average vertical offset of the SRTM-30 dataset for the 4 areas together is 1.51 and 2.14 m, for the 1 and 2 km window, respectively.

After applying the average vertical offset of +1.51 and +2.14 m, 72.0 and 73.4% of all available data pairs were within 1 m of the ICESat/GLAS data, for the 1 and 2 km window, respectively. Despite the slightly better correlation for the 2 km window filter it was decided to continue with the 1 km window filter due to the fact that correlation was based on much more, up to 27%, data points (Table 10).

In Figure 29 the resulting elevation models are presented for open and degraded peatland areas in the provinces of Riau and West Kalimantan, whereas for South Sumatra the elevation model is shown in Figure 30. For a big part of Sumatra (from longitude 102 degree westwards, roughly the middle of the Riau Province) no SRTM-30 data were available and for these areas no elevation model could be constructed. It is noted that despite the removal of the forested areas according to CRISP 2000 prior to running the window filtering, the effect of vegetation is still visible along the edges of the forest.

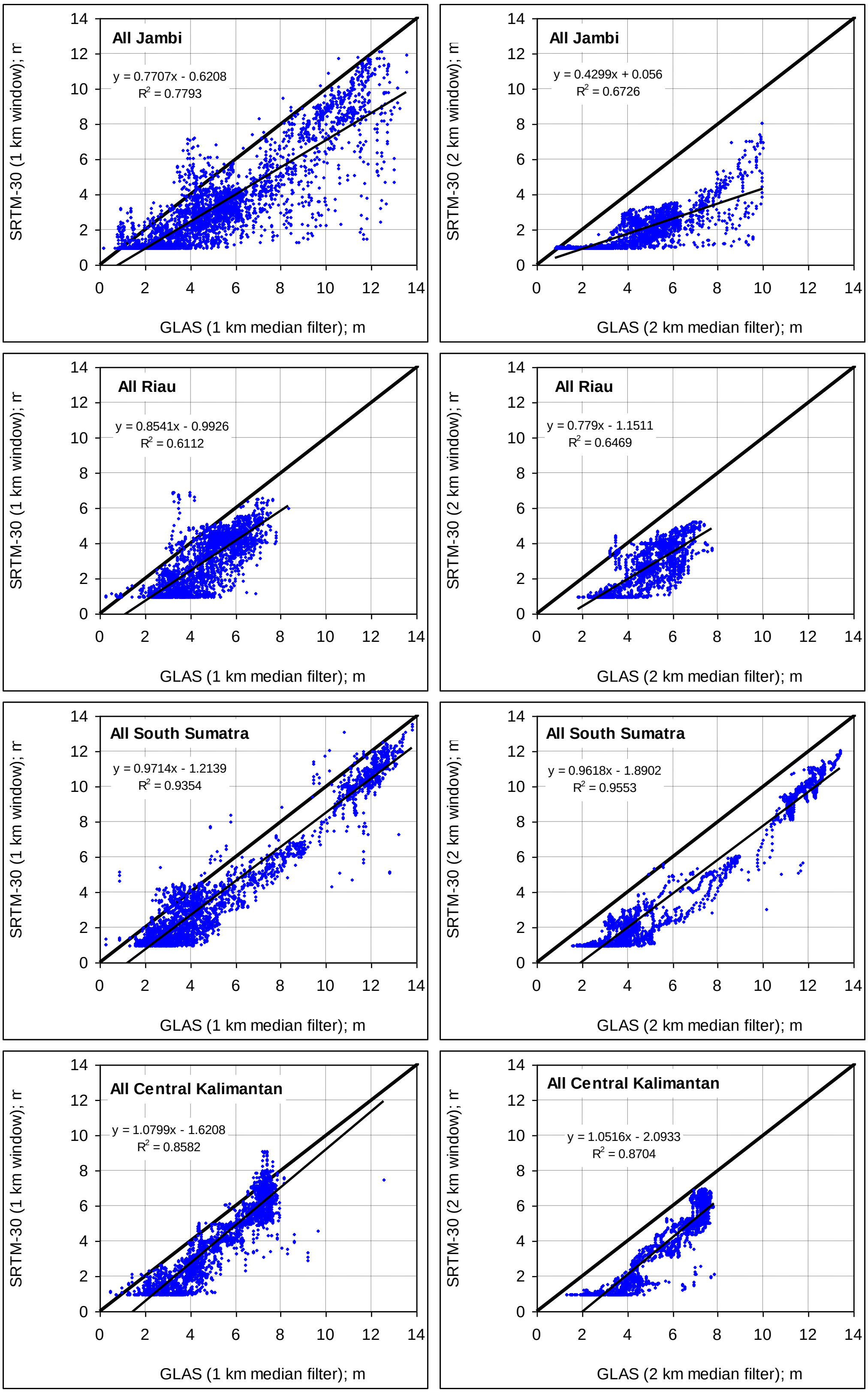
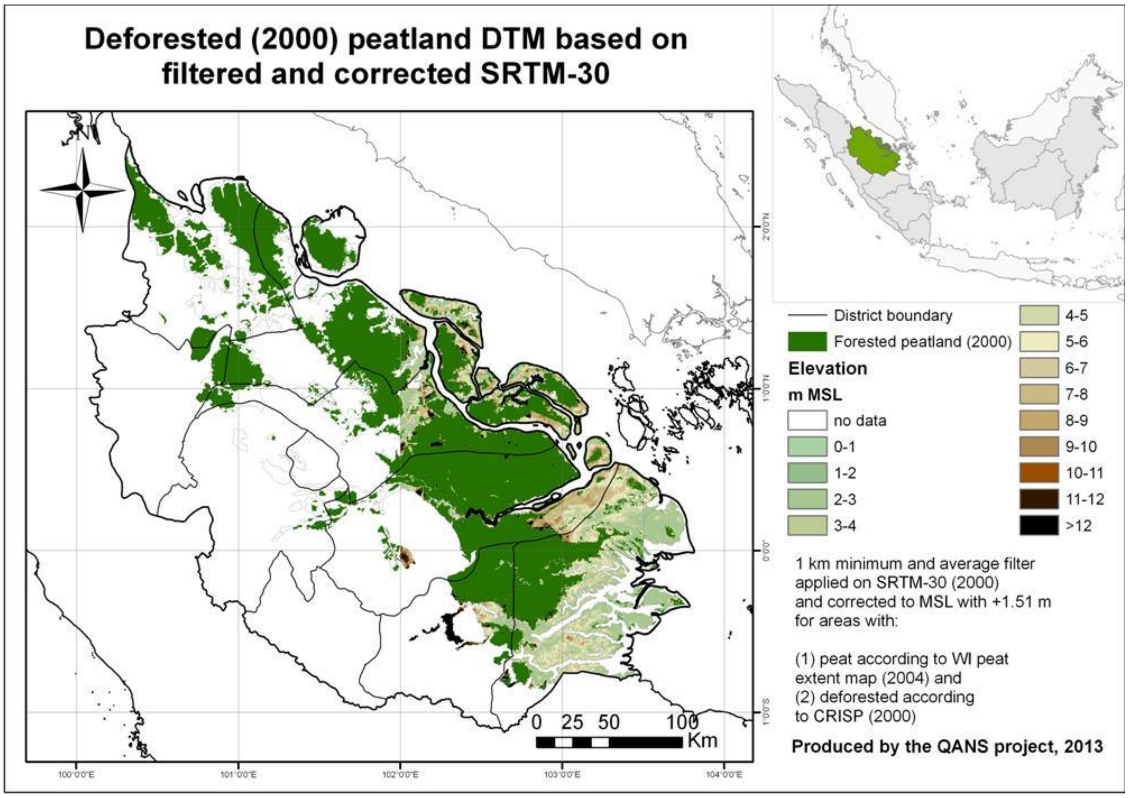


Figure 28 Correlation between (left) 1 km and (right) 2 km window filtered SRTM-30 and ICESat/GLAS data points for all transects combined in Jambi, Riau, South Sumatra and Central Kalimantan



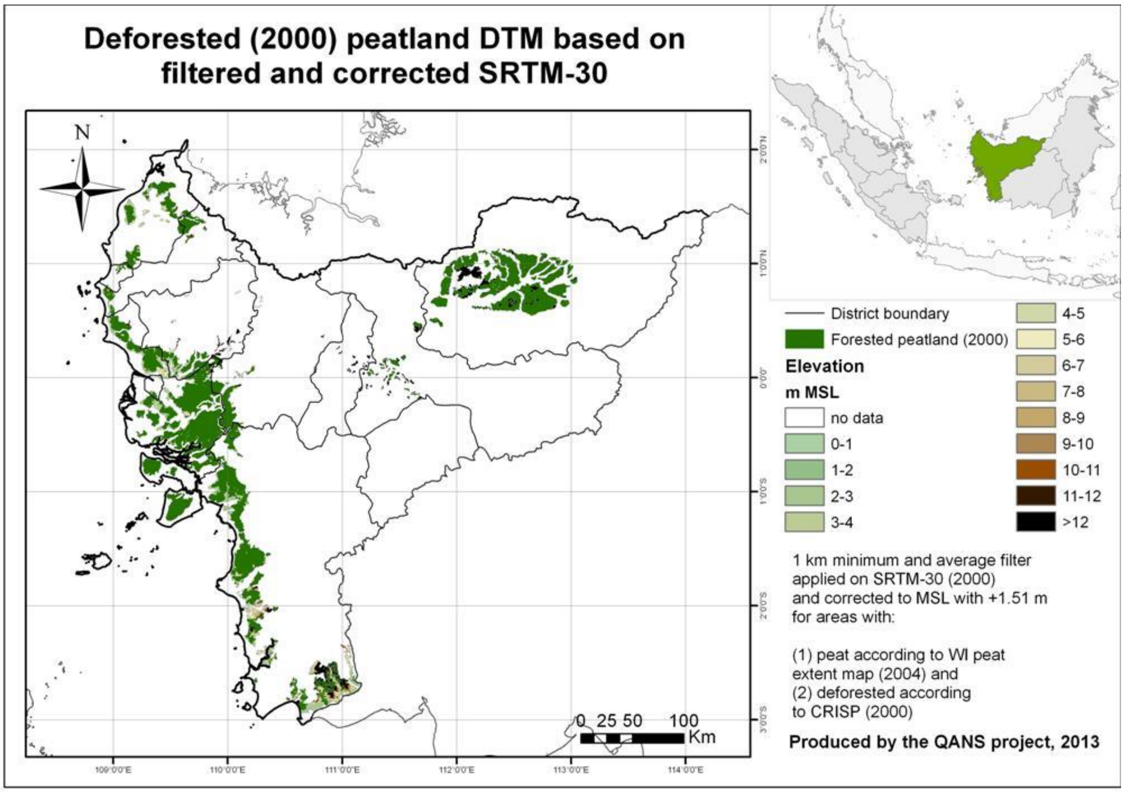


Figure 29 Elevation model for open and degraded peatland areas in Riau (top) and West Kalimantan (bottom)

Notes: Elevation model for open and degraded peatland areas (in 2000) in Riau (top) and West Kalimantan (bottom) derived from 1 km window filtered SRTM-30 corrected for MSL with an offset of +1.51 m. Due to unavailable SRTM-30 data and much remaining forest cover by 2000, an elevation model could be constructed only for the eastern part of Riau Province.

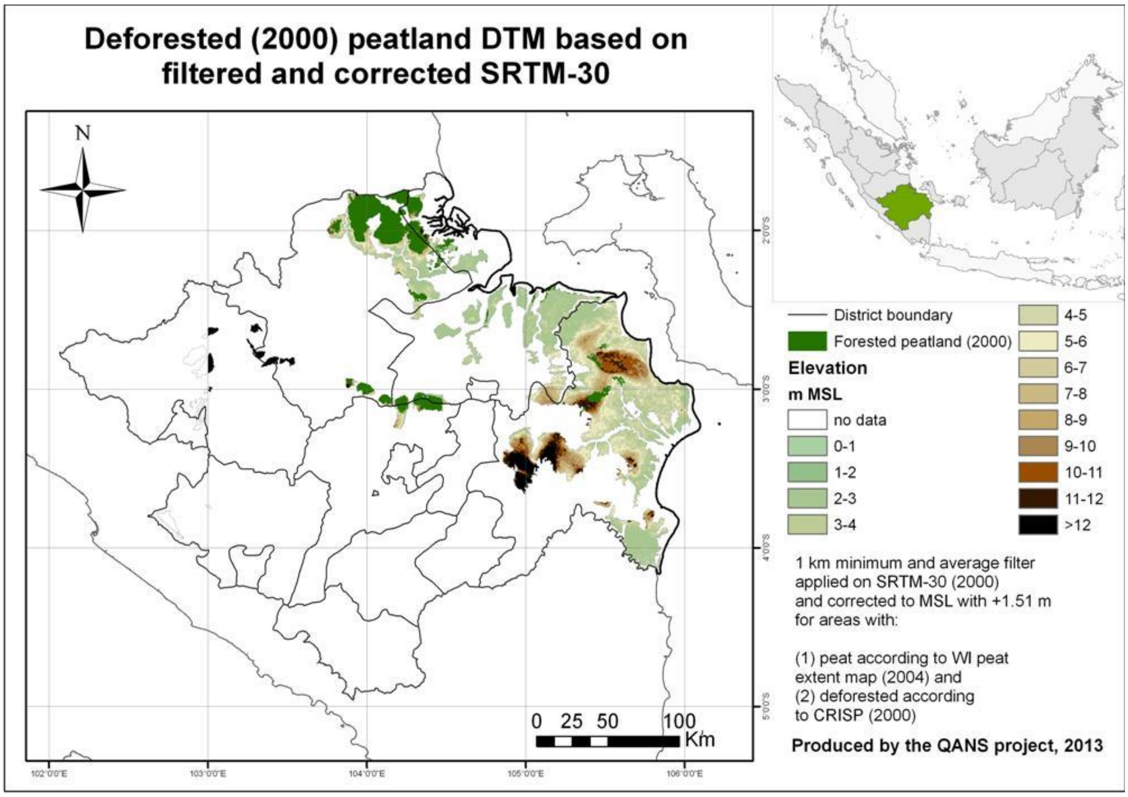


Figure 30 Elevation model for open and degraded peatland areas (in 2000) in South Sumatra

Notes: Elevation model for open and degraded peatland areas (in 2000) in South Sumatra derived from 1 km window filtered SRTM-30 corrected for MSL with an offset of +1.51 m.

3.2.2 Peat surface elevation for forested areas (in 2000)

In forested areas, the SRTM-30 window filtering method will not work as the data represent vegetation canopy elevation rather than peat surface elevation. ICESat/GLAS satellite LiDAR data (Schutz *et al.*, 2005) however, can penetrate the canopy in forested areas (after filtering) and could thus be used to validate and complete DTMs for such areas (Ballhorn *et al.*, 2011).

Because of the presence of a relatively large number of ICESat/GLAS transects over a densely forested peat dome, the Kampar Peninsula in Riau was selected to test the application of morphological relations derived from such transects, combined with riverside elevation as derived from SRTM-30 as anchor points.

3.2.2.1 Digitization of river locations and determining river side elevation

Because the location of the black water rivers present on the Kampar Peninsula (KP) were not included in any of the available data sources (FAO Hydrosheds river layer for SE Asia, FAO, 2010; WACLIMAD basemap), these were digitized using SRTM-30 and Bing satellite WMS layers aided by Landsat composites (542 RGB bands) and Spot images in areas where Bing maps had too

much cloud cover. For the larger (sedimentary and estuary) rivers the FAO Hydrosheds river layer could be used (which is an SRTM-90 based drainage network).
Each river was categorized into one of the following river types:

1. Black water river (BWR); these have their entire catchment area on the peat dome.
2. Sedimentary river (SED); this is the Kampar river to the south of the KP,and represents a normal situation.
3. Estuary river with erosive features (ERO); this is the Siak Estuary to the north of the KP, and represents an unusual feature as in some locations there is a relatively steep drop-off of the peat surface into salt water; it appears that the peat dome has been eroded away.

On the Kampar Peninsula a total of 16 rivers were identified of which 13 were characterized as black water rivers (Sungai Apung, S. Belat, S. Kutup, S. Lakar, S. Metas and an additional 8 without a known name on the map). A further two rivers were sedimentary (S. Kampar and S. Siak Kecil), and one is an estuary (S. Siak) (Figure 31).

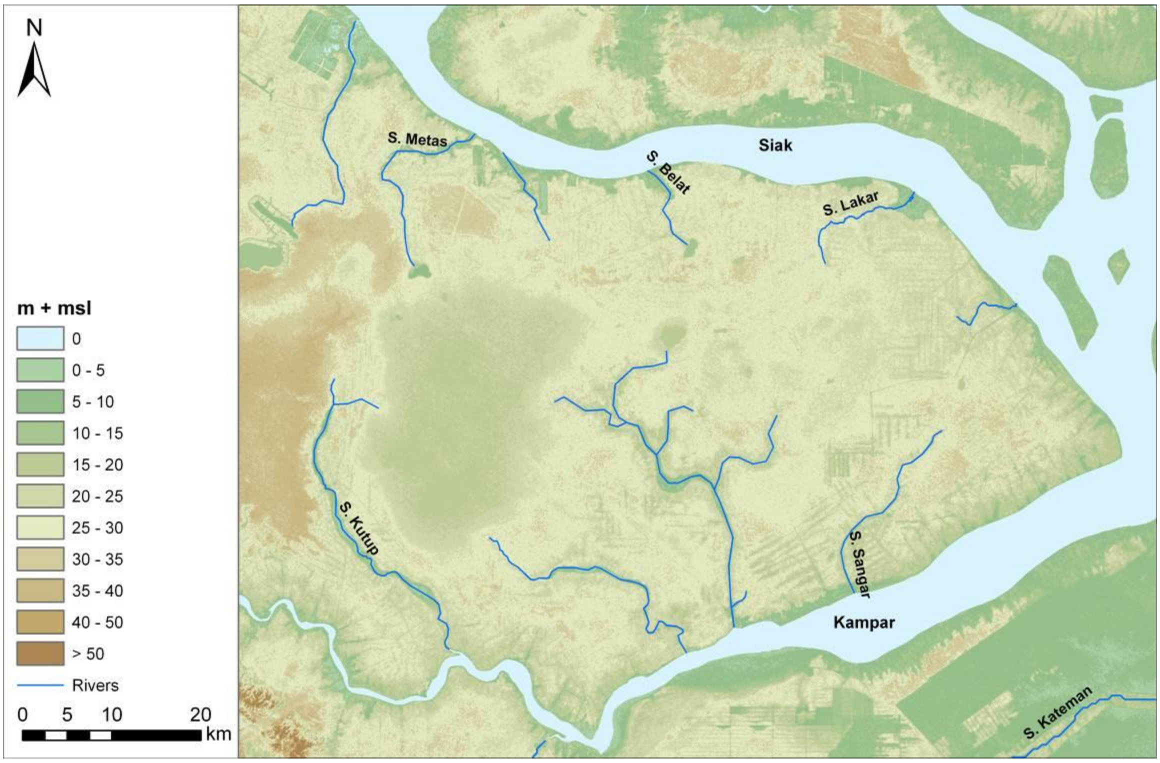


Figure 31 Location of rivers on the Kampar Peninsula.

Note: Unfiltered SRTM-30 data is shown in the background.

From the SRTM-30, 1 km minimum window filtered dataset (see Section 3.2.1) it proved possible at some locations along rivers to determine river side elevation, even within forested peatland areas where clearings occasionally occur (NB such clearings are mostly not apparent in the online version of SRTM, the SRTM-90 data at a 90 m spatial resolution). The identification and selection of such points was done manually and served as ‘anchor points’ in black water rivers along which slopes could be calculated. For rivers where no slope could be determined based on local data (i.e. no anchor points were selected because no suitable SRTM-30 points could be identified) the slope from the mouth of the river until 5 km inland was assumed to be the same as the average of the slope of rivers for which data were available (a slope of 75 cm/km). For the remaining length of these rivers and for rivers where no end anchor point could be found a fixed slope of 25 cm/km

was applied, as determined from a few rivers. This longitudinal profile, with a low upstream gradient and a steeper drop-off to the sea, is a common feature of many black water rivers in SE Asia.

The rivers and river side elevation anchor points were gridded to the resolution of the DTM (100 m) and for each river cell for which no elevation was available from an anchor point this was obtained through linear interpolation using the distance along the river and the slope.

3.2.2.2 Selection and additional filtering of ICESat/GLAS transects

A total of 48 transects were available over the Kampar Peninsula concentrated in four clusters (Figure 32). From the most western cluster the transects on the West and East ends of the cluster were used. From the other cluster the one with the largest number of available data points were used. Altogether, this resulted in 5 GLAS transects that were used in the analysis (Figure 33). Each transect was split into sections that represented sub-domes situated between two rivers, yielding 14 (sub-)dome-transects. For these transects a total of 1489 data points are available.

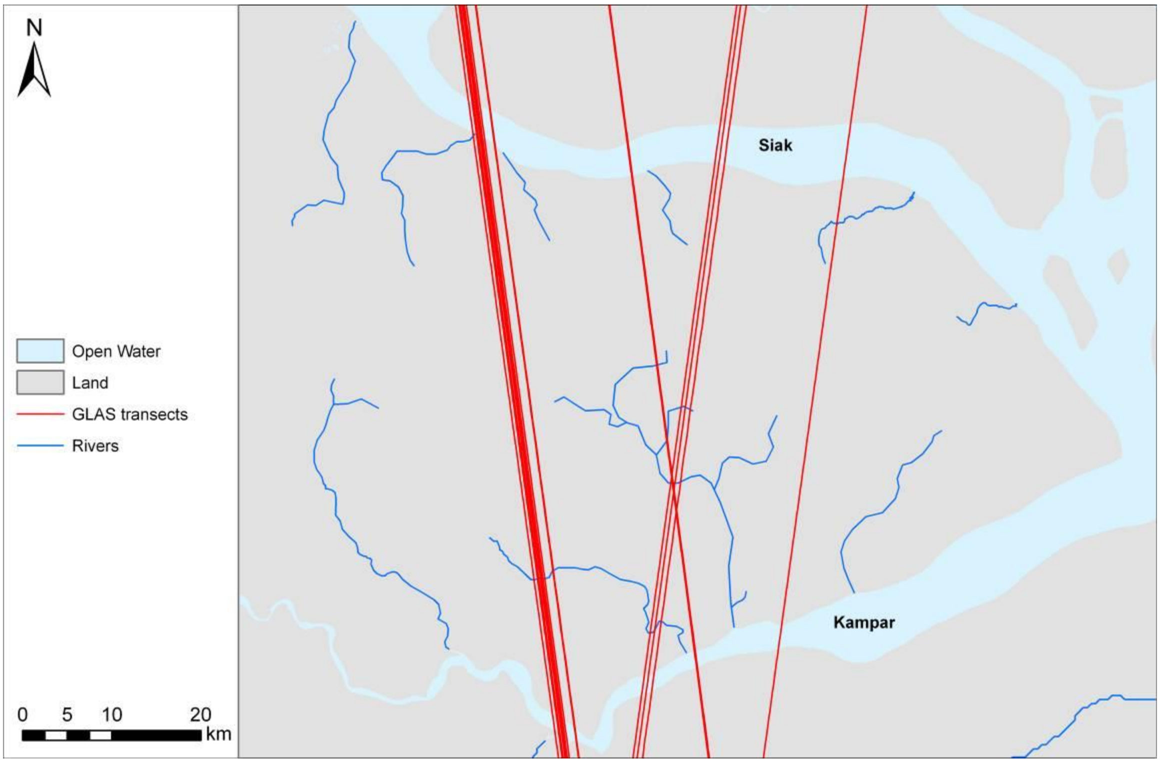


Figure 32 Kampar Peninsula and available ICESat/GLAS transects

As for the open and degraded areas discussed earlier, the selected ICESat/GLAS transects on the forested KP peat dome needed a second-stage filtering, due to the occurrence of outliers (Figure 34). Data points that had an elevation less than 0 or greater than 14 m were removed, since the peat surface at the KP is not expected to be lower than current sea level or higher than 14 meter (the latter estimate is based on visual inspection of the ICESat/GLAS data, and on field surveys that show no points above 12 metres MSL). On the remaining data points a moving median filter was applied of 19 ICESat/GLAS data points (some 3-3.5 km along transects). Data points for which no median value could be calculated (i.e. at the start and end of a transect, but also when

distance between start and end point of a median calculation was more than 1 or 2 km) were removed from the comparison.

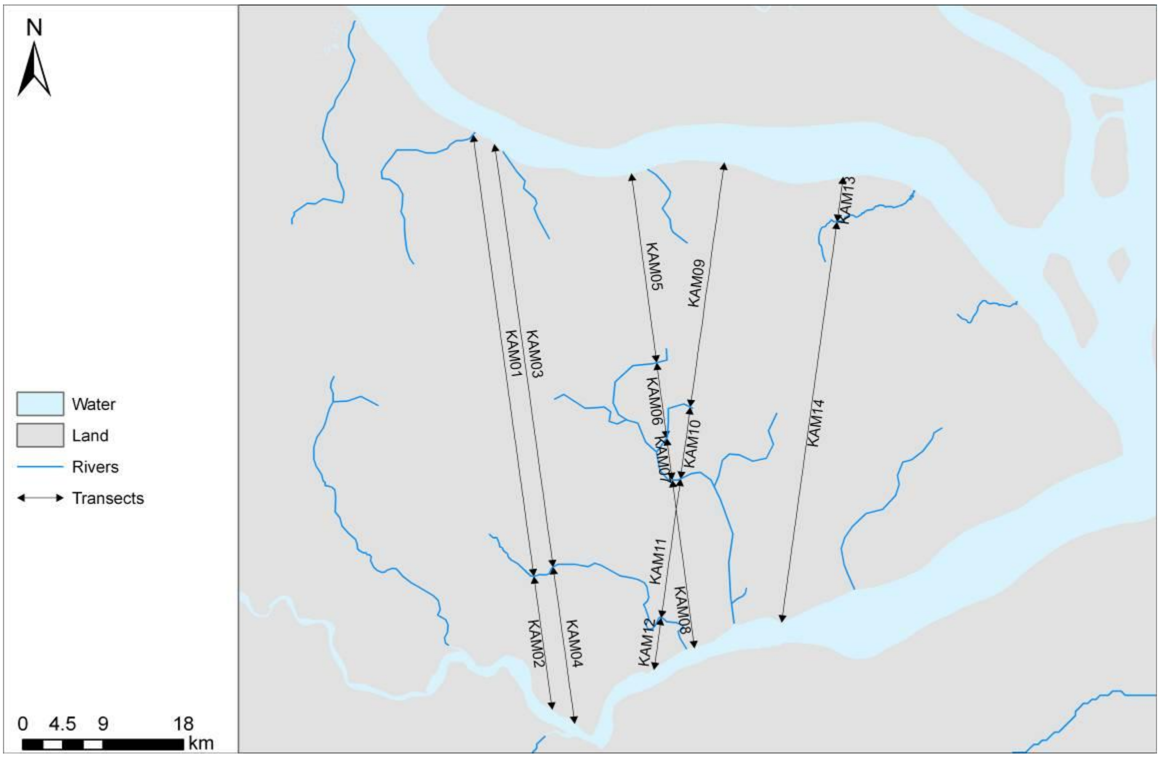


Figure 33   Kampar Peninsula and ICESat/GLAS transects used in the analysis

Note: Each transect between two rivers was given a unique id (KAM01 until KAM14).

The applied filtering steps may be refined in future work to ensure that all filtering steps can be done automatically. One additional filtering step that could be applied is taking into account a slope criterion. The filtering approach described above results in a selection of ICESat/GLAS points that collectively represent a credible peat surface (Figure 34). It is expected that method refinements will not have a significant effect on the selection.

Each transect profile was split at the catchment boundary which was manually determined by inspecting profiles such as KAM01 presented in Figure 34. Profiles that did not show a clear elevation rise from the river embankment, due to the angle with the river or disturbing features such as lakes or roads and plantation schemes that had caused visible land subsidence, were removed. Profiles were classified per river type. A total of 11 ‘black water river’ (BWR) profiles, 4 ‘sedimentary river’ (SED) profiles and 4 ‘estuary river’ (ERO) profiles were identified (Figure 35) having a total of 807 filtered data points.

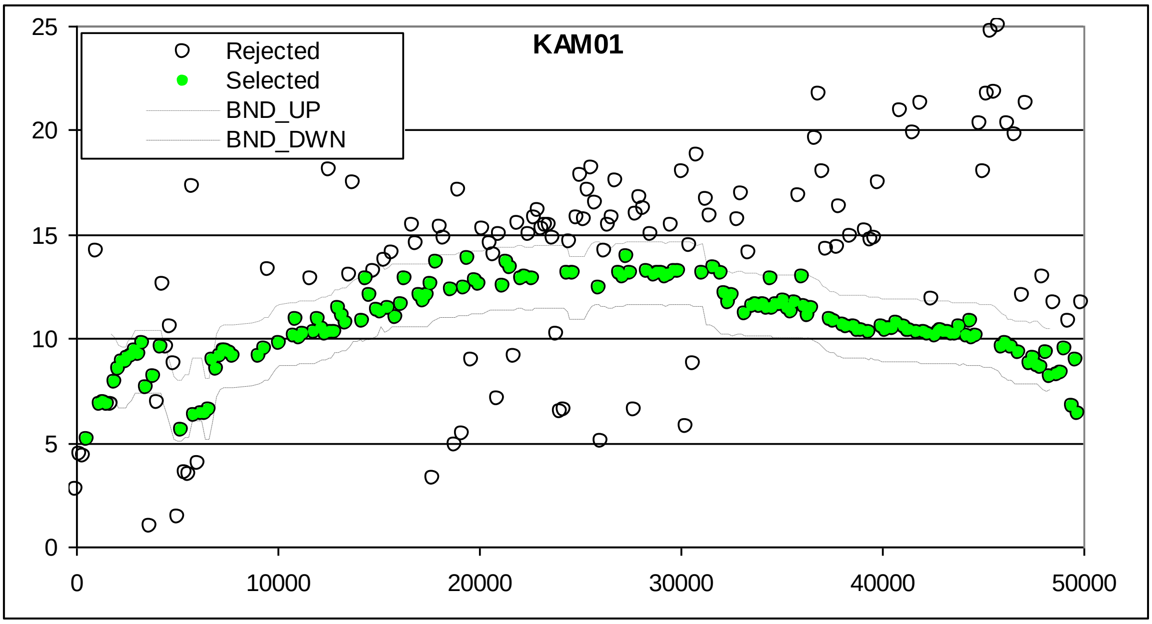


Figure 34 ICESat/GLAS data points for transect KAM01 over the Kampar Peninsula prior (white dots) and after (green dots) filtering

Note: ICESat/GLAS data points for transect KAM01 (see Figure 33) over the Kampar Peninsula prior (white dots) and after applying the second-stage filtering (green dots). Also shown is the boundary filter (+/- 1.5 m around the median; dashed line).

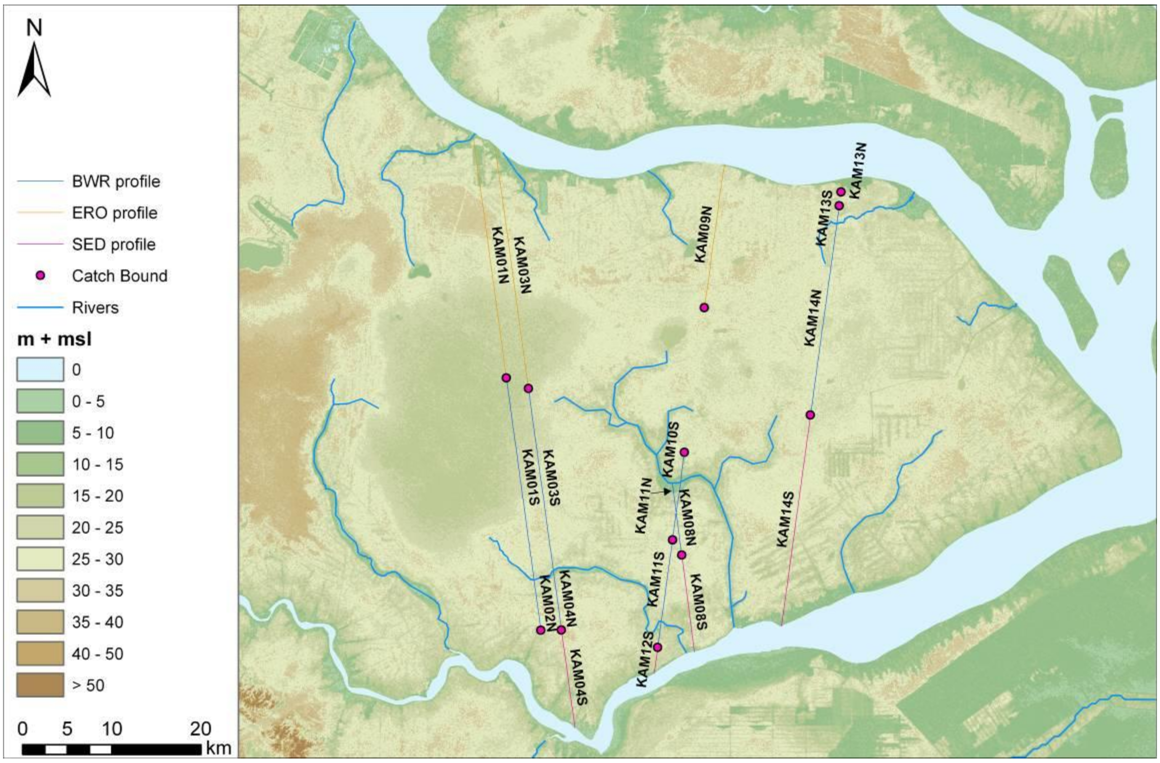


Figure 35 Location of selected ICESat/GLAS transects on the Kampar Peninsula

Notes: Each transect between two rivers was split up in a North-South or South-North oriented part ending at the catchment boundary. Unfiltered SRTM-30 data is shown in the background.

For the derivation of the general relationship to be applied in the creation of the DTM, the distance from the first ICESat/GLAS data point to the river embankment was taken into account (which could be up to 500 m in some cases). Furthermore, for the black water rivers the ICESat/GLAS elevation of the individual profiles was referenced to the embankment level of the rivers (to SRTM-30 derived anchor points; up to -6 m). The resulting ICESat/GLAS profiles as derived for the different river types are presented in Figure 36. The relations derived for the 'sedimentary' and 'estuarine' river relations are found to be remarkably similar, as shown in Figure 36, with the greatest difference being 1.3 m and the average difference over 28 km being 1.1 m.

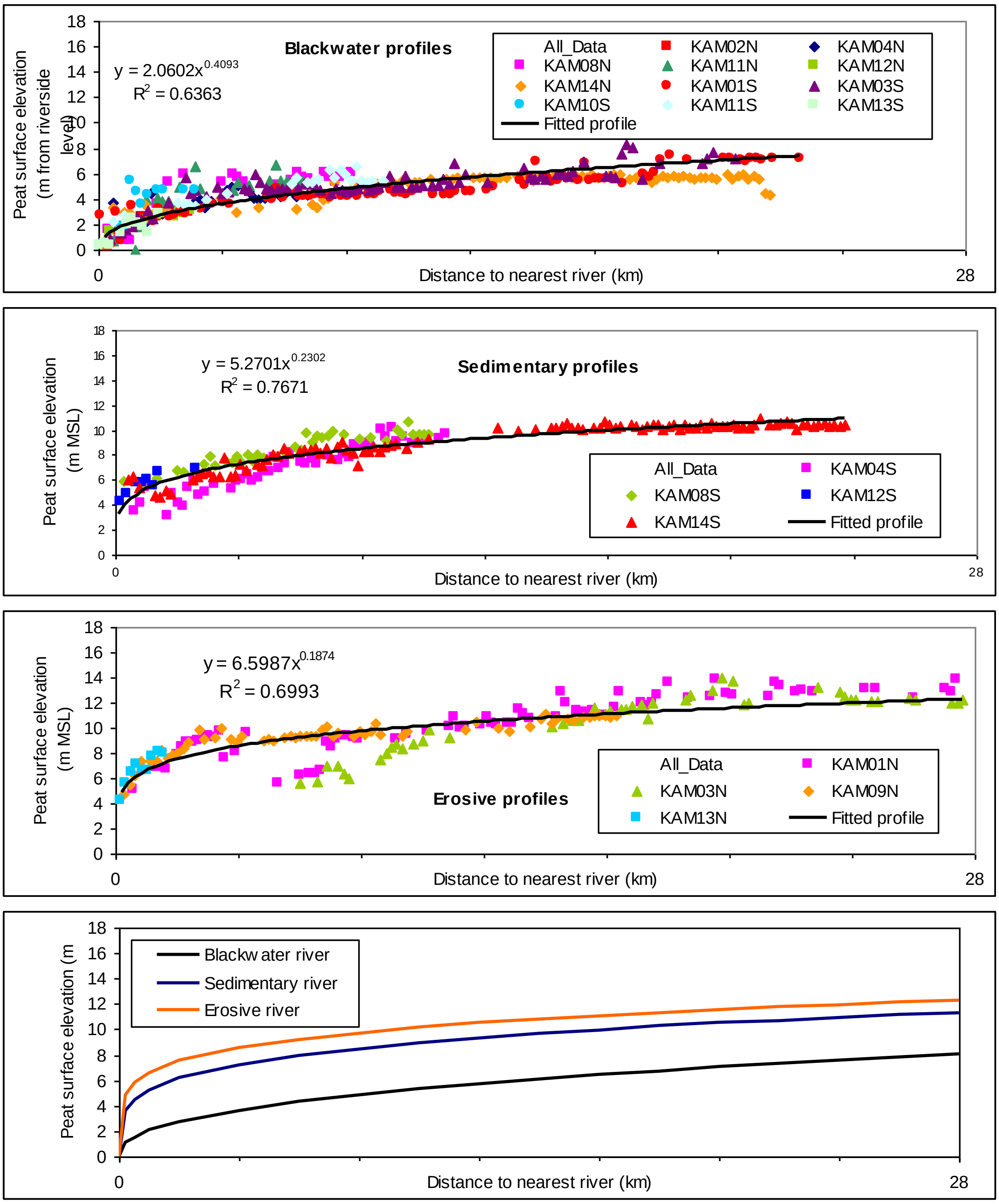


Figure 36 Profiles derived from ICESat/GLAS transects, as used in the analysis

Notes: 'Sedimentary river' and 'estuary river' profiles are relative to MSL, whereas 'blackwater river' profiles are relative to the position of the riverside along such rivers. In the lowest panel all 3 profiles are combined.

3.2.2.3 DTM creation and validation

Combining knowledge on the shape of the peat dome from the different ICESat/GLAS profiles, the location and type of rivers and their river side elevation a DTM is created at a spatial resolution of 100 m through the following steps.

For each grid cell the distance to the nearest river was calculated. This distance was used to calculate the elevation based on the derived morphological relations for each river. This was done separately for each river, resulting in a total of 16 intermediate elevation maps. Since the derived relations start from the river side (base height), each grid cell also needed to have this base height elevation added to the elevation resulting from application of the derived relations. The base height elevation map was derived for each grid cell through interpolation of the previously derived river side elevation for each river cell (see Section 3.3.2.1). As a final step, for each grid cell it was determined which of the 16 intermediate elevation maps had the lowest elevation. This lowest value was considered to represent the true elevation of that grid cell and the resulting DTM is shown in Figure 37.

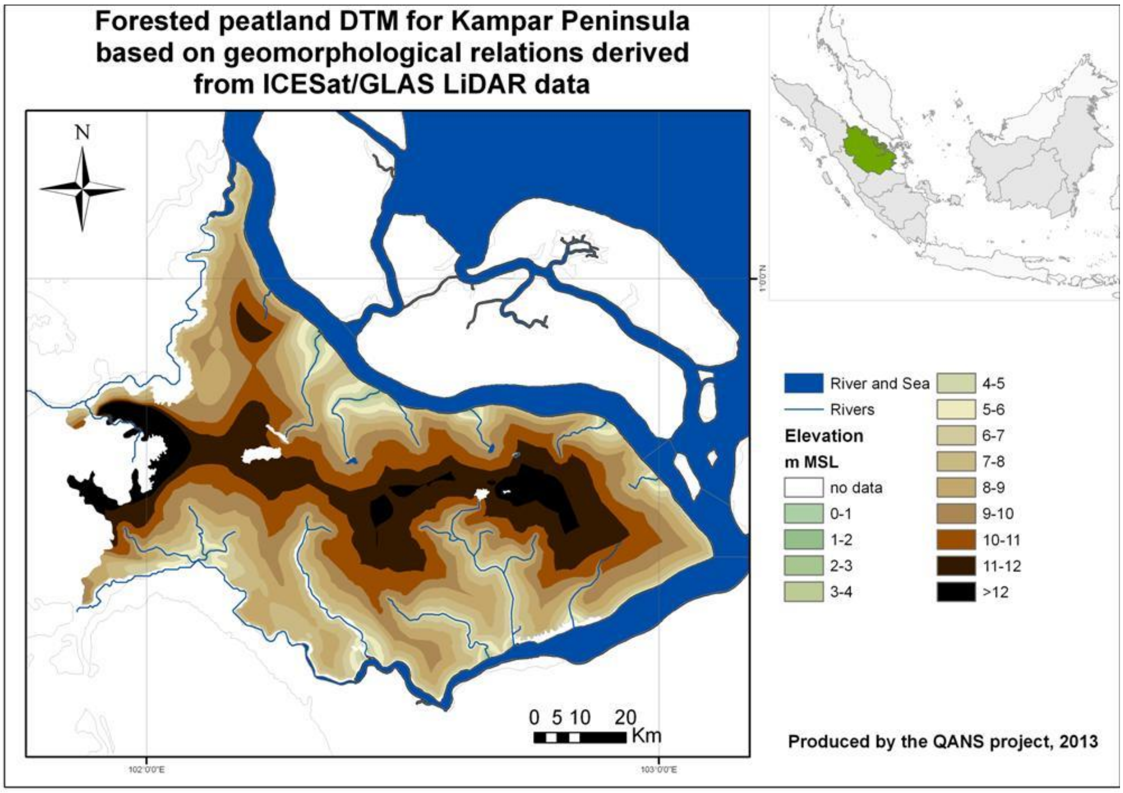


Figure 37 Elevation model for the Kampar Peninsula constructed through application of morphological relations derived from ICESat/GLAS profiles

To confirm whether the followed approach resulted in a reliable DTM the original ICESat/GLAS transects used in the derivation of the morphological relations were compared with the elevation values of the new DTM (Figure 38). As can be seen from Figure 38 the overall comparison is quite good for most GLAS transects, with a correlation coefficient ranging from 0.29 to 0.95 (with 14 out of the 19 transects having an R^2 >0.70) and a RMSE ranging from 0.18 to 1.87 m or some 2.7 to 26.4% from the average. When all data points for all transects are considered together an R^2 of 0.70 (Figure 39) is found with a RMSE of 1.13 m or 12% from the average.

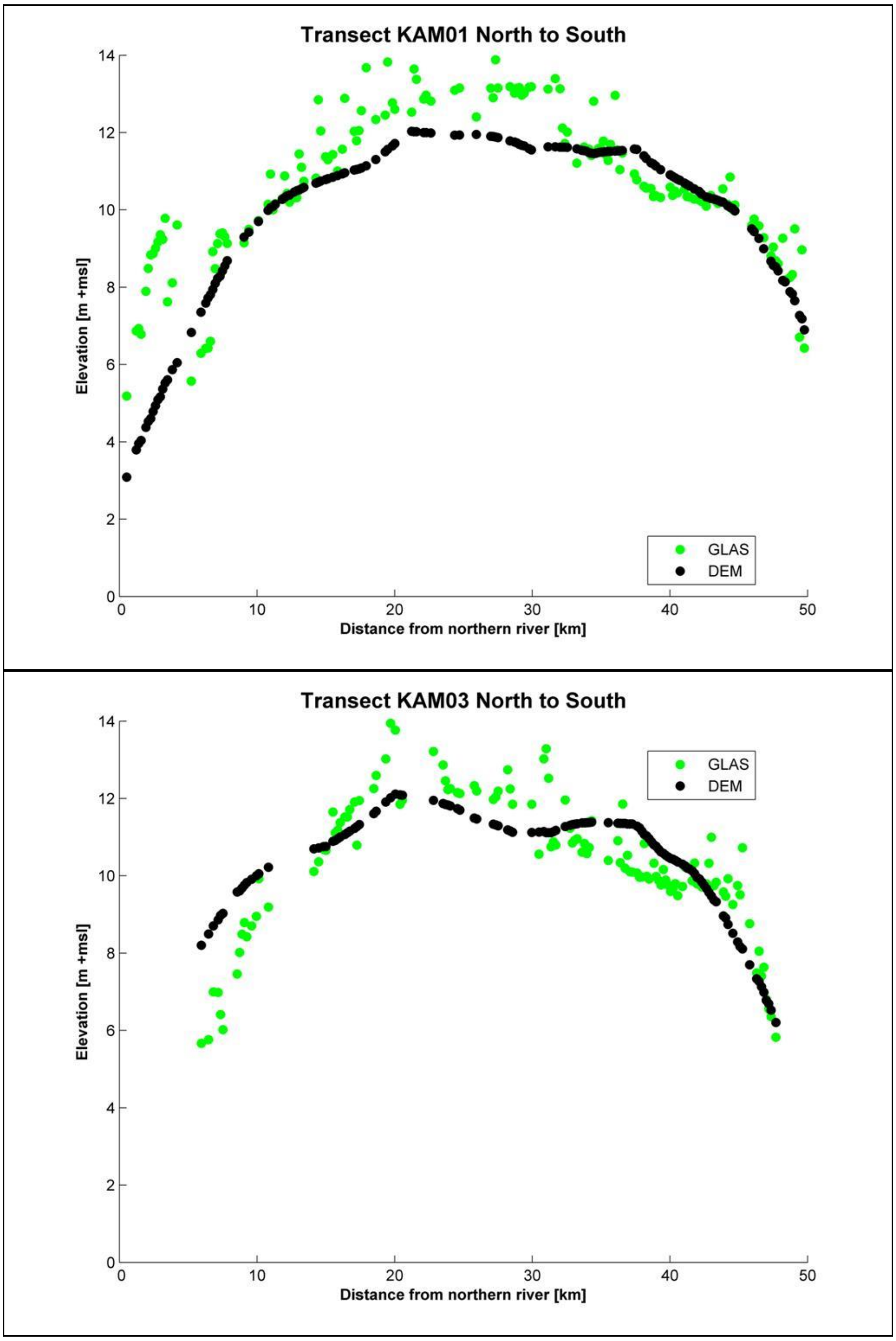


Figure 38 Elevation for ICESat/GLAS data points (green dots) and the artificially created DTM (black dots) on the Kampar Peninsula

Notes: Elevation for ICESat/GLAS data points (green dots) and for the same locations elevation from the artificially created DTM (black dots) along the KAM01 (top) and KAM03 (bottom) transects over the Kampar Peninsula.

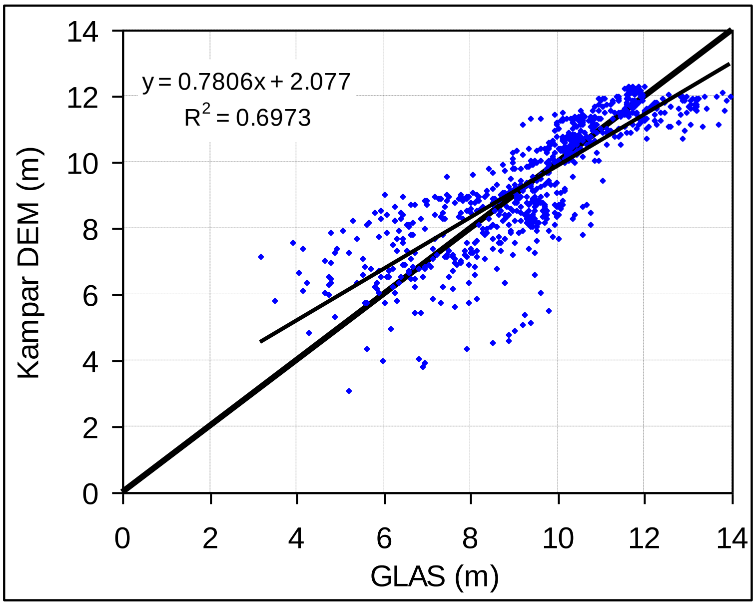


Figure 39 Correlation between elevation data points of ICESat/GLAS and artificially created DTM for Kampar Peninsula: all transects together

3.2.3 Conclusions and recommendations for improved peat thickness mapping using geomorphological principles and elevation models

3.2.3.1 Application of basic geomorphological principles

The advanced data and methods applied in QANS confirm, and allow quantification of, basic principles that have long been known for peatlands around the world, and that can also be observed from earlier publications on peatlands in SE Asia. These principles follow from the way peatlands develop, and are generally applicable throughout SE Asia, yet they have not been applied in peatland mapping to date, resulting in peatland maps that suggest shapes that are often physically impossible. The principles are:

1. First of all, in coastal peatlands the bottom of the peat deposit will usually be around Mean Sea Level, as this is where peat development started in the mid-Holocene. It is possible in theory that the bottom level has since shifted upwards or downwards, but there is little evidence of this in practice. Of the locations in Indonesia where peat thickness and elevation data are available, 33% is below Sea level and 74% below 2 m above Sea level (Table 9), whereas the peat bottom in Sarawak in Malaysia appears to be nearly always below Sea level.
2. Secondly, a peat deposit must always have a domed shape, with surface slopes that are steepest near the river and nearly horizontal in the central parts. This shape is a hydrological necessity: if the dome surface is too flat over too large a distance the surface would be too often flooded for healthy vegetation growth and peat accumulation to be possible, whereas rainfall would be lost quickly if slopes were too steep, resulting in drier peat and less peat accumulation. These requirements for peat accumulation explain why peat dome shapes are often similar throughout the region (and indeed throughout the world).
3. Thirdly, based on the above two characteristics, peat thickness usually increases when going away from the river, in a manner that is similar to the increase in elevation. The

exception to this is in peatlands that have entirely lost their dome shape, as they were drained at least several decades ago and have lost most of their peat volume through oxidation and fires. However such peatlands, as are found mostly in South Sumatra and Jambi, have little or no rehabilitation or conservation value and are therefore not a priority for mapping in any case. Remaining areas with remaining rehabilitation or conservation potential, that are a priority for mapping, nearly always have a more or less intact dome shape.

4. Finally, based on the above principles and on available peat thickness data, it is possible to quantify some simple guiding rules for estimating peat thickness patterns. Most peat thickness measurements by far in Indonesia indicate a peat thickness over 3 m (77% in the QANS database; Table 6), with an average of 5.6 m, and measurements less that 3 m are especially rare in peatlands with remaining rehabilitation or conservation potential (see above). This applies even more so to peat more than 1 to 3 km away from the river , which is usually over 3 m in depth unless the peat dome has already been lost (see above). The simplest and first step towards peat map improvement would therefore be to classify all peat (as mapped by WI) that had forest remaining in 2000 as being over 3 m in depth.

3.2.3.2 Elevation mapping

In Section 3.1 it is shown that where accurate elevation data are available for peat domes, in this case LiDAR data for two domes (Blok B and Blok A+E) in the KFCP area, it is possible to produce a peat thickness map that is substantially more accurate than the existing peat maps by Wetlands International and Puslitanak.

On this basis, and knowing from experience that accurate field surveys of peat thickness are very difficult, costly and error-prone, and moreover would take many years to cover much of Indonesia's peatlands, we conclude that elevation data potentially offer the fastest and most reliable method to improve Indonesia's peat thickness maps in the short to medium term, with refinements based on field measurements following in the longer term as such measurements become available in sufficient density.

The essential data in this approach is of course the availability of accurate elevation data. Only very few peatland areas in Indonesia have LiDAR data coverage, and most of this is not in the public domain. In Section 3.2.1 we show that a DTM of the very minimum accuracy required, within 1 m for 72% of points, can be achieved using SRTM-30 data for areas that were deforested in 2000. A result with somewhat lower accuracy was demonstrated using a spatial model using ICESat/GLAS data input, for a forested area.

We conclude that the DTMs derived from SRTM-30 and ICESat/GLAS data may be useful to derive peat thickness maps that may be very rough but probably still more accurate than existing peat thickness maps, for large peat dome areas that were deforested by 2000 such as Kerumutan in Riau and Blok C in Central Kalimantan. This will be further evaluated in Section 4.2. However we also note that the total inaccuracy of this approach may be up to 4 m in such areas, considering that the inaccuracies in both the DTMs and the assumption of a peat bottom level can be up to 2 m, and sometimes more. Therefore, this approach should only be seen as a first step towards much more accurate peat thickness maps to be produced in the coming few years.
The only sources of accurate peat elevation information for large areas are therefore remote sensing data. The most accurate but possibly also most expensive would be airborne LiDAR data,

although it should be considered that the price will drop dramatically if a lower point density is accepted and no full coverage data is collected (flights at e.g. 5 km intervals may suffice in these cases).

Moreover, at least two types of new elevation data have recently been collected, and are now being processed, that have much higher resolution and accuracy than earlier sources: TanDEM-X (radar at 12 m horizontal resolution and a height accuracy of better than 2 m; http://www.dlr.de/eo/en/desktopdefault.aspx/tabid-5727/10086_read-21046/) and airborne Radar data for Sumatra by BIG (IFSAR, Interferometry Synthetic Aperture Radar). When these data become available they could be used to further validate, refine and apply the elevation-based peat thickness mapping method.

4 QANS Pilot Maps

4.1 Map products

The QANS peatland mapping activity has yielded two types of new peat thickness map products, in addition to maps showing the deviation of existing maps relatively to field measurements of peat thicknesses, as described in Section 2.3:

1. A tentatively **reclassified Wetlands International Atlas map**, applying lessons learnt from the accuracy assessment in Section 2, for Riau and West Kalimantan.
2. **Maps derived from elevation and geomorphological modelling**, applying the techniques presented in Section 3, for selected areas that i) were suitable for the methods applied and ii) had sufficient data availability at present.

These maps are available as softcopies in GIS format upon request (with conditions for use and distribution).

Both map types are meant to demonstrate different approaches on how maps can be further improved in follow-up activities, by Indonesian organizations. Insofar as the products are useful for application, at this stage of development, this is <u>for broad scientific analyses and for macro-scale land use zoning</u> (i.e. not for detailed scientific analyses and meso-micro scale land use planning).

4.1.1 Tentatively reclassified Wetlands International peat map, for Sumatra and Kalimantan

The comparison between the WI Atlas peat thickness classes and actual field measurements (Section 2.3) has shown consistent and major differences. While these differences were highly variable in space, they showed an underestimation of peat thickness by the WI map in nearly all areas. By increasing the value of classes, the WI map can therefore be made a bit more accurate, even without changing class boundaries.

New WI peat thickness classes are calculated from available peat thickness measurements occurring within each WI class. This was done separately for Sumatra (Table 11) and Kalimantan (Table 12). Some of the original WI thickness classes were lumped together to allow for a sufficient number of measurements to be included in the average. For Kalimantan the peat thickness measurements in the EMRP and Sebangau NP area were excluded, because the measurement density there is far higher than anywhere else while comparison with field data shows that the WI map for that area was derived in a very different manner, resulting in smaller errors (Annex 1). The new peat thickness values were then assigned to the existing WI classes without changing the peat extent. In Figure 40, the resulting reclassified WI Atlas maps are provided for Riau and West Kalimantan, the QANS focus Provinces.

Apart from an underestimation in peat thickness, the WI map also underestimates peat extent as discussed in Section 2. In Sumatra, 10% of locations where peat >0.5 m was found occur outside the WI peat map boundaries, while for Kalimantan (excluding EMRP and Sebangau NP) this was 28% (Table 11 and Table 12). This underestimation of peat extent is not accounted for in our current analysis, as we still use the WI boundaries for lack of an available alternative.

Table 11 Deviations for peat thickness measurements Sumatra per WI peat thickness class

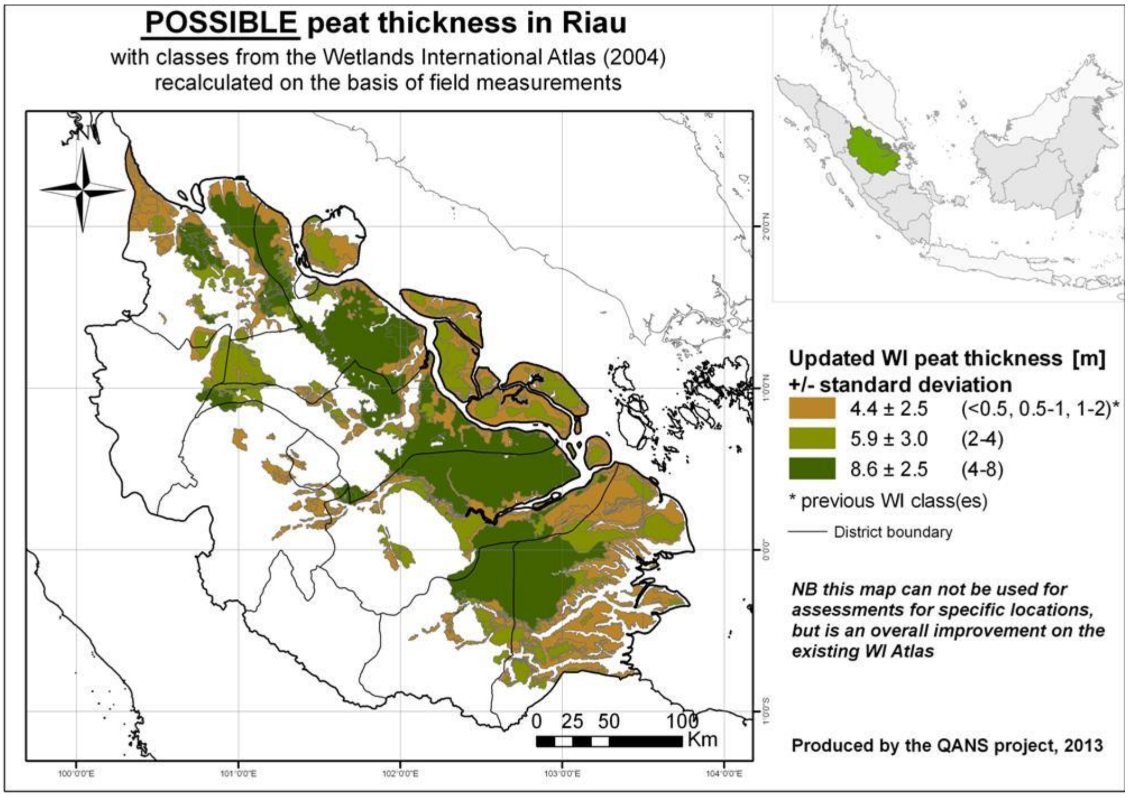
WI class (m)	Number of data points	Avg ± std thickness (m)
no peat	154	2.8 ± 2.7
<0.5	18	2.6 ± 1.8
0.5-1	54	5.5 ± 3.5
1-2	565	4.3 ± 2.4
2-4	284	5.9 ± 3.0
4-8	529	8.6 ± 2.5
Total	***1604***	***5.9 ± 3.3***
Lumped		
0-2	637	4.4 ± 2.5
2-4	284	5.9 ± 3.0
4-8	529	8.6 ± 2.5
Total	***1450***	***6.2 ± 3.2***

Notes: All peat thickness measurements <0.5 m were included in this calculation, but only for measurements after 2000 or before 2000 while still forested in year 2000. The lumped classes are used in the updated map (Figure 40).

Table 12 Deviations for peat thickness measurements in Kalimantan (excluding EMRP and Sebangau NP) per WI peat thickness class

WI class (m)	Number of data points	Avg ± std thickness (m)
no peat	292	2.6 ± 2.6
<0.5	7	0.5 ± 1.1
0.5-1	76	4.8 ± 3.9
1-2	267	4.4 ± 2.8
2-4	82	4.6 ± 3.0
4-8	304	5.6 ± 3.0
8-12	18	2.0 ± 1.1
Total	***1046***	***4.2 ± 3.1***
Lumped		
0-2	350	4.4 ± 3.1
2-4	82	4.6 ± 3.0
4-12	322	5.4 ± 3.0
Total	***754***	***4.8 ± 3.1***

Notes: All peat thickness measurements <0.5 m were included in this calculation, but only for measurements after 2000 or before 2000 while still forested in year 2000. The lumped classes are used in the updated map (Figure 40).



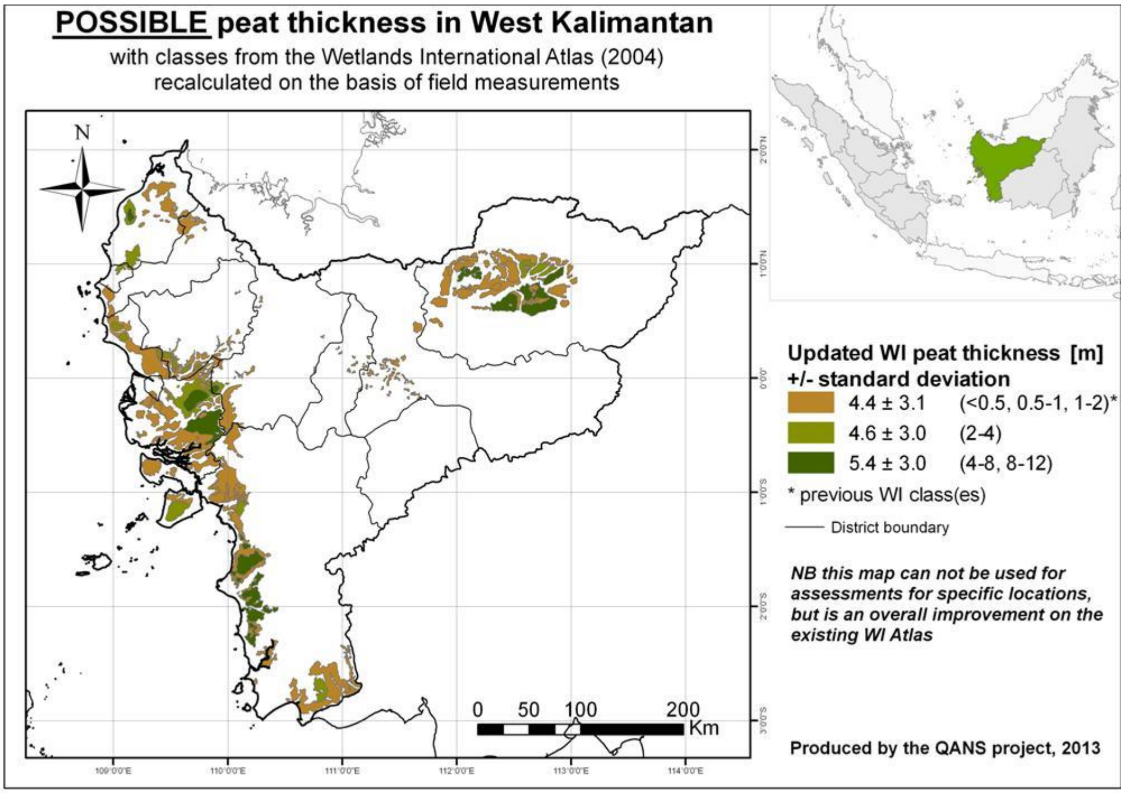


Figure 40 Updated WI peat thickness maps for Riau (top) and West Kalimantan (bottom)

Average peat thickness calculated using the new WI class legends for the same locations as the peat thickness measurements, becomes 7.6 and 4.1 m for Riau and West Kalimantan respectively, compared to 5.1 m and 3.7 m according to the WI map (Table 6). For Sumatra and Kalimantan (excluding EMRP and Sebangau) as a whole this becomes 5.8 m and 3.7 m, respectively, compared to 3.2 m and 2.8 m according to the WI map (Table 6). Overall application of the improved legend to the WI map increases peat thickness by 81% for Riau and by 95% for Kalimantan (excluding EMRP and Sebangau).

Overall map improvement for Riau is better than for West Kalimantan, whereby the average difference with peat thickness measurements is reduced from 2.8 m (Table 6) to 0.3 m for Riau, compared to a reduction from 1.0 (Table 6) to 0.6 m for West Kalimantan. The improvement for both provinces is illustrated in Figure 41 where the field measurements are correlated with both the original and reclassified peat map values for the same locations. In Figure 42 differences are illustrated on the map for both Riau and West Kalimantan (cf. Figure 5 and Figure 6).

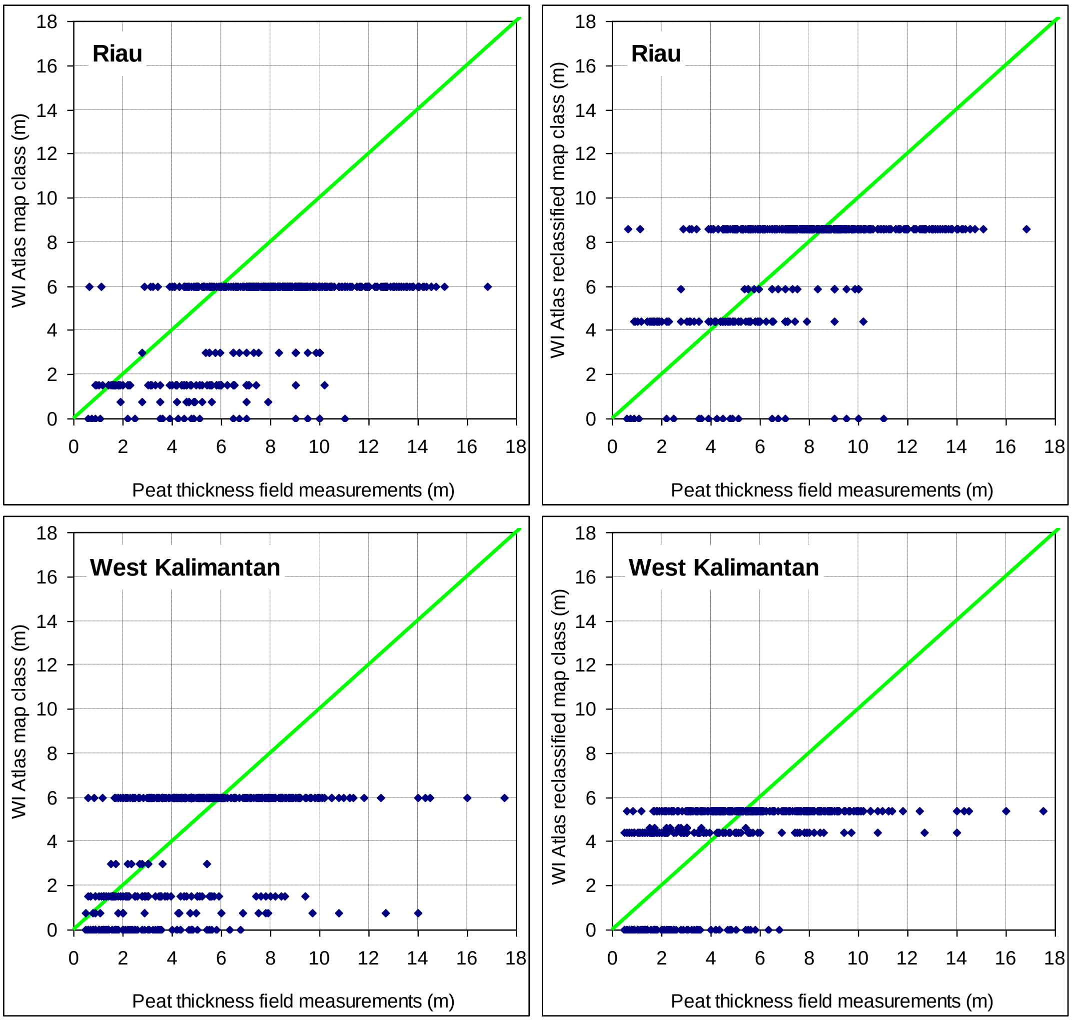
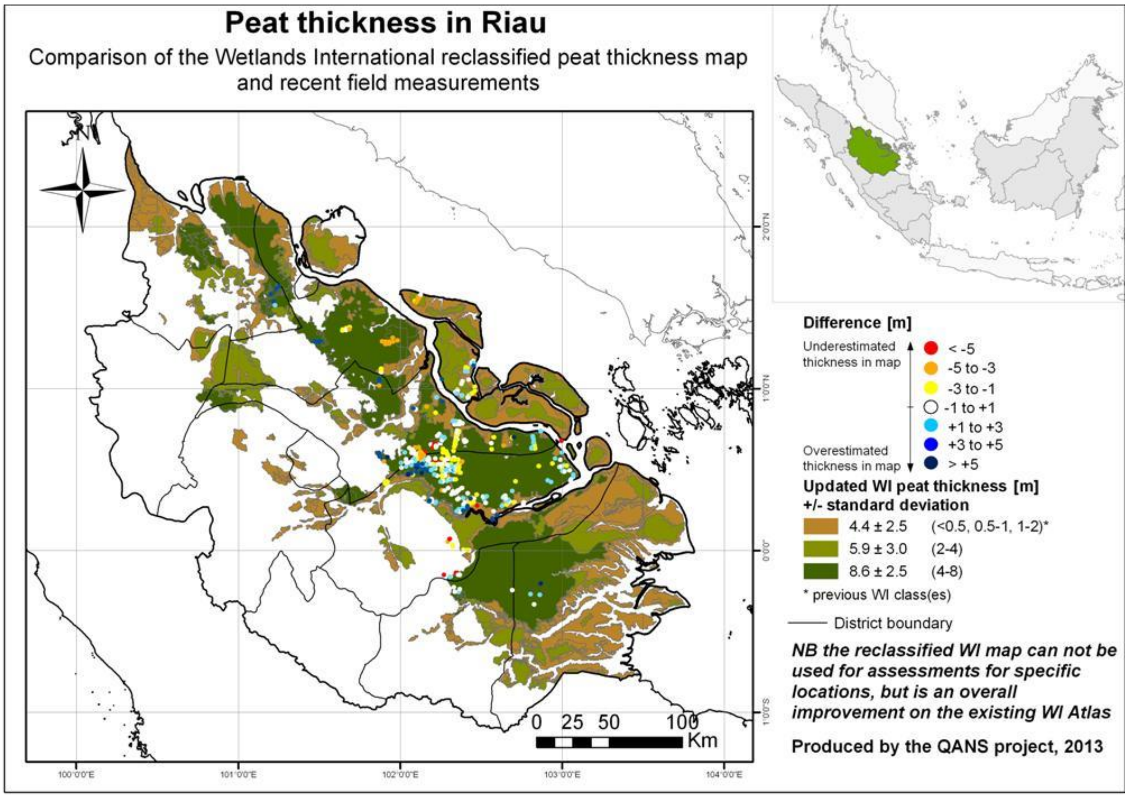


Figure 41 Comparison of original (left) and reclassified (right) WI peat map and field measurements

Notes: Comparison of the original (left) and reclassified (right) Wetlands International peat map and field measurements (>0.5 m, after 2000 or had still forest before 2000), for Riau (top) and West Kalimantan (bottom).



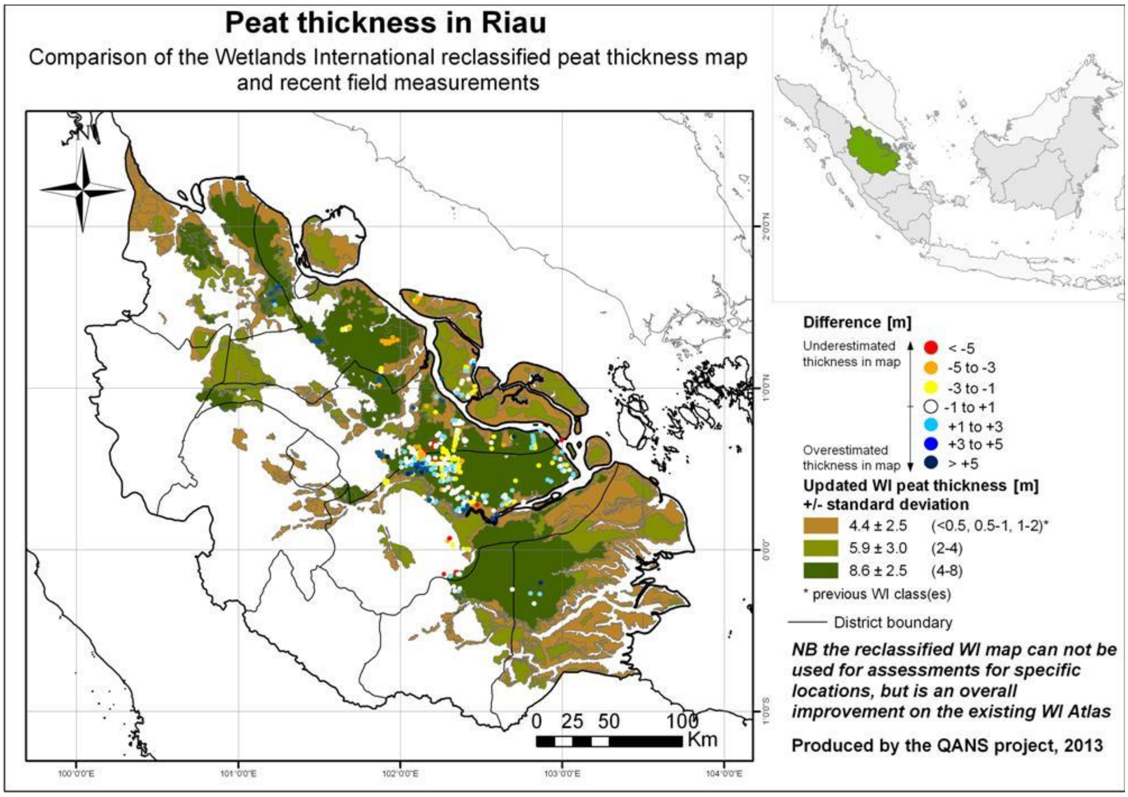


Figure 42 Comparison of the WI reclassified peat thickness map and recent field measurements for Riau and West Kalimantan

Notes: Comparison of the Wetlands International reclassified peat thickness map and recent field measurements (>0.5 m, after 2000 or had still forest before 2000) for Riau (top) and West Kalimantan (bottom). Compare with Figure 5 and Figure 6 to see the result for the original WI map.

4.1.2 Maps derived from elevation and geomorphological modelling

In Sections 3.2.1 and 3.2.2 it was demonstrated that fairly accurate elevation models can be constructed from window filtered SRTM-30 for deforested (by the year 2000) areas and by application of geomorphological relations (dome surface shape in relation with distance to the nearest river) for forested peat domes. Peat thickness models can be derived by subtracting the position of the peat bottom from the surface elevation.

Peat thickness maps created from elevation information are consider most accurate for those areas where the peatland morphology has developed in parallel with river delta expansion over the last 5000 years, i.e.:

A. a close relation between surface elevation and peat thickness is expected, i.e. lowland areas within 135 km from the coast (see Section 3.1.3), with

B. no (dominant) outcrops of older mineral surface morphology (i.e. no hills over 14 m MSL) adjacent to the peat, and

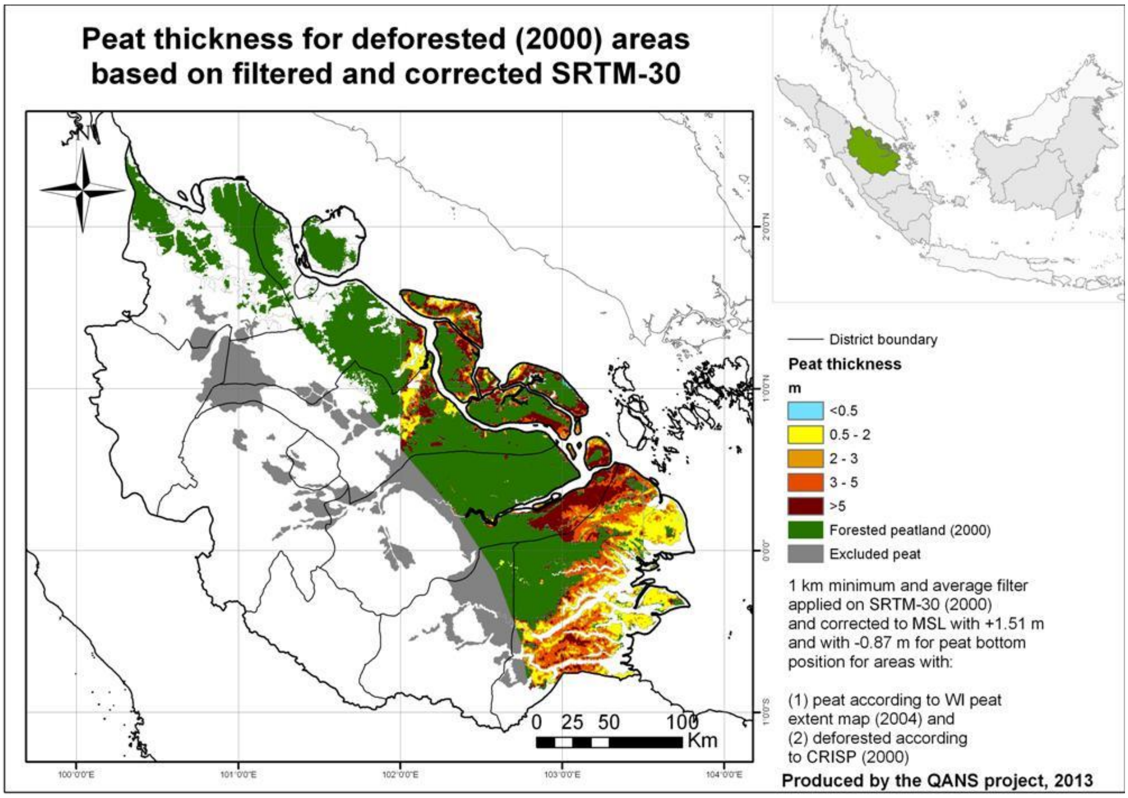
C. sufficient elevation data were available (i.e. deforested areas with SRTM-30 data, or any areas with LiDAR information), or

D. large and relatively undisturbed peat domes are present (i.e. still largely unburned, undrained and forested).

4.1.2.1 Maps for selected areas deforested before 2000, applying SRTM-30 and LiDAR

Applying these criteria, peat thickness models for deforested areas in both Riau (1.6 Mha by 2000, 40.6% of total provincial peatland area; Table 1; albeit only for the part of Riau East of the 102 degrees Meridian) and West Kalimantan (0.4 Mha by 2000, 23.7% of total provincial peatland area; Table 1) are shown in Figure 43, whereas for South Sumatra (1.2 Mha by 2000, 84.4% of total provincial peatland area; Table 1) the peat thickness model is shown in Figure 44. Peatlands excluded from peat mapping on the basis of the above criteria are called ‘excluded peat’ in these maps.

Similar to the peat thickness model derived from filtered and corrected SRTM-30, a peat thickness model for the KFCP area was created using the LiDAR DTM (Figure 22).



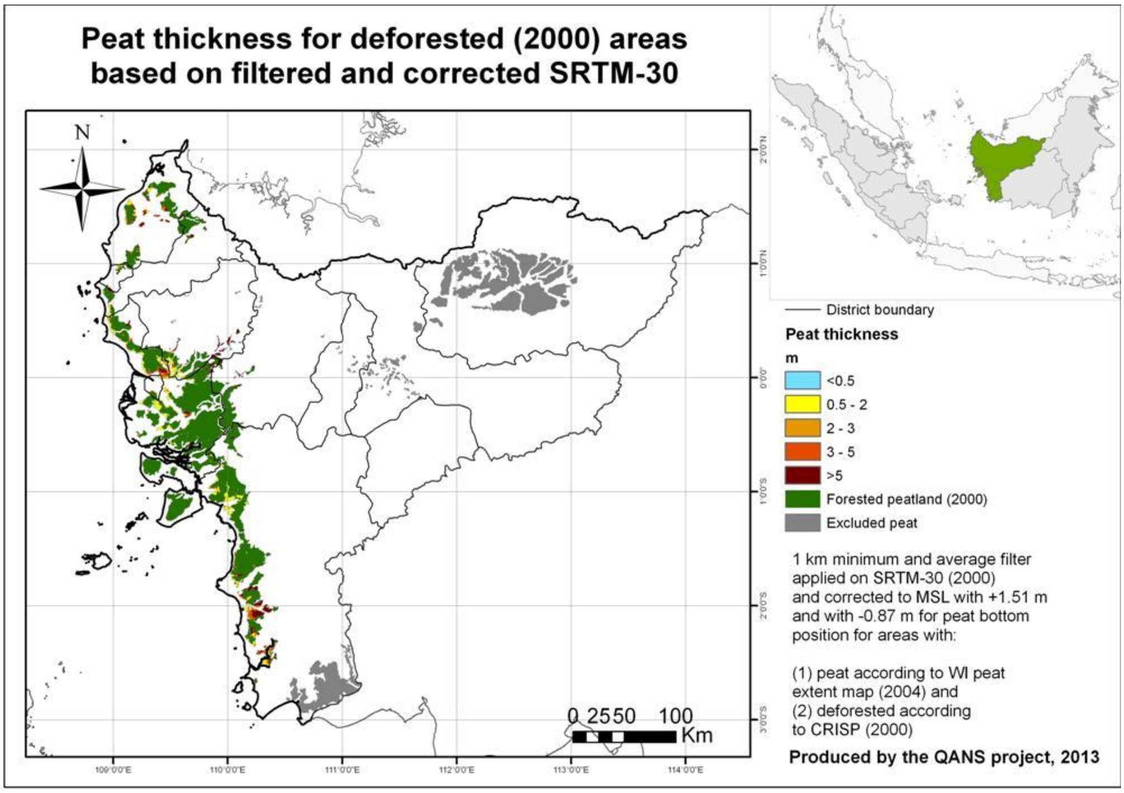


Figure 43 Peat thickness for deforested (by 2000) areas in Riau (top) and West Kalimantan (bottom) based on filtered and corrected SRTM-30.

Notes: Note that for Riau only SRTM-30 data was available to the East of the 102 degrees Meridian). Peat thickness was derived by subtracting the position of the peat bottom (+0.72 m MSL) from the filtered and corrected elevation (see Section 3.1.3, Table 9).

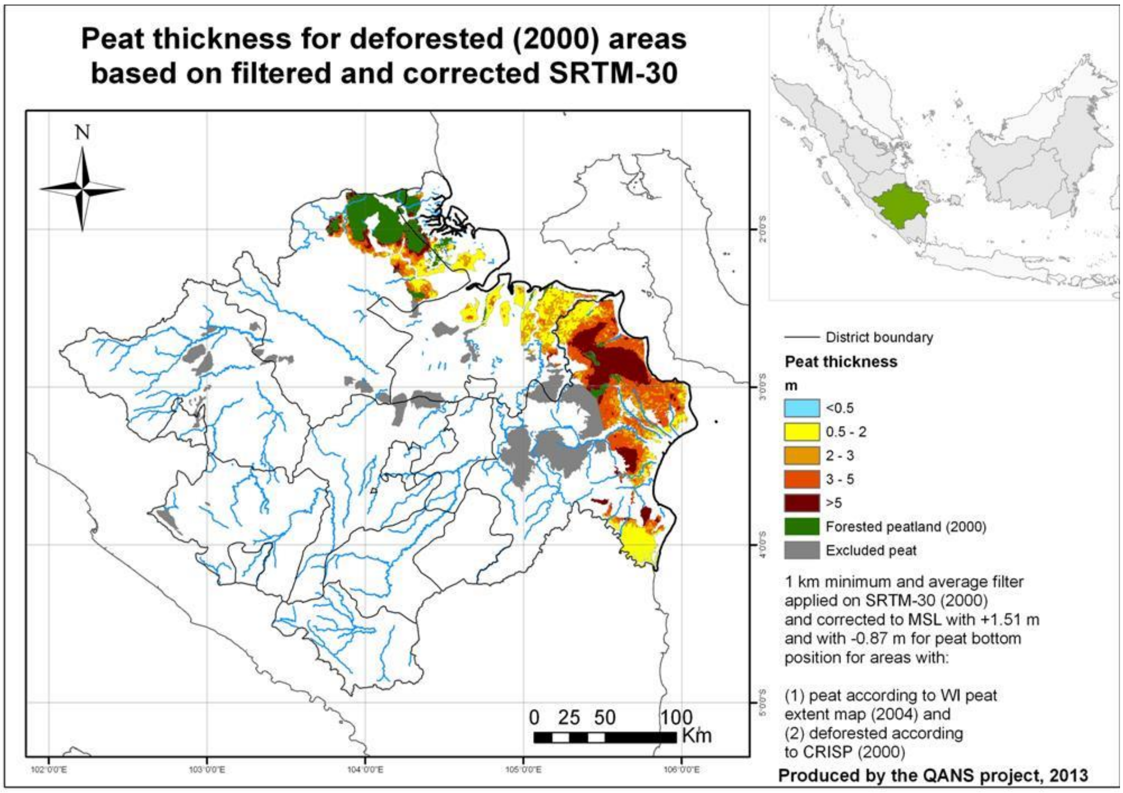


Figure 44 Peat thickness for deforested (by 2000) areas in South Sumatra based on filtered and corrected SRTM-30

Notes: Peat thickness was derived by subtracting the position of the peat bottom (+0.72 m MSL) from the filtered and corrected elevation (see Section 3.1.3, Table 9).

4.1.2.2 Maps for selected areas forested in 2000, applying geomorphological models

For the Kampar Peninsula where an elevation model was generated by applying geomorphological relations derived from ICESat/GLAS LiDAR data (Figure 37) a peat thickness model could also be created by subtracting the position of the peat bottom (+0.72 m MSL). The resulting peat thickness model is shown in Figure 45.

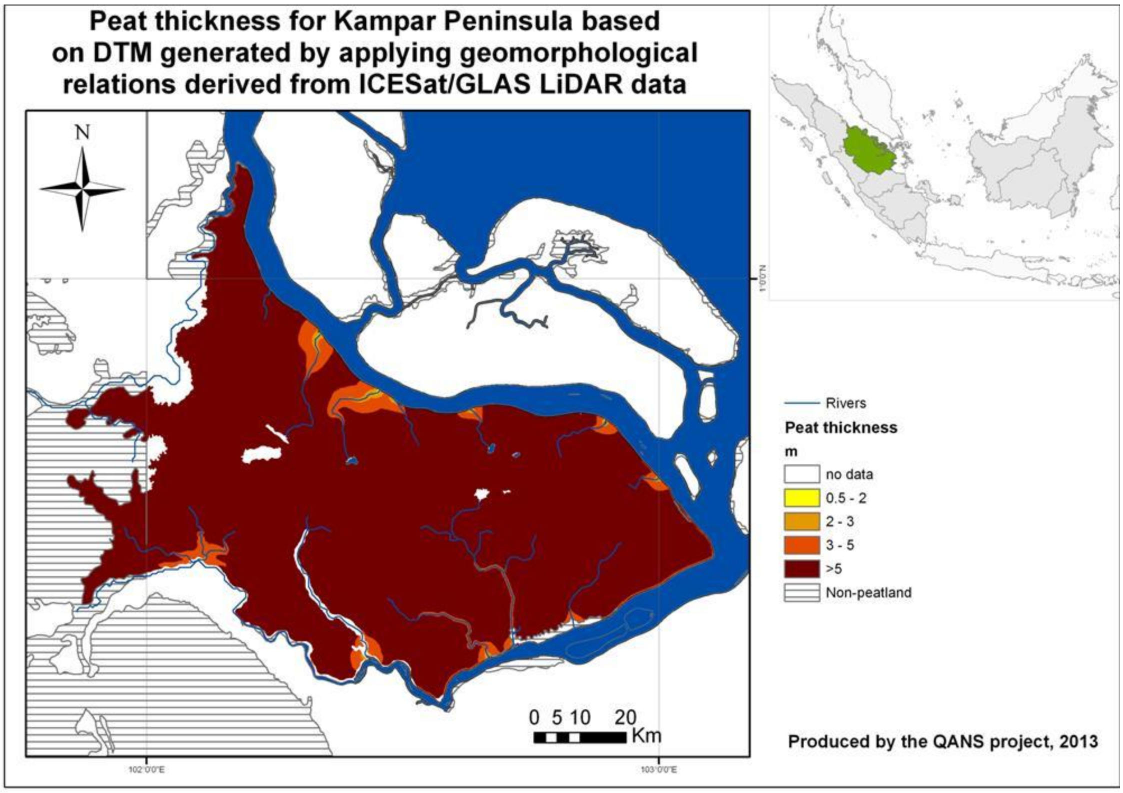


Figure 45 Peat thickness model for Kampar Peninsula based on elevation model generated by applying geomorphological relations

Notes: The geomorphological relations were derived from ICESat/GLAS LiDAR data (Figure 37). Peat thickness was derived by subtracting the position of the peat bottom (+0.72 m MSL) from the filtered and corrected elevation (see Section 3.1.3, Table 9).

4.2 Accuracy assessment through comparison with field data

The peat thickness models for deforested areas in the Kerumutan area are compared for the peat thickness locations surveyed from November 2012 – February 2013 in the Kerumutan area and the Reteh and Enok districts. The surveys were organized and conducted jointly by the University of Pekanbaru and Gadjah Mada University (UGM) and supported by the QANS project. The surveys followed the same protocol (i.e. 2 to 3 replicate samples were taken at each measurement location) as applied in the KFCP project and the survey teams were trained by KFCP staff prior to starting the field survey. The peat thickness at survey locations (90 in total) are shown in Figure 46, whereas the comparison with the peat thickness model is shown in Figure 47 and Figure 48. It should be noted that these survey data were not included in any of the other analysis except the one presented in this Section, as the data were available only by the end of the project.

For the Kampar Peninsula peat thickness model, created from ICESat/GLAS LiDAR data, the comparison with peat thickness measurements is shown in Figure 49 and Figure 50. For the KFCP peat thickness model, created from airborne LiDAR data, the comparison with peat thickness measurements is shown in Figure 51.

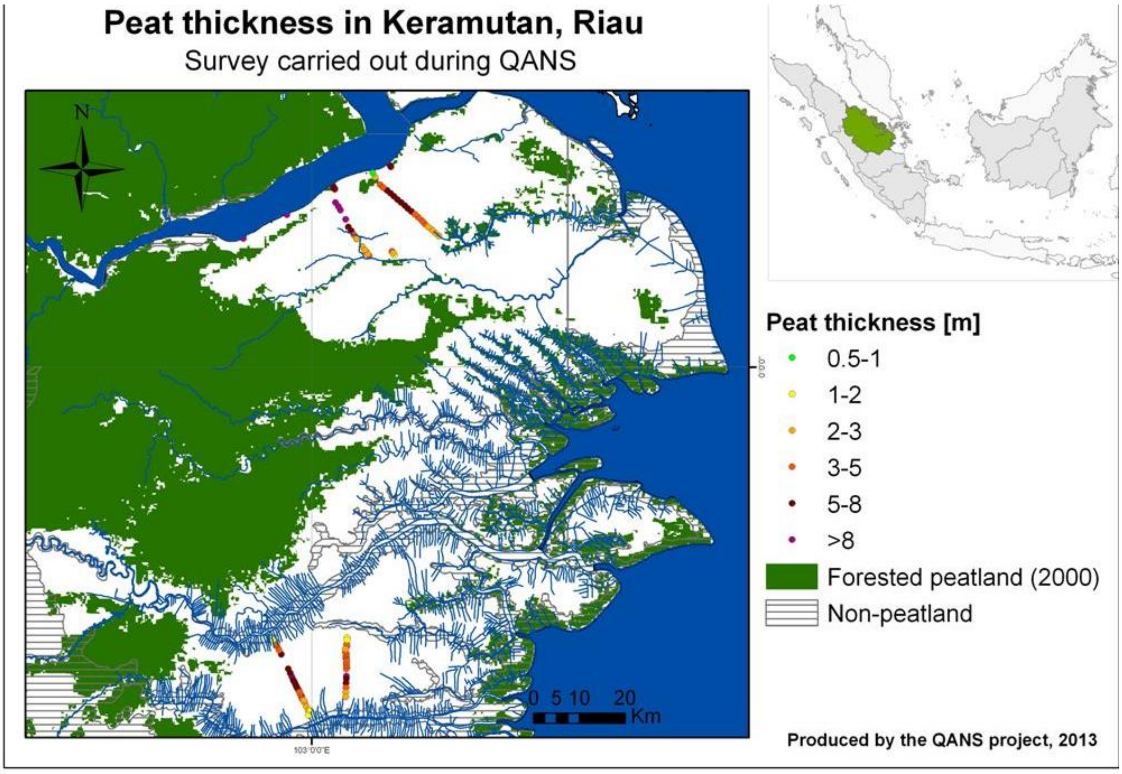
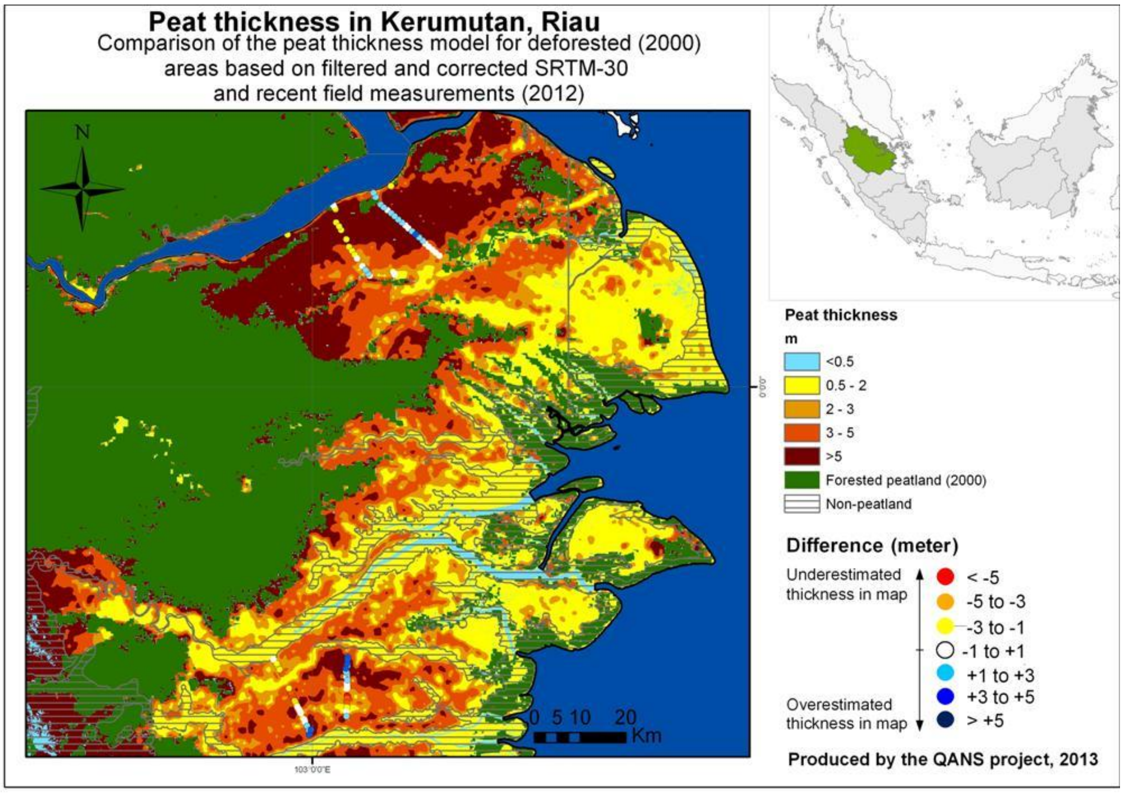


Figure 46 Peat thickness locations surveyed during the QANS project



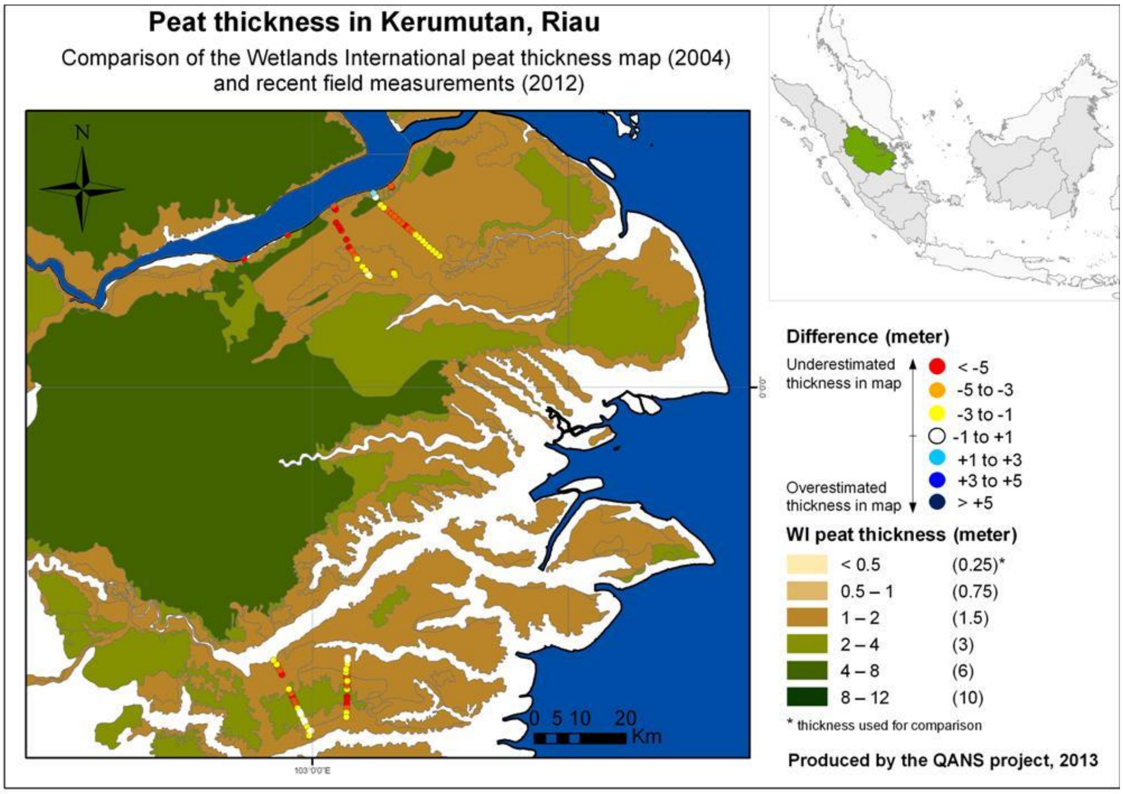


Figure 47 Comparison of (top) the peat thickness map derived from filtered and corrected SRTM-30 and (bottom) the WI Peat Atlas with QANS field measurements

Notes: Comparison of the peat thickness map derived from filtered and corrected SRTM-30 (Figure 29) and field measurements from the peat thickness survey carried out under QANS.

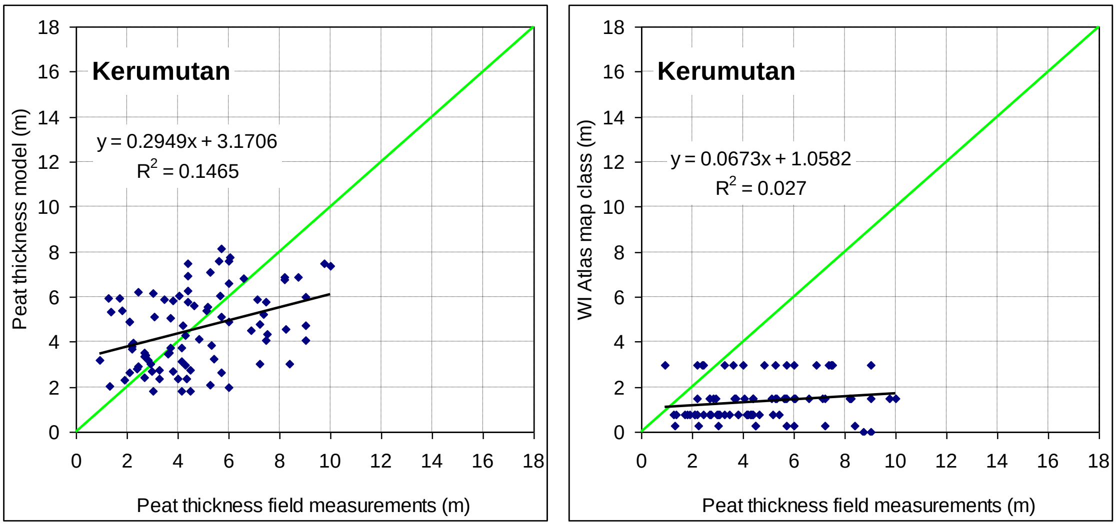


Figure 48 Comparison of peat thickness measured during QANS with (left) the peat thickness model derived from filtered and corrected SRTM-30 and (right) the WI peat map for Kerumutan

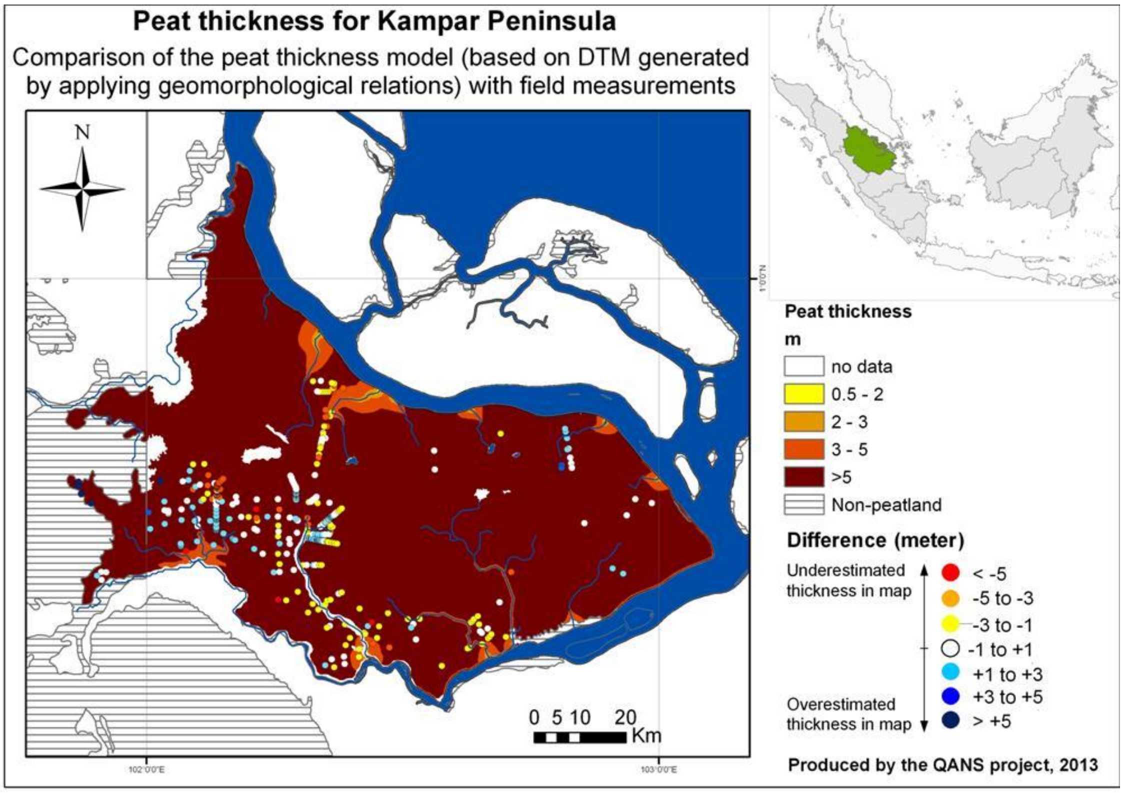


Figure 49 Comparison of the peat thickness map for Kampar Peninsula based on the elevation model generated and field measurements

Notes: The elevation model was generated by applying geomorphological relations derived from ICESat/GLAS LiDAR data (Figure 37).

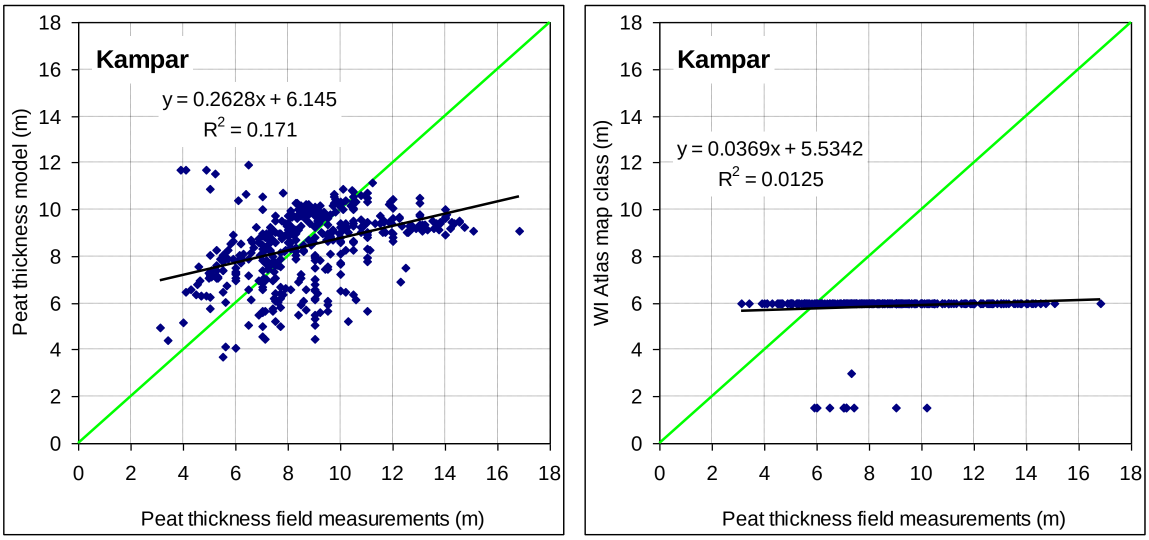


Figure 50 Comparison of peat thickness measurements with (left) the peat thickness model based on the elevation model and (right) the WI peat map for Kampar

Notes: The thickness model was based on the elevation model generated by applying geomorphological relations derived from ICESat/GLAS LiDAR data for Kampar Peninsula, Riau (Figure 49).

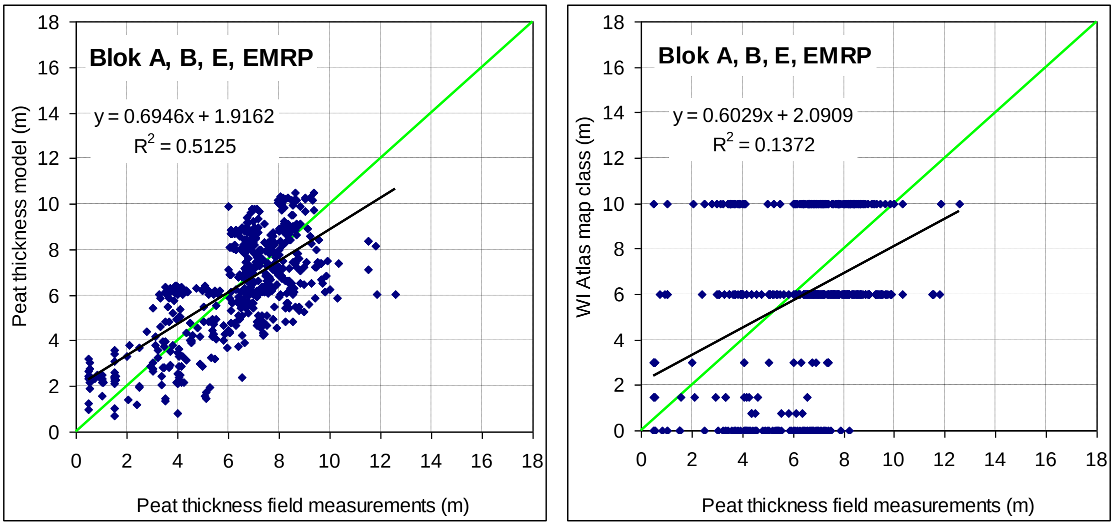


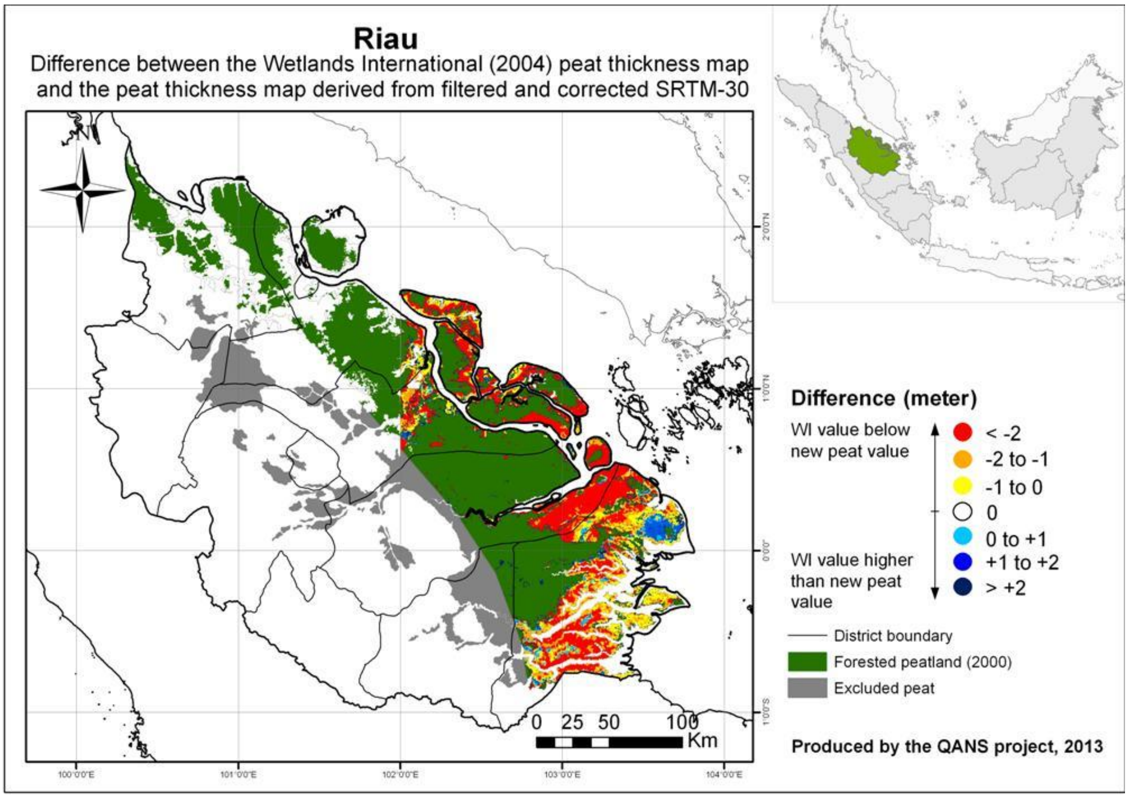
Figure 51 Comparison of recent peat thickness measurements collected by KFCP with (left) LiDAR derived peat thickness model and (right) the WI peat map for Blok A, B and E of the EMRP area

Notes: The peat thickness measurements were collected by KFCP in 2011-2012; these were compared with LiDAR derived peat thickness model for Blok A, B and E of the EMRP area, Central Kalimantan (Figure 22).

The comparison for all three areas shows that at more than 30% of locations, the difference between modelled peat thickness and accurate field measurement is less than 1 m; the percentages for Kerumutan, Kampar Peninsula and KFCP area are 31.8%, 32.5% and 41.2% respectively. Differences greater than 3 m occur 19.3%, 16.0% and 5.4% of cases respectively, and mostly where measured peat thickness is well over 5 m and such differences are less important.

4.3 Comparison with existing maps

The peat thickness maps of Wetlands International and BBSDLP were compared with the peat thickness model derived for deforested (2000) areas from filtered and corrected SRTM-30. The resulting maps for both Riau (Figure 52) and West Kalimantan (Figure 53) show an underestimation of peat thickness in the existing maps of more than 2 m for most of the deforested (2000) areas compared to the newly derived peat thickness map, and confirms the previous findings with comparison of peat thickness measurements.



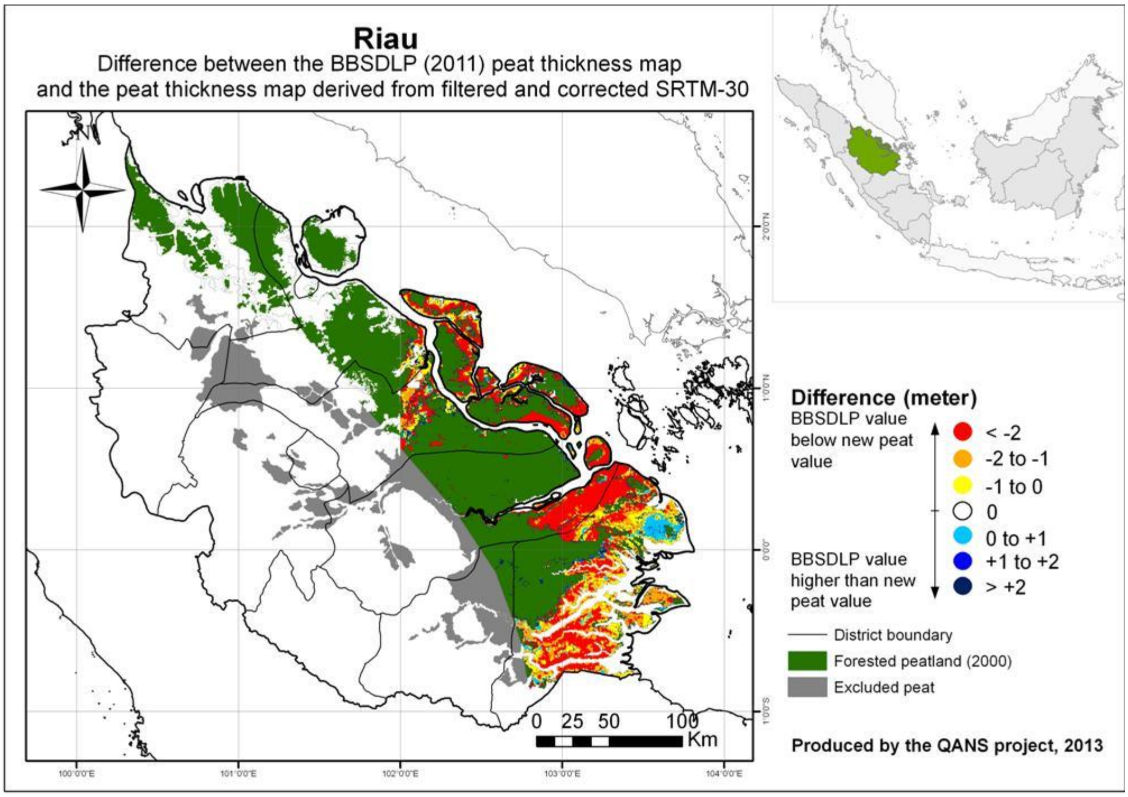
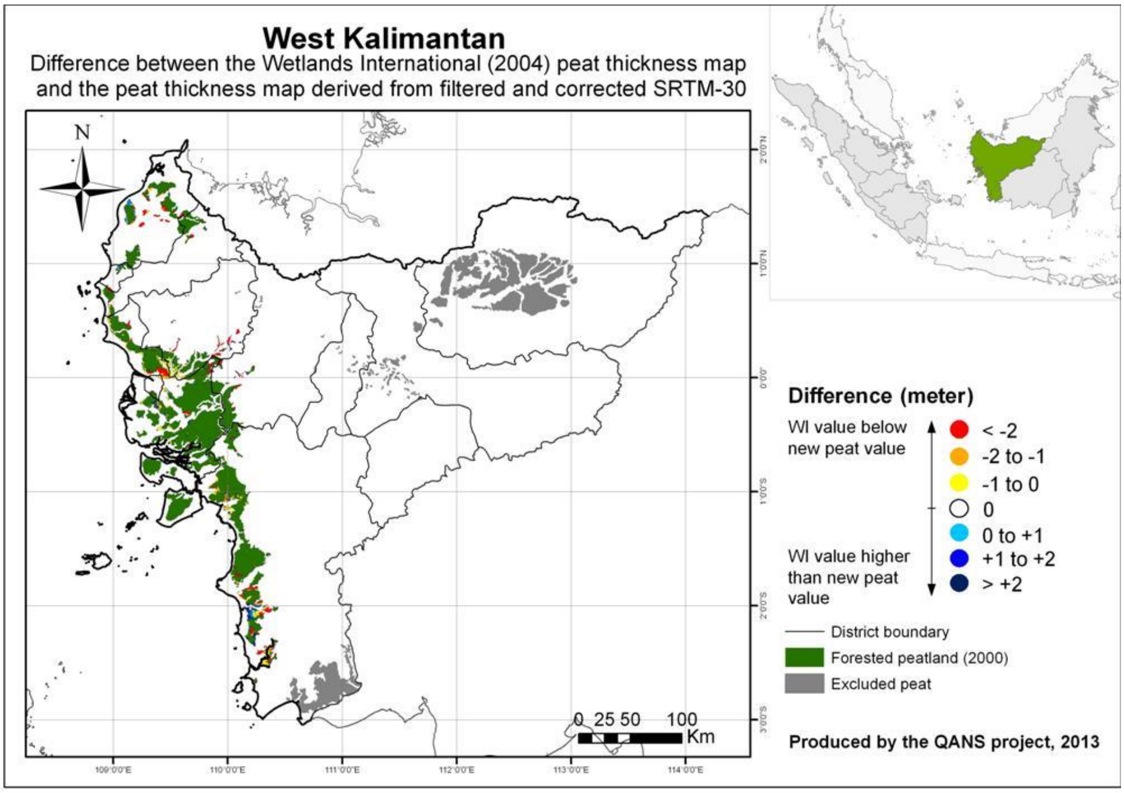


Figure 52 Difference between (top) WI peat thickness map and (bottom) BBSDLP peat thickness map and the peat thickness map derived from filtered and corrected SRTM-30 for Riau

Notes: The mid value of class ranges in the WI and BBSDLP maps were used in the comparison where 6 m peat thickness was arbitrarily used for the '>3 m' BBSDLP peat thickness class.



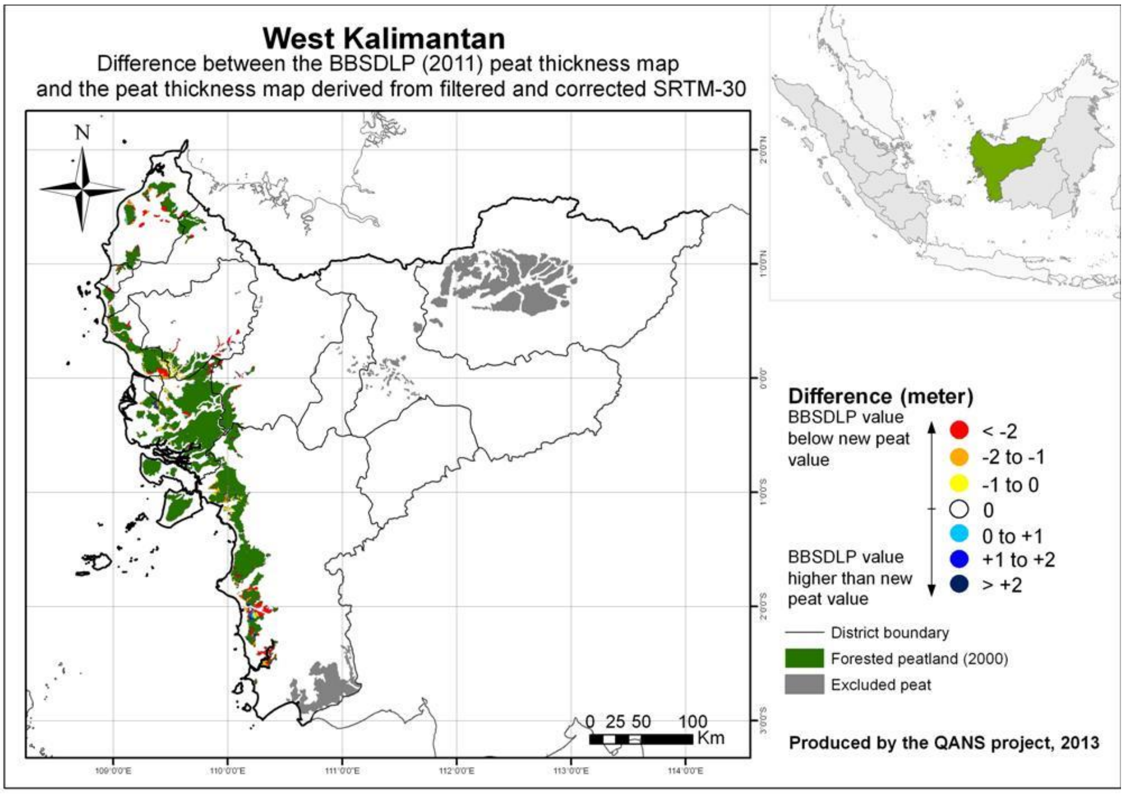


Figure 53 Difference between (top) WI peat thickness map and (bottom) BBSDLP peat thickness map and the peat thickness map derived from filtered and corrected SRTM-30 for West Kalimantan

Notes: The mid value of class ranges in the WI and BBSDLP maps were used in the comparison where 6 m peat thickness was arbitrarily used for the '>3 m' BBSDLP peat thickness class.

5 Tentative assessment of future drainability

It is well known that both in temperate and tropical peatland areas, the peat surface will subside after drainage due to consolidation (first years after drainage), compaction and oxidation (Hooijer *et al.*, 2012). Peat subsidence is further exacerbated by fires, which frequently occur in peatland areas which have experienced degradation due to deforestation and drainage (Page *et al.*, 2002).

It is found that beyond the first few years after drainage, when subsidence rate often exceeds 1 m over 5 years but declines rapidly in time, subsidence rates are relatively constant and depend on the type of landcover, drainage density of the canals and drainage depth, which directly influences the groundwater table in the peat itself. In general, the deeper the ground water depth and the more open the land the higher the subsidence rates. For SE Asian peatlands it is estimated that when water table depth would be kept constant over decades, at around 0.7 m depth, subsidence will amount to 2.5 m after 25 years and possibly to over 5 metres in a century; similar amounts of cumulative subsidence has also been reported in drajned peatlands in for instance the USA and UK as reviewed in Hooijer *et al.* (2012).

Subsidence will continue until there is no more peat left or if the remainder is near-permanently waterlogged as in natural conditions. The latter process of ‘rewetting’ may result from management interventions aiming to end subsidence and carbon loss, or from the subsidence itself as at some point this brings the peat surface to the drainage limit and excess rainwater can no longer be naturally drained through gravity (i.e. without the use of pumps).

To assess the extent of future drainability problems on peatlands, three peatland areas were chosen where we now have relatively accurate (within 2 m estimated uncertainty) peat surface elevation models and combined with peat thickness measurements can determine the position of the peat bottom:

1. KFCP project area in EMRP area in Central Kalimantan, Blok A, B and E: where peat surface data were derived from airborne LiDAR
2. Kampar Peninsula in Riau: forested peat dome, where peat surface data were derived from ICESat/GLAS LiDAR data
3. Kerumutan area in Riau: deforested peat dome, where peat surface data were derived from filtered SRTM-30

To test at what point peatland drainability would be seriously affected by subsidence, we defined four threshold levels:

1. Drainability is assumed to end in all cases when the peat surface is at MSL.
2. In near-coastal tidal areas, drainability is affected when the surface is at High Tide level (estimated to be 1.5 m above MSL on average).
3. Further away from the coast or rivers, drainability is affected when the surface approaches a Drainage Limit which is defined by adding a conveyance gradient of 0.2 m km^{-1} to High Water Level for river dominated water levels, and to MSL for Sea dominated water levels. The conveyance gradient represents the water table gradient that should be maintained in

canals to allow rainfall to be discharged from the land; the value of 0.2 m km^{-1} is a rule of thumb that is often applied in drainage system design and assessment (e.g. DID Sarawak, 2001). The conveyance gradient is calculated from Mean Sea Level at the coast.

4. Another way of calculating the local Drainage Base is from High River Water level at the river side, which controls the local drainage conditions in areas that are further inland.

To all levels, except the high tide threshold level an unsaturated zone of 0.5 m was added to allow the land to be suitable for agricultural use.

Drainage conditions in the KFCP area, and the more inland parts of the Kampar Peninsula and Kerumutan areas, are controlled by the high river water levels. For the KFCP area, which is located relatively far inland (more than 100 km from the coast) levee height along the Kapuas River, could be accurately assessed from the LiDAR DTM at +3.5 m MSL. In the Riau areas, the levee elevations along the rivers is less accurately known due to the relatively coarse resolution of the available DTM (30 m, filtered SRTM-30) and were therefore tentatively estimated at +1.5 m MSL.

Distance to the nearest river or coast was estimated for each of the peat thickness measurement locations to allow determination of the drainage base elevation applying the conveyance gradient of 0.2 m km^{-1}.

For each of the three peatland areas, the elevation of the peat bottom was calculated for the available peat thickness measurements by subtracting the peat thickness from the surface elevation. For each of the threshold levels used, the results are summarized in Table 13. Average peat bottom elevation was found to range from 0.60 to 0.84 m MSL, which is a remarkably narrow distribution that confirms the idea that the peat bottom must usually be around Sea level because of the way peatlands developed (see Section 3). Similarly, the number of peat thickness measurement points indicating a peat bottom below MSL (plus an unsaturated zone, UZ, of 0.5 m that is required for agriculture) is in a narrow range of 37% to 46%. The number of peat bottom measurements below High Tide level is 57% to 67%. The number of measurements below ‘MSL + UZ + conveyance gradient’ is 58% to 70%, and the number below ‘RHWL + UZ + conveyance gradient’ is 82% to 100%.

It is clear from the results in Table 13 that no matter which drainage limit definition is used, even under the most conservative threshold (MSL + UZ), at least 40% of the peat thickness measurement locations will sooner or later be below drainage limit and become undrainable, unless pumping is economically and technically feasible which appears to be highly unlikely for such large areas with high rainfall and relatively low economic value.

The average peat thickness for the different areas is 7.4 m (Table 13). Applying subsidence rates varying from 2 to 5 cm/yr under different assumptions, on top of an initial subsidence of around 2.5 m in the first 25 years after drainage (Wösten *et al.*, 1997; Hooijer *et al.*, 2012), suggests that the point at which gravity drainage becomes impossible in these example areas, under continued drainage, is between 25 and 200 years away depending on assumptions of subsidence rate and drainage limit, and on whether the initial 2.5 m subsidence has already taken place.

The above projection implies that the productive live span of agriculture or silviculture on drained peatlands in Indonesia is limited, and that it will end within 25 to 200 years.

The use of average peat thickness and peat bottom elevation for flooding projections is indicative and inaccurate, as in reality there is large variation in both, that will determine more accurate projections for specific areas. Moreover, it is expected that the deepest peat deposits will be conserved in future, so agricultural production will concentrate in areas of shallower peat as is already the case at present. This makes the above projection very conservative; assuming an average peat thickness of 4 m in agricultural areas would result in the large majority of such areas becoming undrainable within 100 years, and possibly within 50 years. In some peatland areas which have been drained for many years flooding already occurs frequently (Figure 54).

The estimates above are conservative, as they do not yet account for Sea level rise or for additional subsidence due to fires.

Table 13 Characteristics of peat thickness measurements and peat bottom position relative to different defined drainage limits for three peatland areas

Area	Kampar Peninsula	Keramutan	EMRP Blok A,B,E	Average
No. Peat thickness measurements	510	88	325	923
Avg. Peat thickness (m)	8.36	4.66	6.72	7.43
Avg. Elevation (m)	9.20	5.27	7.47	8.21
Avg. Peat bottom elevation (m)	0.84	0.60	0.74	0.78
Median peat bottom elevation (m)	1.10	0.76	1.11	1.09
River high water level (m)	1.5	1.5	3.5	-
% below SL + UZ	39.6	45.5	36.6	39.1
% below HT	56.7	67.0	62.2	59.6
% below SL + UZ + conveyance gradient	58.0	62.5	70.2	62.7
% below RHWL + UZ + conveyance gradient	82.0	86.4	100.0	88.7

Notes: Characteristics of peat thickness measurements and the peat bottom position relative to different defined drainage limits for three peatland areas (Kampar Peninsula, Kerumutan and EMRP Blok A, B and E) and all three of them combined, SL = sea level, UZ = unsaturated zone, HT = high tide, RHWL = river high water level. This analysis covers 20.7% of the total amount of available peat thickness measurements.

Figure 54 Example of increasing flooding problems in Aceh

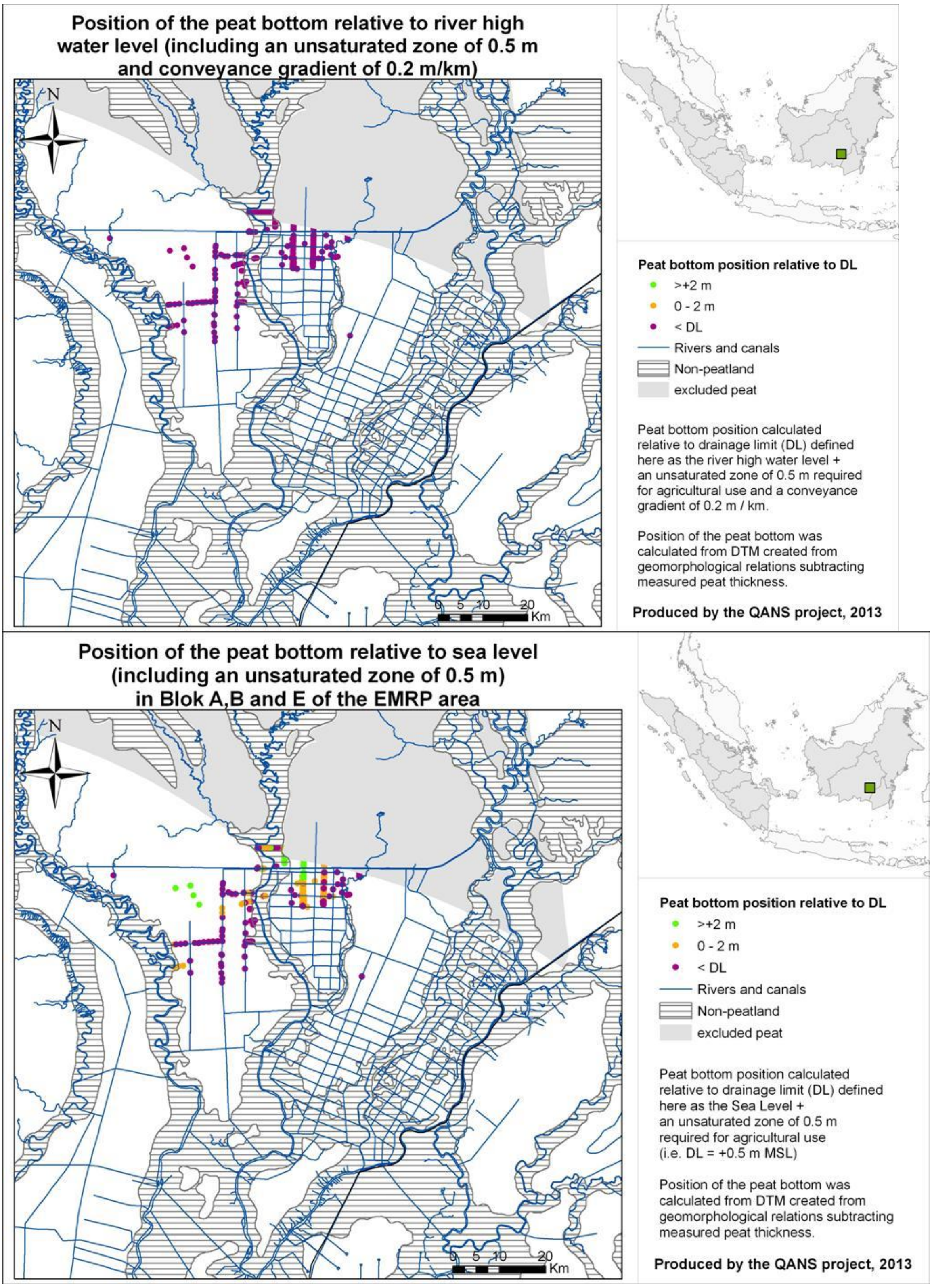
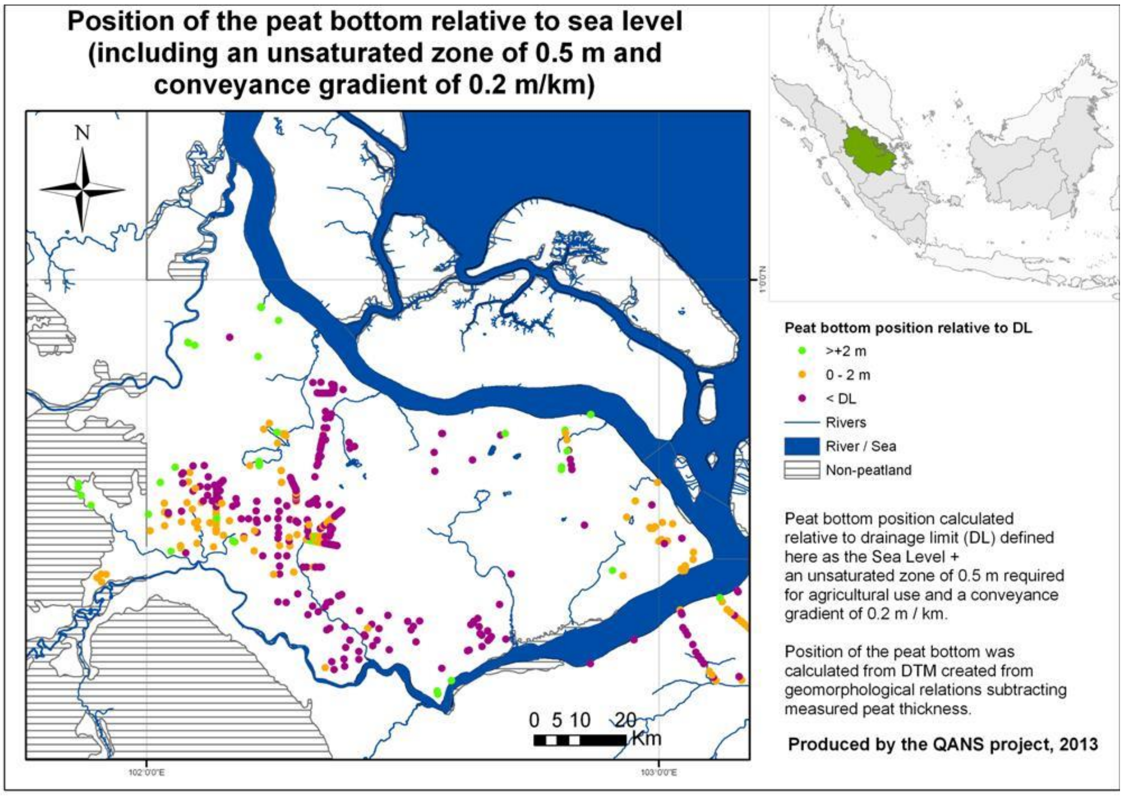


Figure 55 Peat bottom position relative to drainage limit in the EMRP area, Central Kalimantan

Notes: Peat bottom position relative to drainage limit in the EMRP area, Central Kalimantan, shown here for (top) the most extreme but still plausible definition of drainage limit (RHWL + UZ + conveyance gradient of 0.2 m/km) and (bottom) most conservative definition of drainage limit (MSL + UZ). See also Table 13.



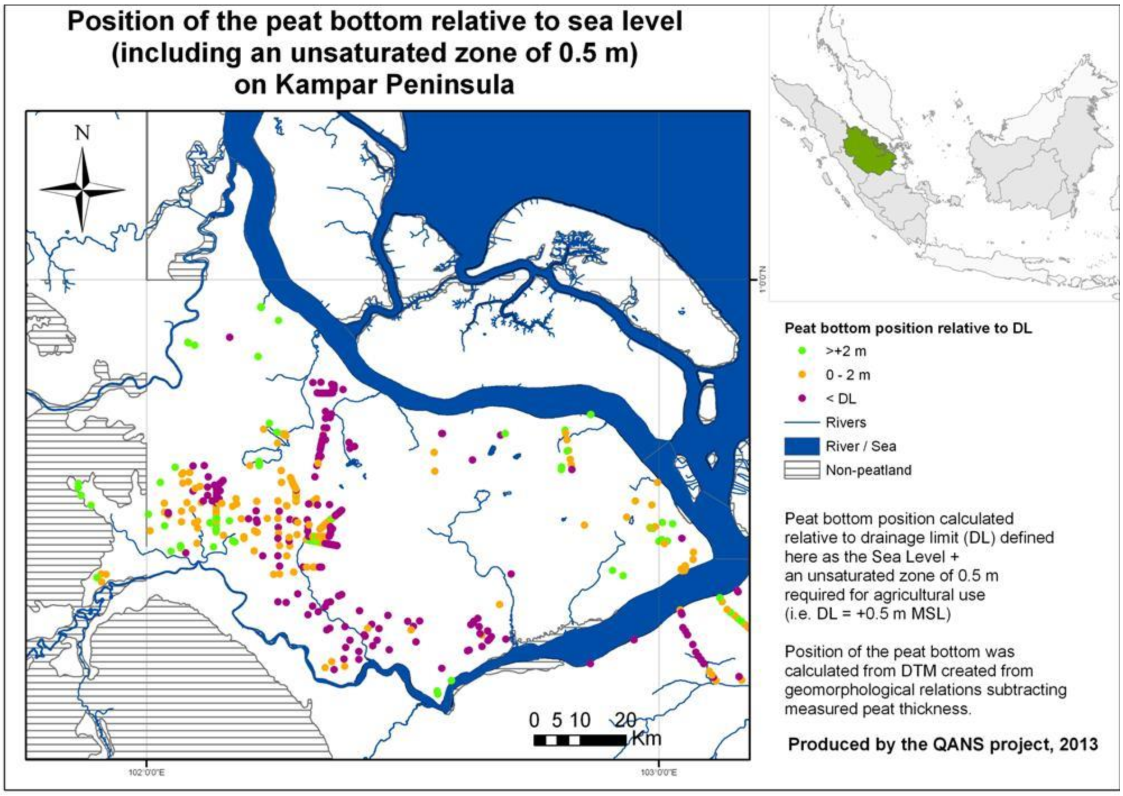
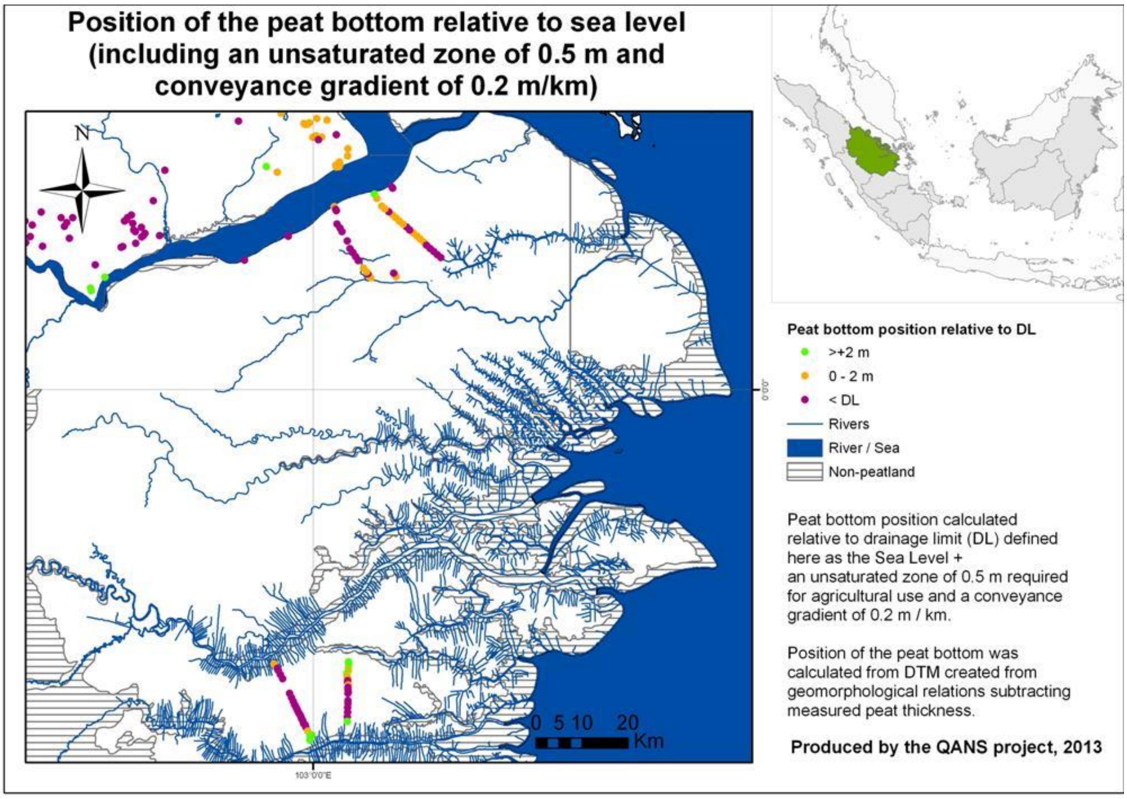


Figure 56 Peat bottom position relative to drainage limit on the Kampar Peninsula, Riau

Notes: Peat bottom position relative to drainage limit on the Kampar Peninsula, Riau, shown here for (top) the most extreme but still plausible definition of drainage limit (MSL + UZ + conveyance gradient of 0.2 m/km) and (bottom) most conservative definition of drainage limit (MSL + UZ). See also Table 13.



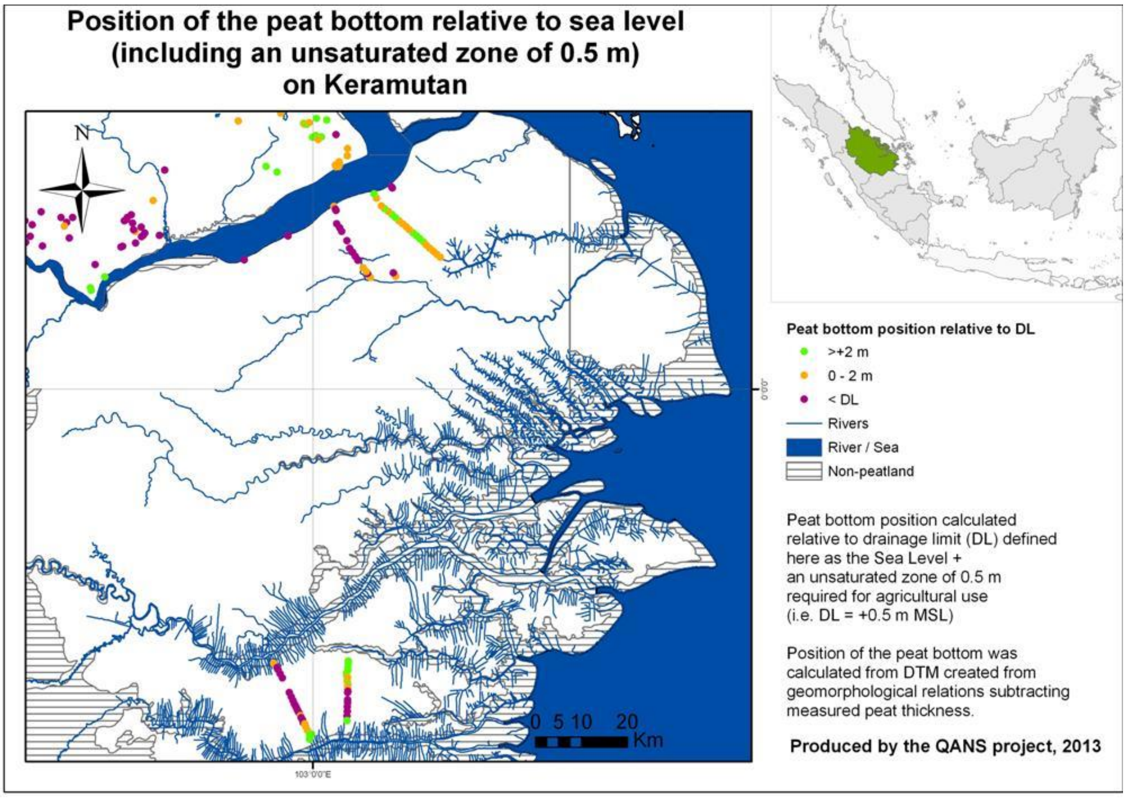


Figure 57 Peat bottom position relative to drainage limit on the Kampar Peninsula, Riau

Notes: Peat bottom position relative to drainage limit on the Kampar Peninsula, Riau, shown here for (top) the most extreme but still plausible definition of drainage limit (MSL + UZ + conveyance gradient of 0.2 m/km) and (bottom) most conservative definition of drainage limit (MSL + UZ). See also Table 13.

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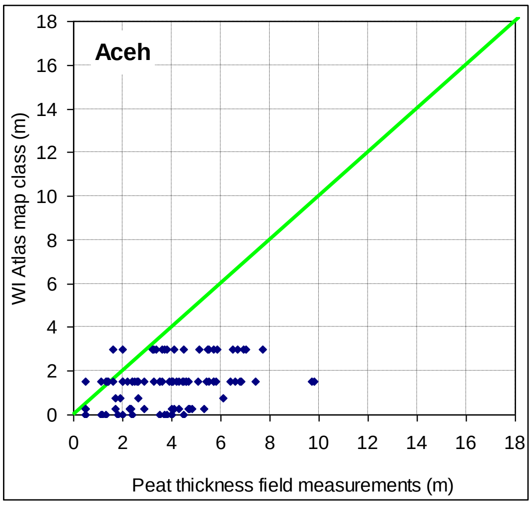
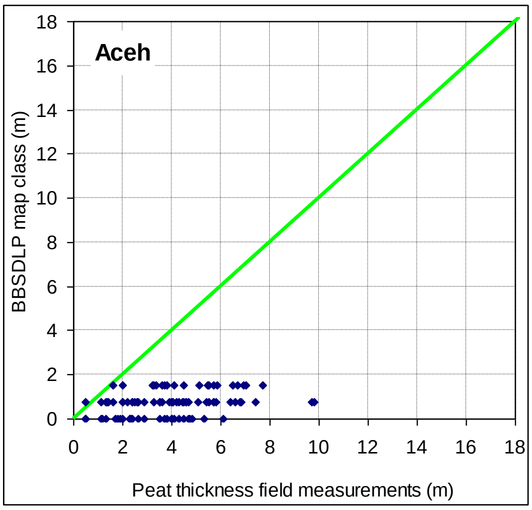
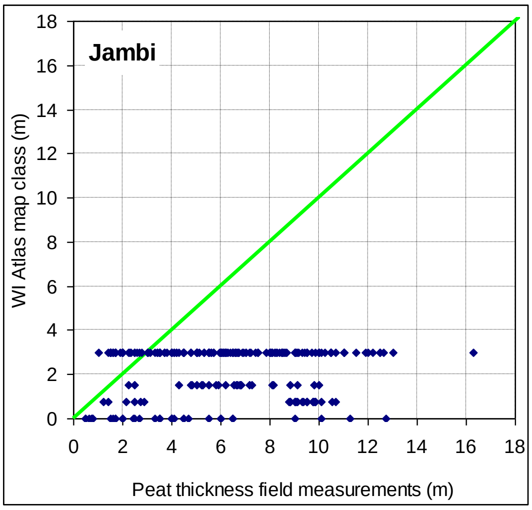
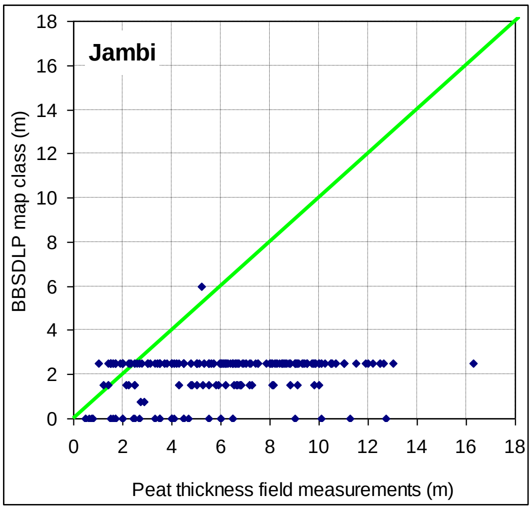
Annex 1 Comparison of peat thickness measurements with peat maps

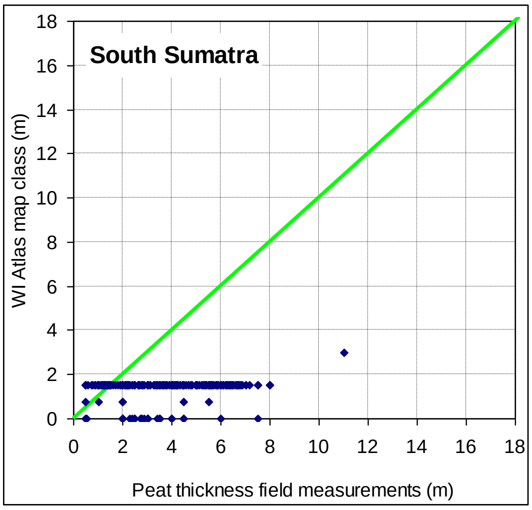
Comparison of the Wetlands International (left) and BBSDLP (right) peat map and field measurements (>0.5 m, after 2000 or had still forest before 2000), for Aceh, Jambi, South Sumatra, Central Kalimantan, East Kalimantan and South Kalimantan. For Riau and West Kalimantan see Figure 4.

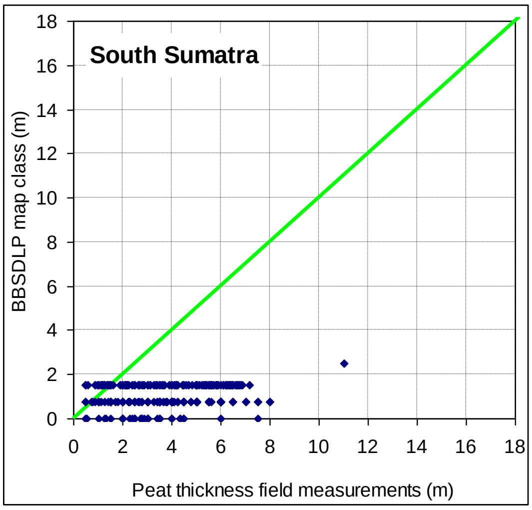


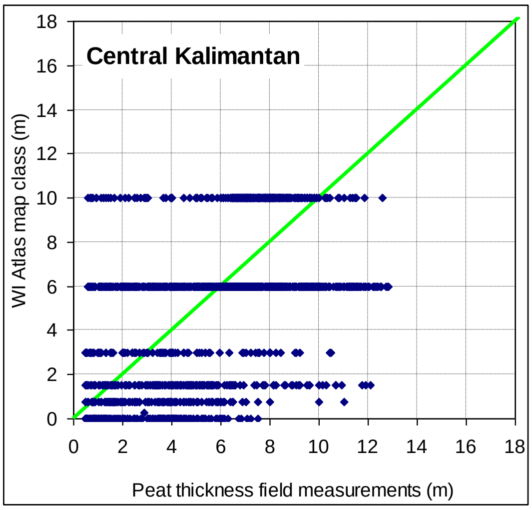


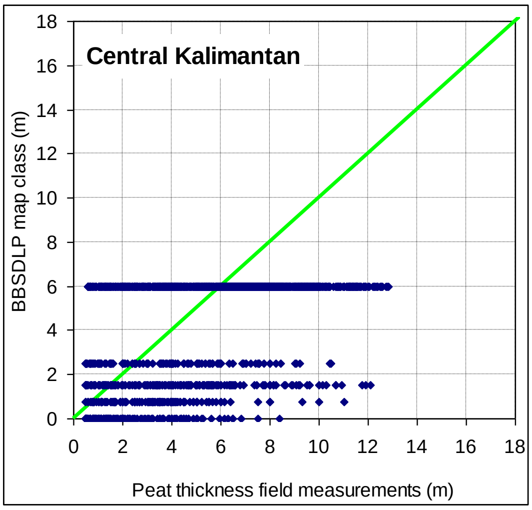

Jambi
WI Atlas map class (m)
Peat thickness field measurements (m)

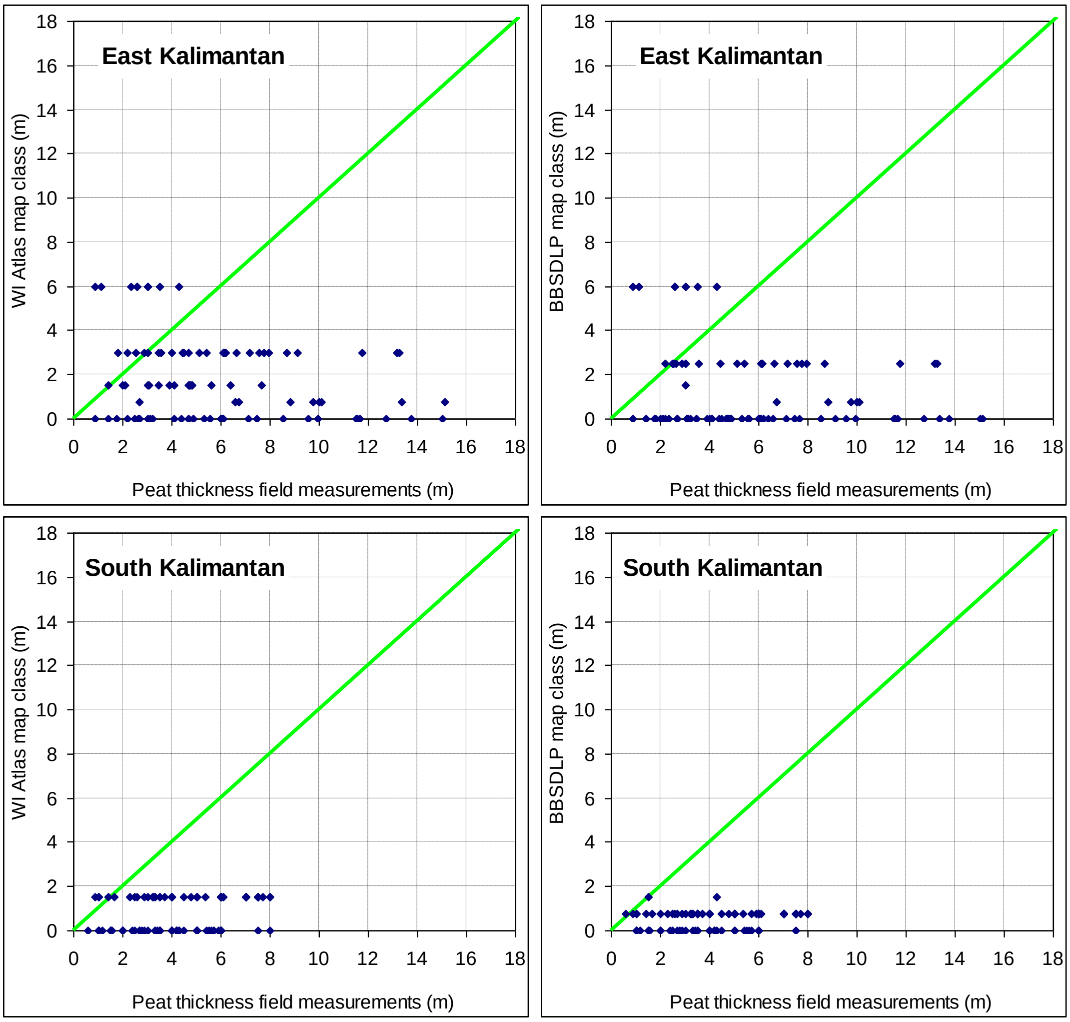

Jambi
BBSDLP map class (m)
Peat thickness field measurements (m)


South Sumatra
WI Atlas map class (m)
Peat thickness field measurements (m)


South Sumatra
BBSDLP map class (m)
Peat thickness field measurements (m)

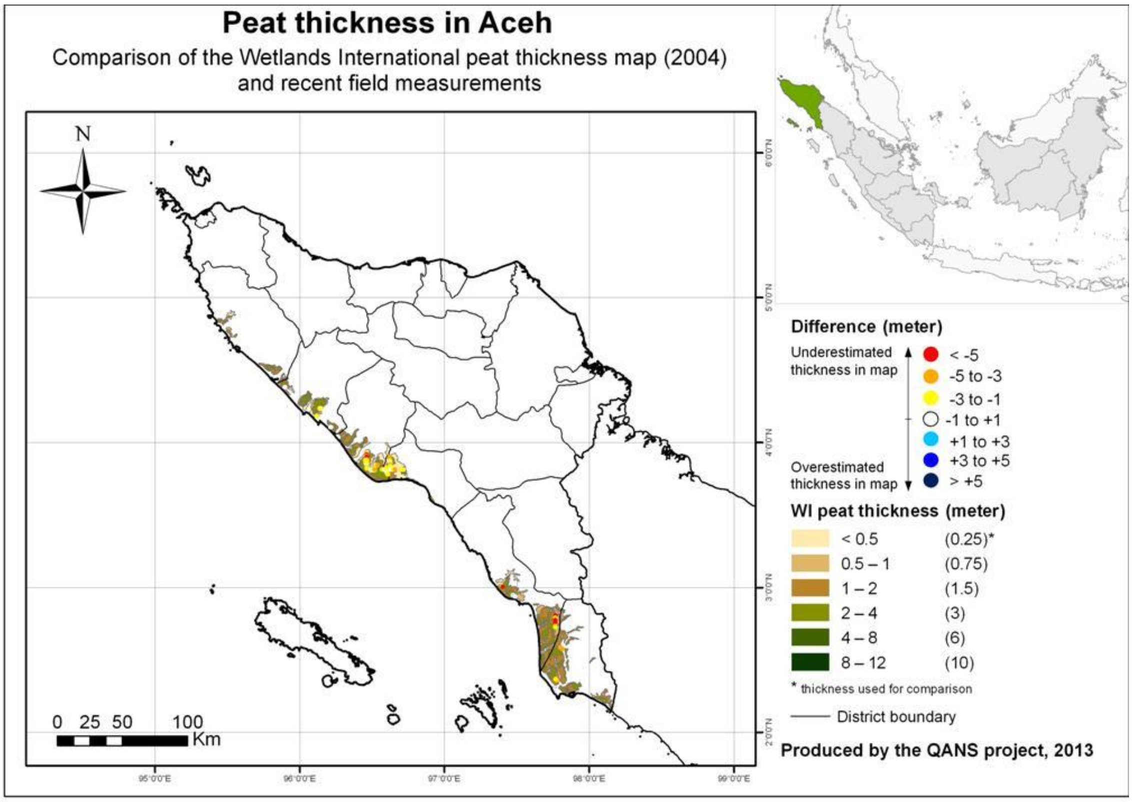

Central Kalimantan
WI Atlas map class (m)
Peat thickness field measurements (m)

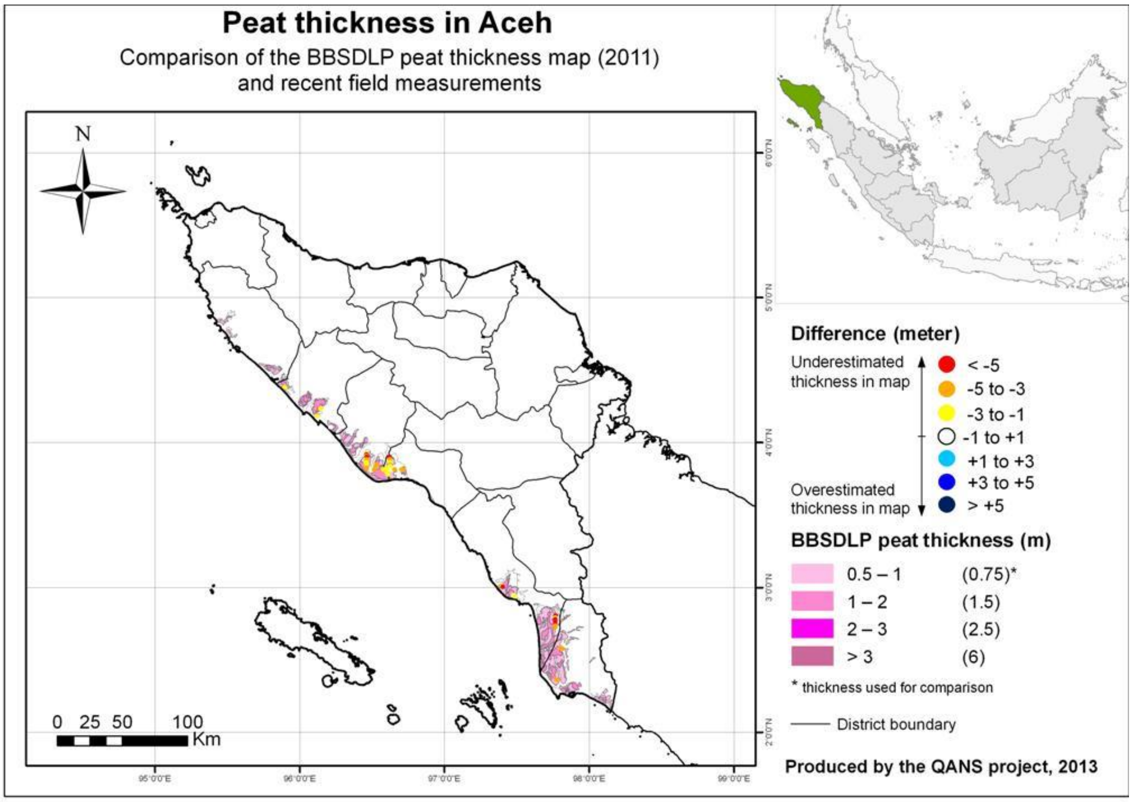

Central Kalimantan
BBSDLP map class (m)
Peat thickness field measurements (m)

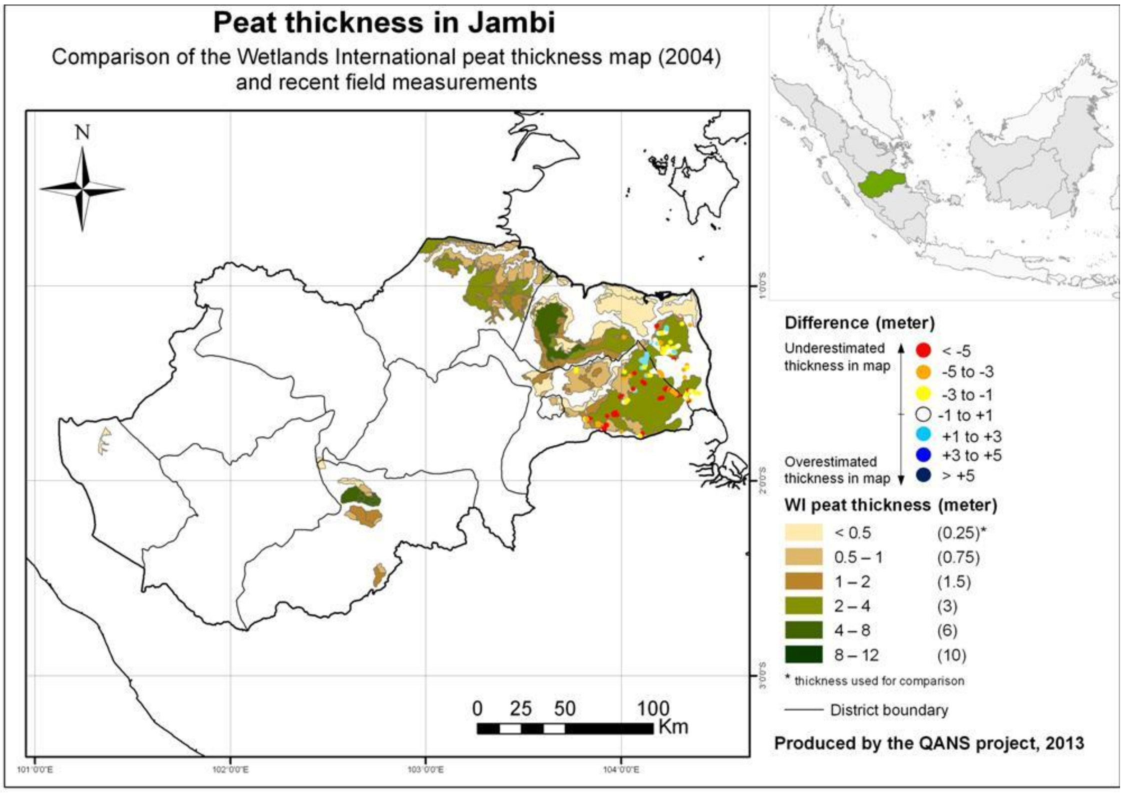

East Kalimantan
WI Atlas map class (m)
Peat thickness field measurements (m)
East Kalimantan
BBSDLP map class (m)
Peat thickness field measurements (m)
South Kalimantan
WI Atlas map class (m)
Peat thickness field measurements (m)
South Kalimantan
BBSDLP map class (m)
Peat thickness field measurements (m)

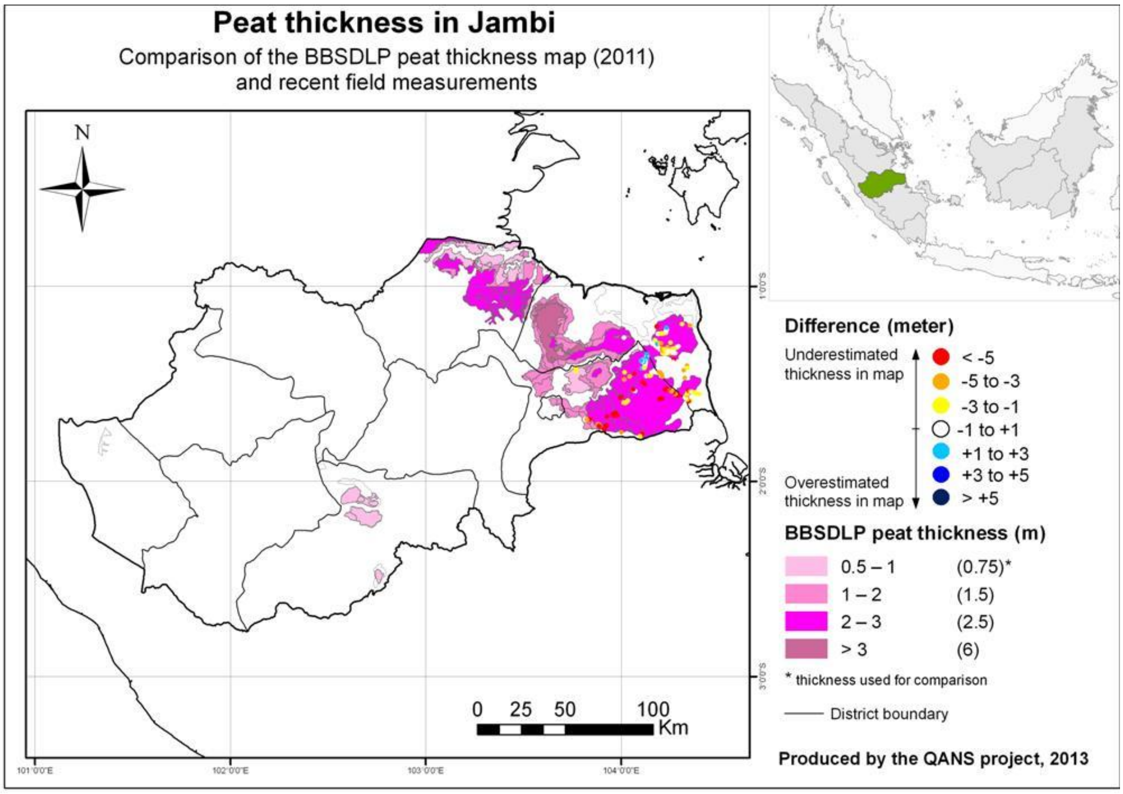
Annex 2 Comparison of the Wetlands International and BBSDLP peat thickness map and recent field measurements

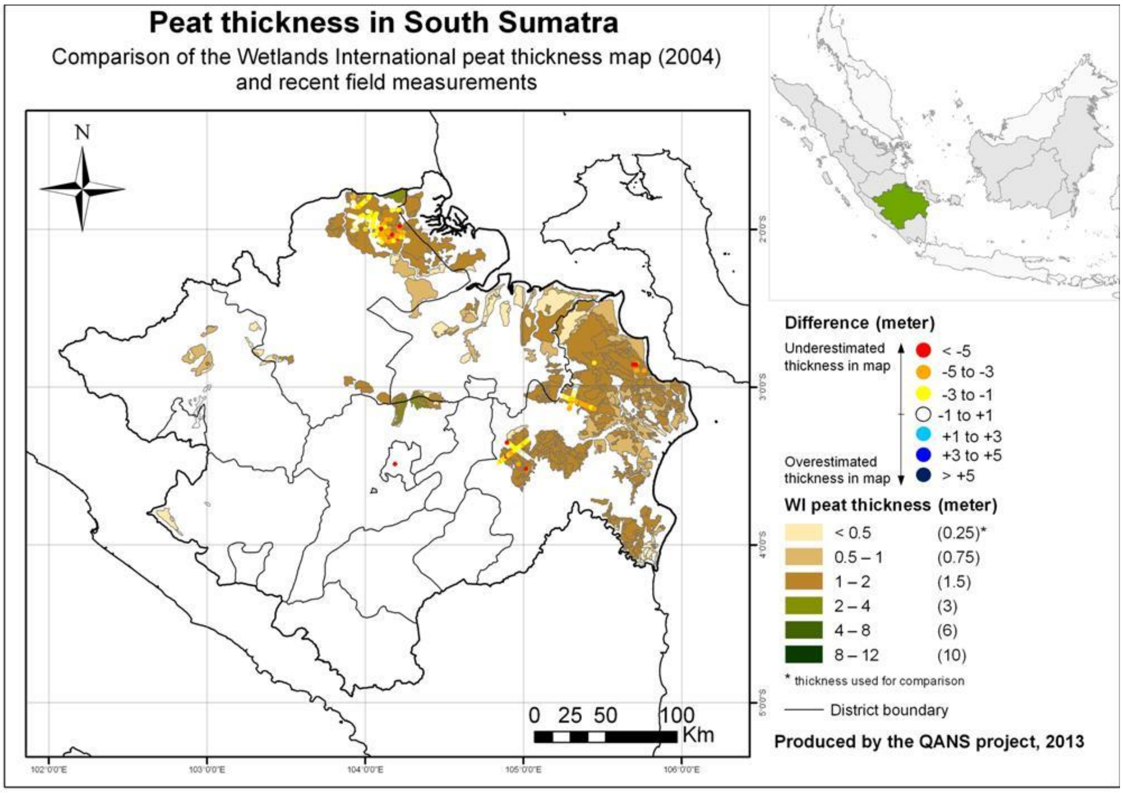
Comparison of the Wetlands International and BBSDLP peat thickness map and recent field measurements (>0.5 m, after 2000 or had still forest before 2000) for Aceh, Jambi, South Sumatra, West Sumatra, Central Kalimantan, East Kalimantan and South Kalimantan. For Riau and West Kalimantan see Figure 5 and Figure 6, respectively.


Peat thickness in Aceh
Comparison of the Wetlands International peat thickness map (2004) and recent field measurements
N
0 25 50 100
Km
Difference (meter)
Underestimated thickness in map
Overestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
WI peat thickness (meter)
< 0.5 (0.25)*
0.5 – 1 (0.75)
1 – 2 (1.5)
2 – 4 (3)
4 – 8 (6)
8 – 12 (10)
* thickness used for comparison
District boundary
Produced by the QANS project, 2013

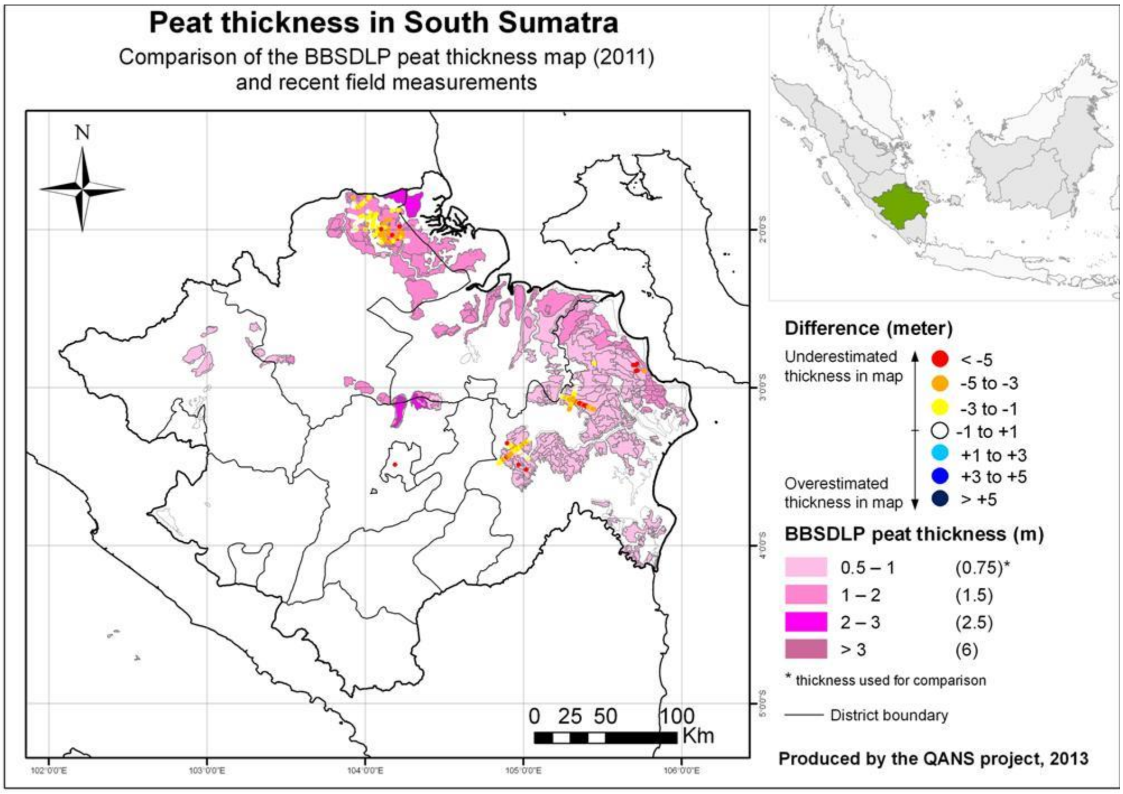

Peat thickness in Aceh
Comparison of the BBSDLP peat thickness map (2011) and recent field measurements
N
0 25 50 100
Km
Difference (meter)
Underestimated thickness in map
Overestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
BBSDLP peat thickness (m)
0.5 – 1 (0.75)*
1 – 2 (1.5)
2 – 3 (2.5)
> 3 (6)
* thickness used for comparison
District boundary
Produced by the QANS project, 2013


Peat thickness in Jambi
Comparison of the Wetlands International peat thickness map (2004) and recent field measurements
N
Difference (meter)
Underestimated thickness in map
Overestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
WI peat thickness (meter)
< 0.5 (0.25)*
0.5 – 1 (0.75)
1 – 2 (1.5)
2 – 4 (3)
4 – 8 (6)
8 – 12 (10)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013

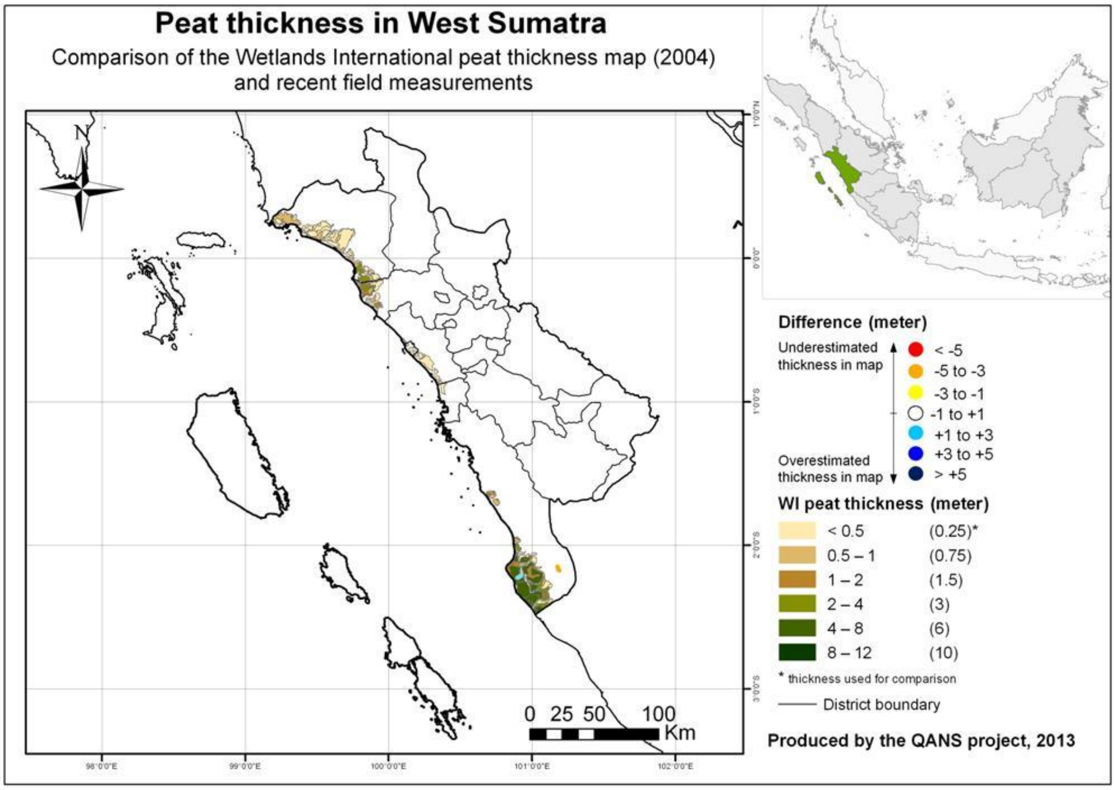

Peat thickness in Jambi
Comparison of the BBSDLP peat thickness map (2011) and recent field measurements
N
Difference (meter)
Underestimated thickness in map
Overestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
BBSDLP peat thickness (m)
0.5 – 1 (0.75)*
1 – 2 (1.5)
2 – 3 (2.5)
> 3 (6)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013

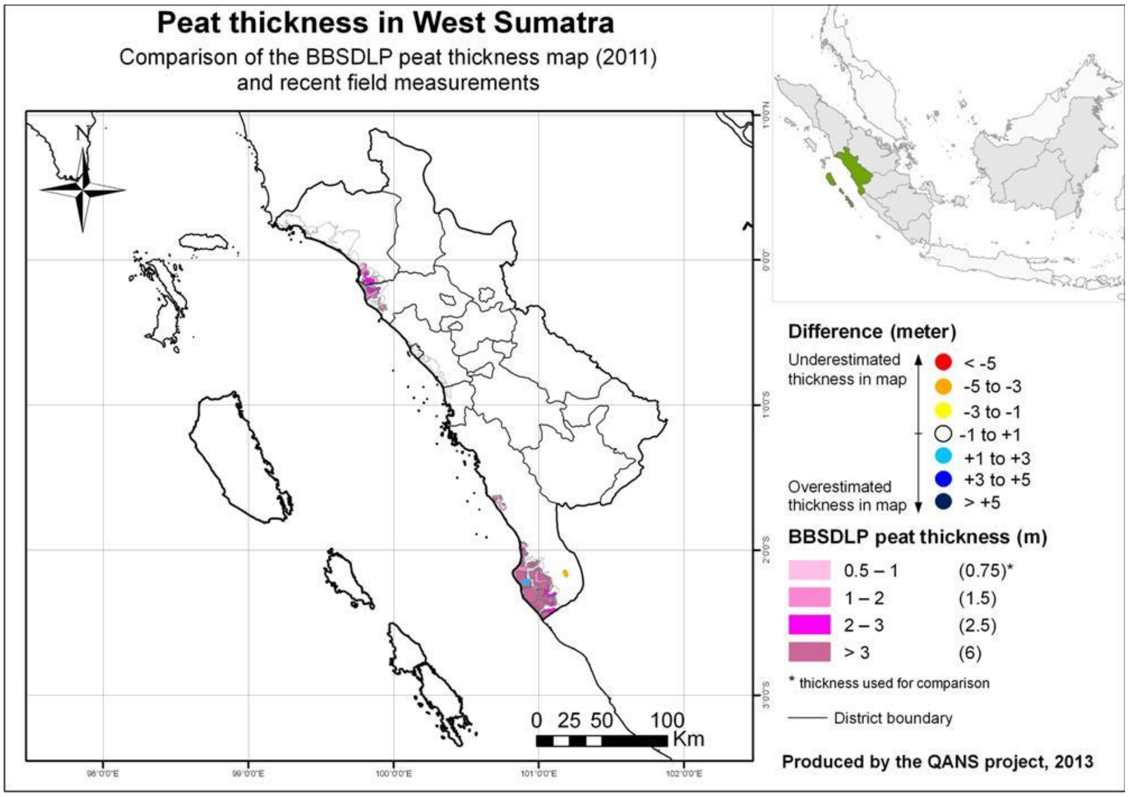


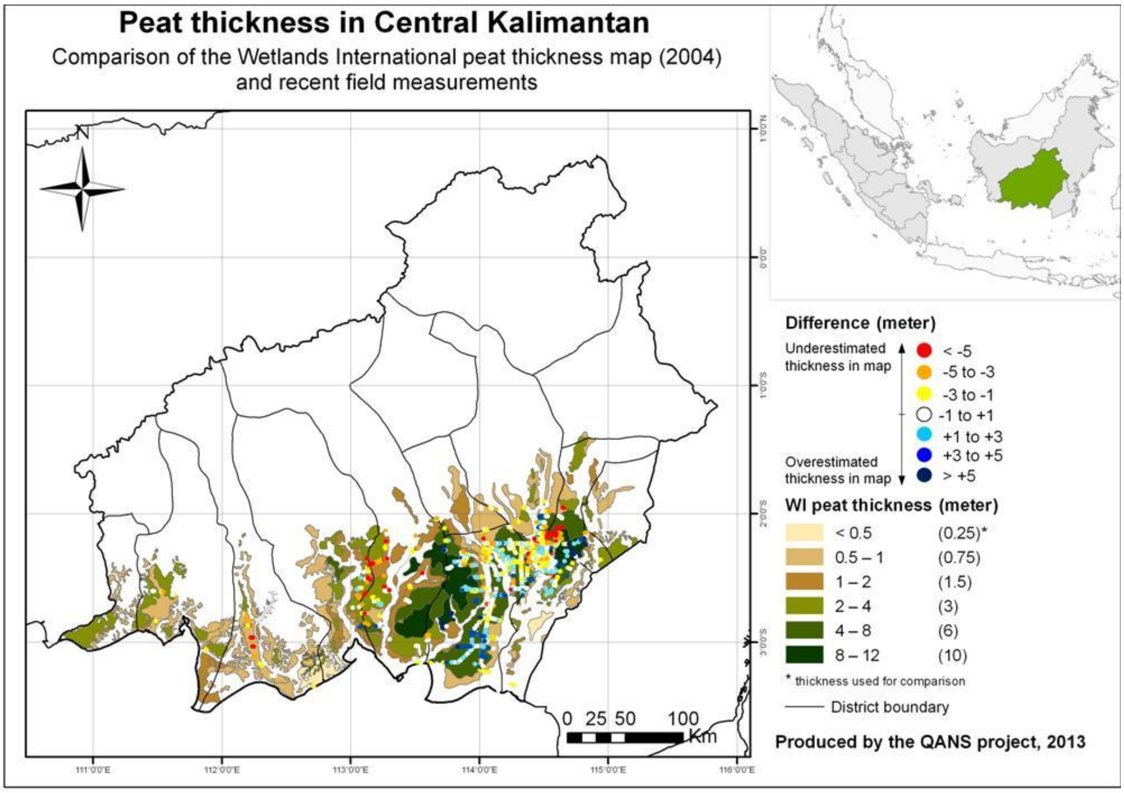
Peat thickness in South Sumatra
Comparison of the Wetlands International peat thickness map (2004)
and recent field measurements
N
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
WI peat thickness (meter)
< 0.5 (0.25)*
0.5 – 1 (0.75)
1 – 2 (1.5)
2 – 4 (3)
4 – 8 (6)
8 – 12 (10)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013

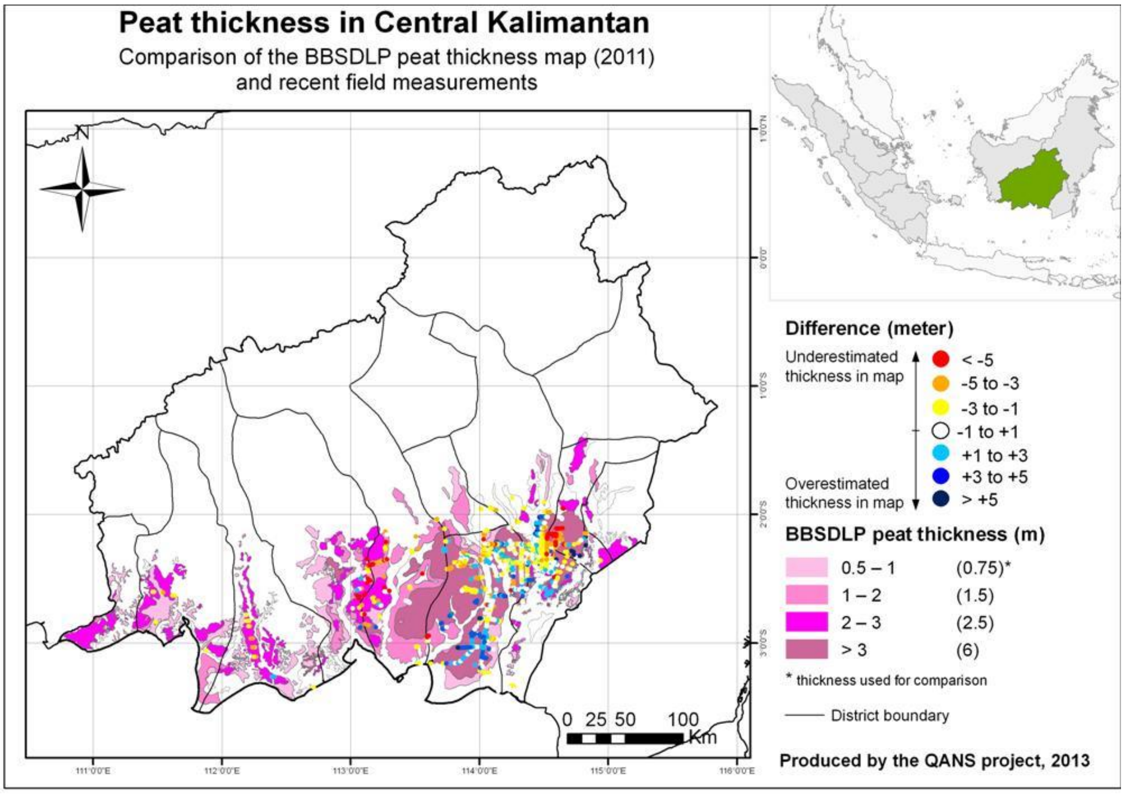


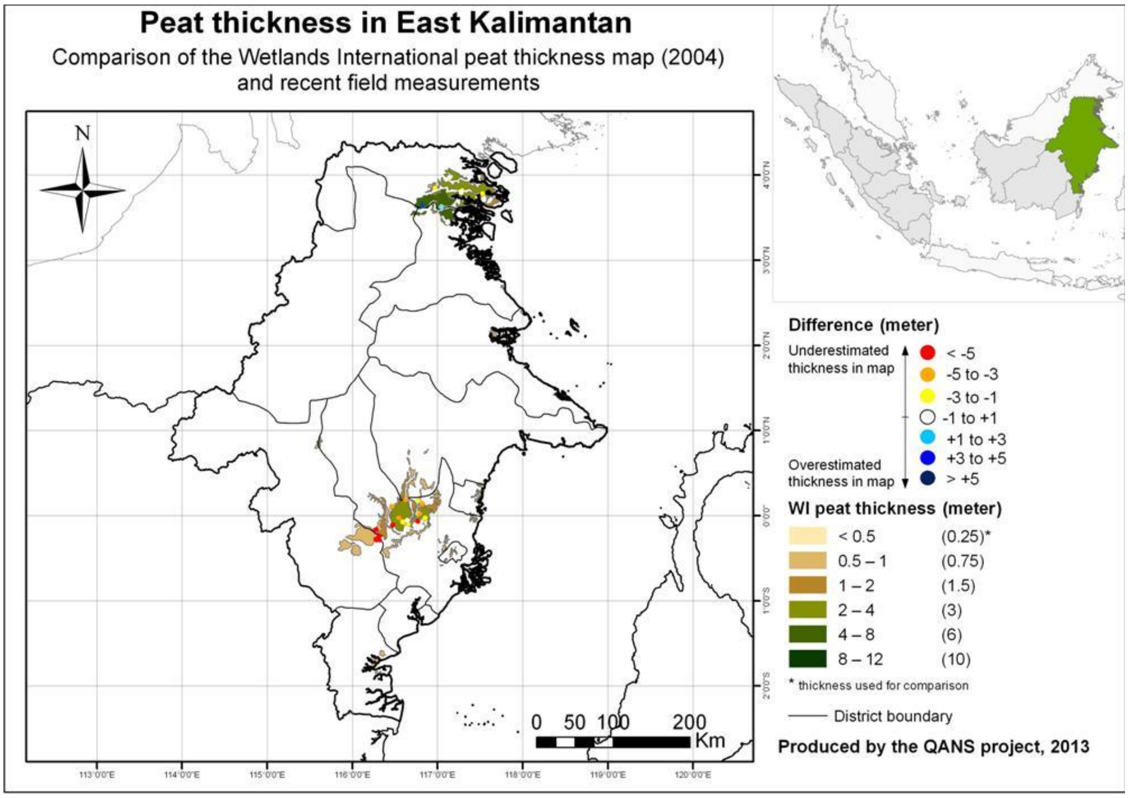
Peat thickness in South Sumatra
Comparison of the BBSDLP peat thickness map (2011)
and recent field measurements
N
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
BBSDLP peat thickness (m)
0.5 – 1 (0.75)*
1 – 2 (1.5)
2 – 3 (2.5)
> 3 (6)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013

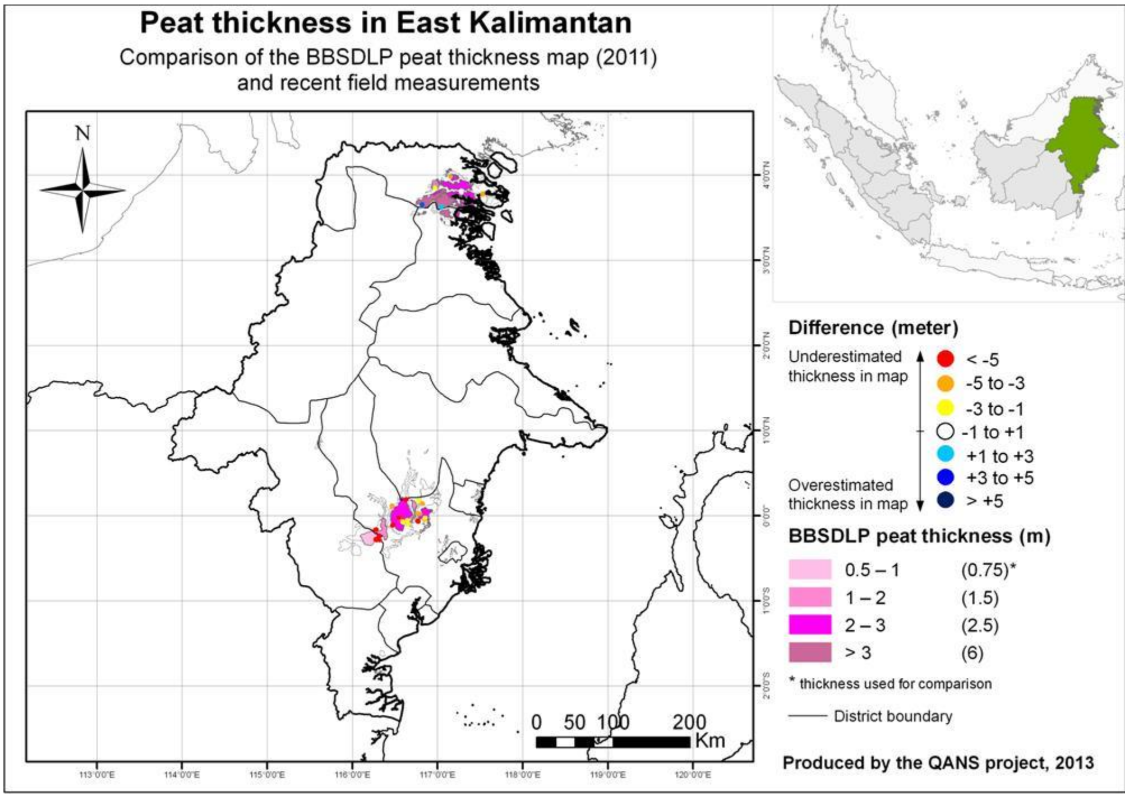

Peat thickness in West Sumatra
Comparison of the Wetlands International peat thickness map (2004) and recent field measurements
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
WI peat thickness (meter)
< 0.5 (0.25)*
0.5 – 1 (0.75)
1 – 2 (1.5)
2 – 4 (3)
4 – 8 (6)
8 – 12 (10)
* thickness used for comparison
District boundary
Produced by the QANS project, 2013
0 25 50 100 Km

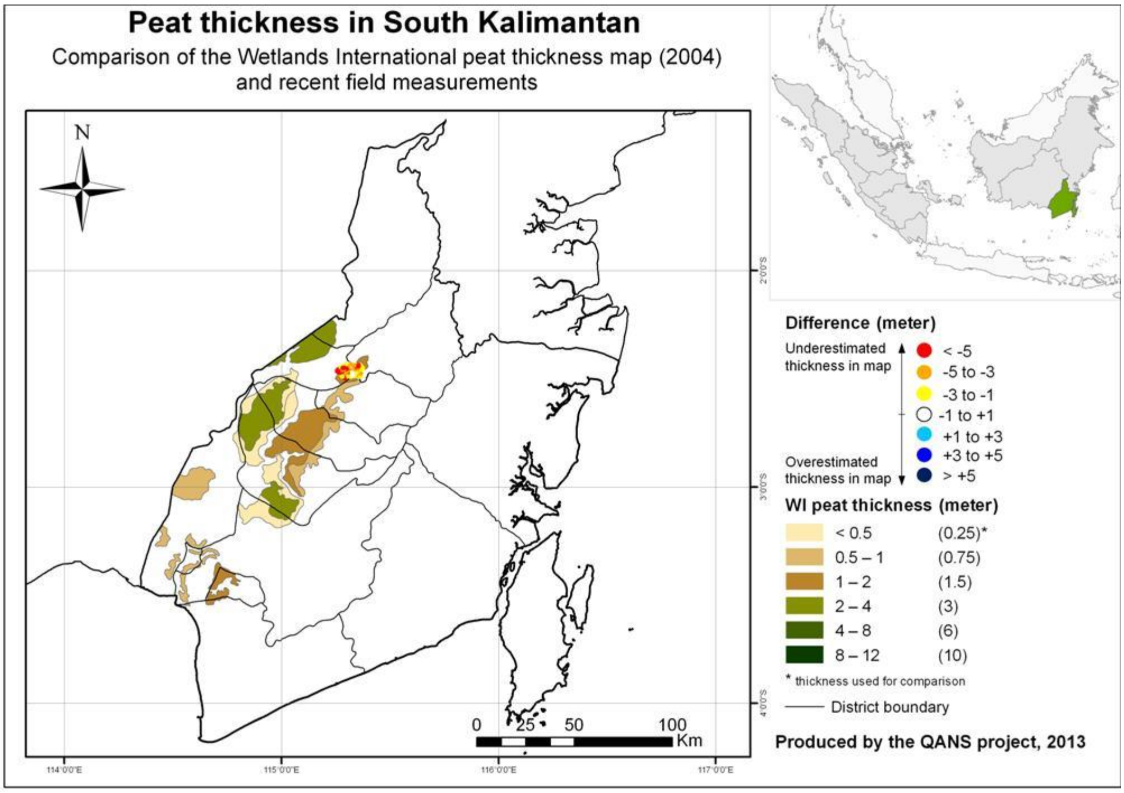

Peat thickness in West Sumatra
Comparison of the BBSDLP peat thickness map (2011) and recent field measurements
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
BBSDLP peat thickness (m)
0.5 – 1 (0.75)*
1 – 2 (1.5)
2 – 3 (2.5)
> 3 (6)
* thickness used for comparison
District boundary
Produced by the QANS project, 2013
0 25 50 100 Km

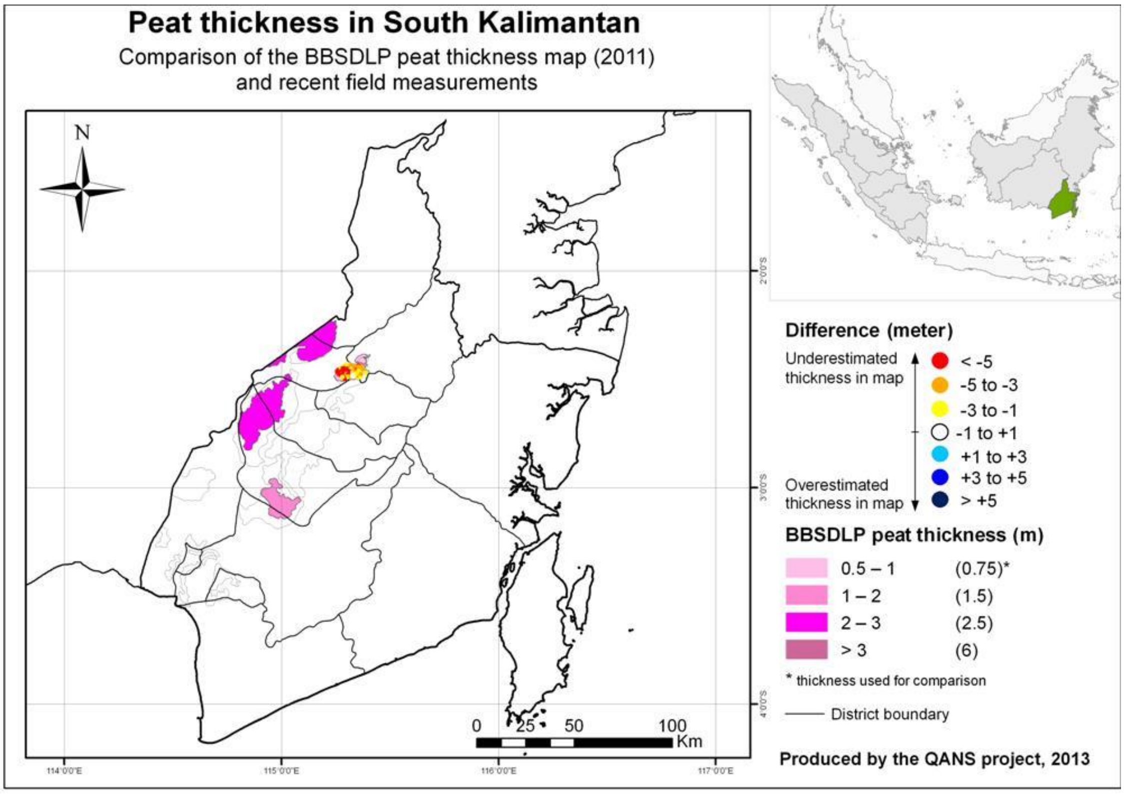

Peat thickness in Central Kalimantan
Comparison of the Wetlands International peat thickness map (2004)
and recent field measurements
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
WI peat thickness (meter)
< 0.5 (0.25)*
0.5 – 1 (0.75)
1 – 2 (1.5)
2 – 4 (3)
4 – 8 (6)
8 – 12 (10)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013


Peat thickness in Central Kalimantan
Comparison of the BBSDLP peat thickness map (2011)
and recent field measurements
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
BBSDLP peat thickness (m)
0.5 – 1 (0.75)*
1 – 2 (1.5)
2 – 3 (2.5)
> 3 (6)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013


Peat thickness in East Kalimantan
Comparison of the Wetlands International peat thickness map (2004)
and recent field measurements
N
0 50 100 200
Km
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
WI peat thickness (meter)
< 0.5 (0.25)*
0.5 – 1 (0.75)
1 – 2 (1.5)
2 – 4 (3)
4 – 8 (6)
8 – 12 (10)
* thickness used for comparison
District boundary
Produced by the QANS project, 2013

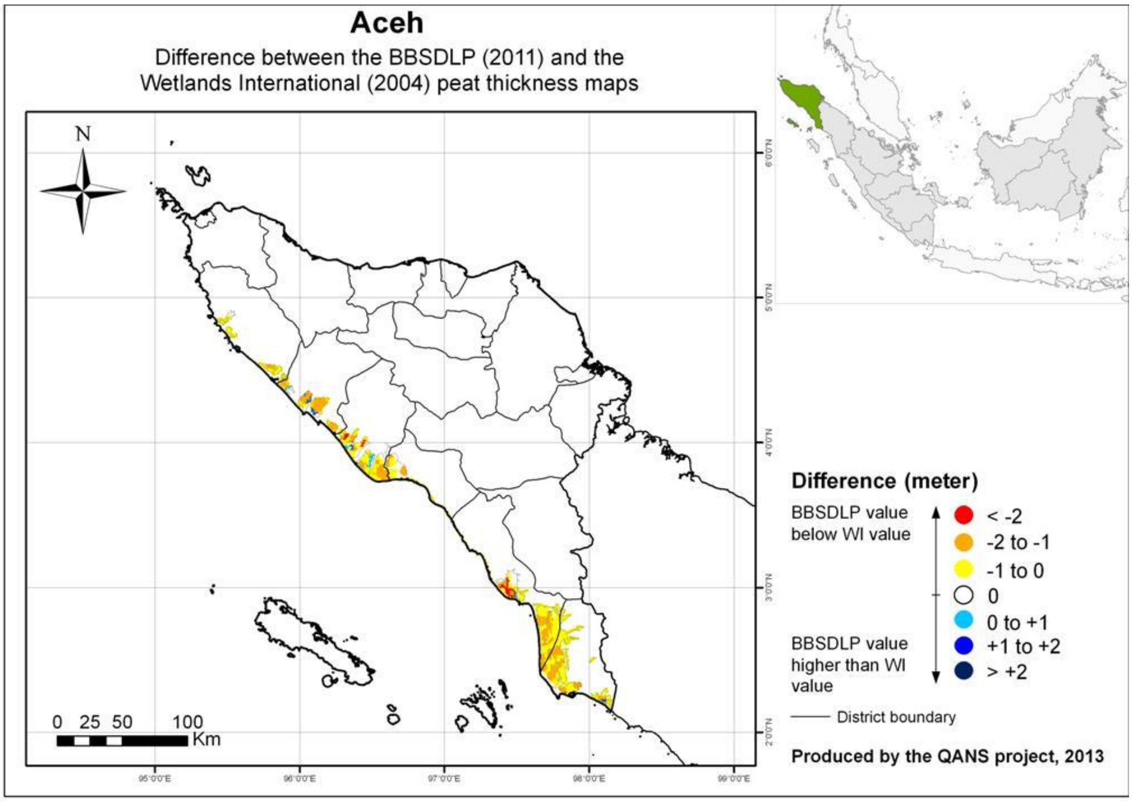

Peat thickness in East Kalimantan
Comparison of the BBSDLP peat thickness map (2011)
and recent field measurements
N
0 50 100 200
Km
Difference (meter)
Underestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
Overestimated thickness in map
BBSDLP peat thickness (m)
0.5 – 1 (0.75)*
1 – 2 (1.5)
2 – 3 (2.5)
> 3 (6)
* thickness used for comparison
District boundary
Produced by the QANS project, 2013

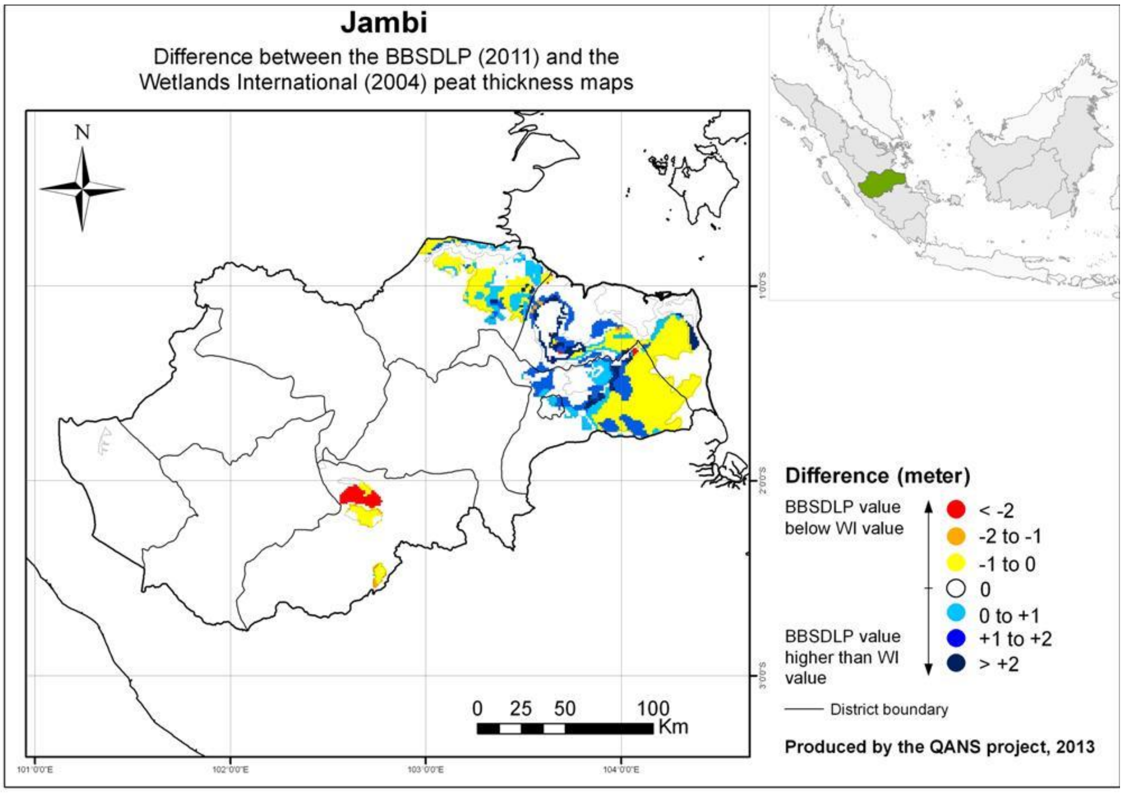

Peat thickness in South Kalimantan
Comparison of the Wetlands International peat thickness map (2004) and recent field measurements
N
Difference (meter)
Underestimated thickness in map
Overestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
WI peat thickness (meter)
< 0.5 (0.25)*
0.5 – 1 (0.75)
1 – 2 (1.5)
2 – 4 (3)
4 – 8 (6)
8 – 12 (10)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013

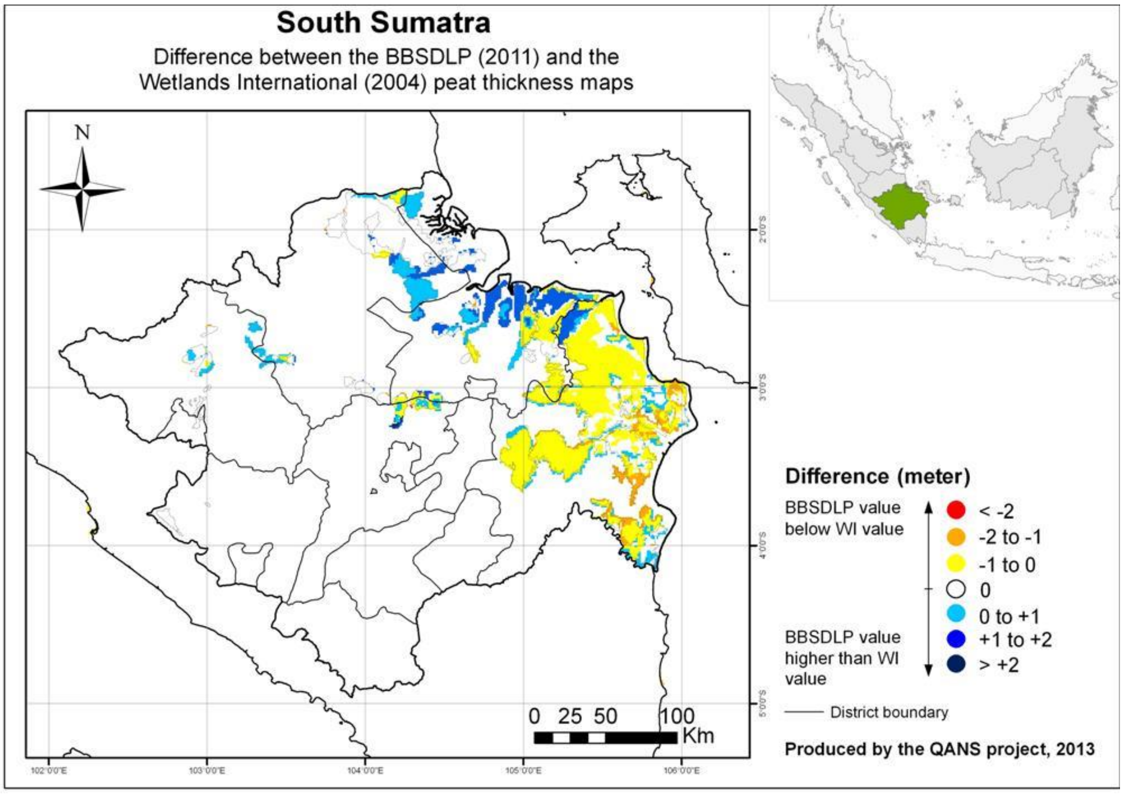

Peat thickness in South Kalimantan
Comparison of the BBSDLP peat thickness map (2011) and recent field measurements
N
Difference (meter)
Underestimated thickness in map
Overestimated thickness in map
< -5
-5 to -3
-3 to -1
-1 to +1
+1 to +3
+3 to +5
> +5
BBSDLP peat thickness (m)
0.5 – 1 (0.75)*
1 – 2 (1.5)
2 – 3 (2.5)
> 3 (6)
* thickness used for comparison
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013

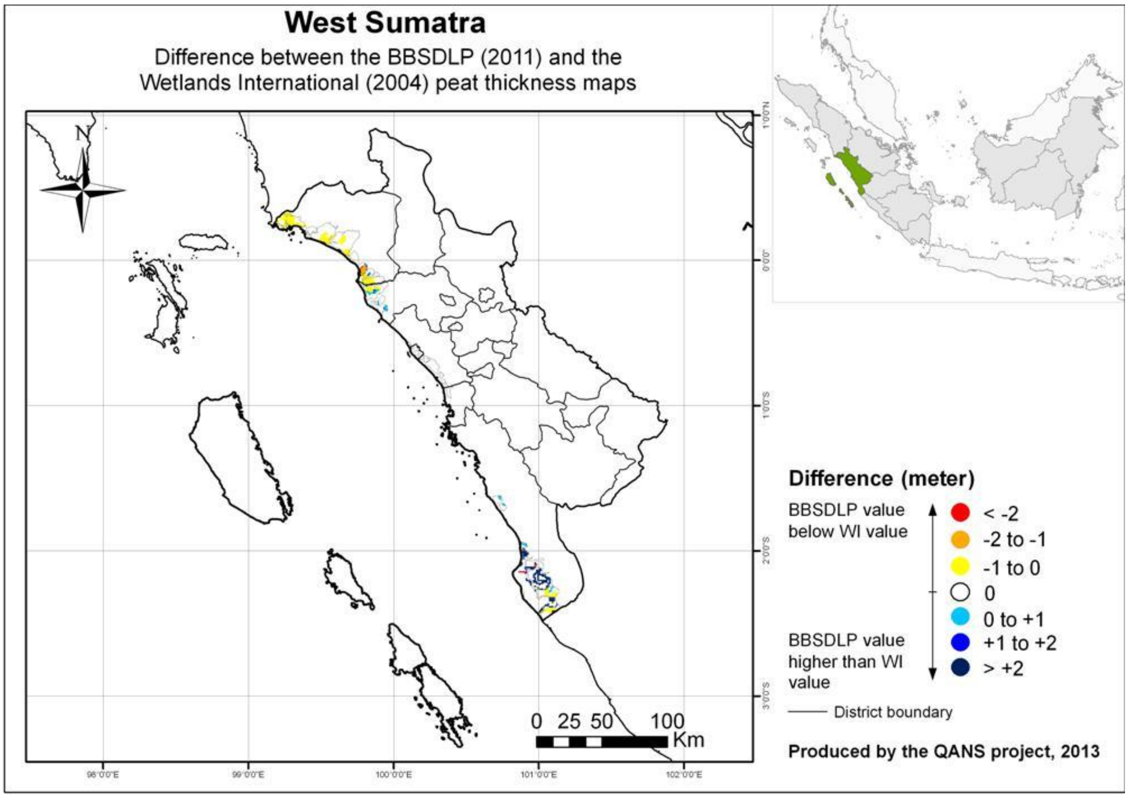
Annex 3 Difference between BBSDLP and Wetlands International peat thickness maps

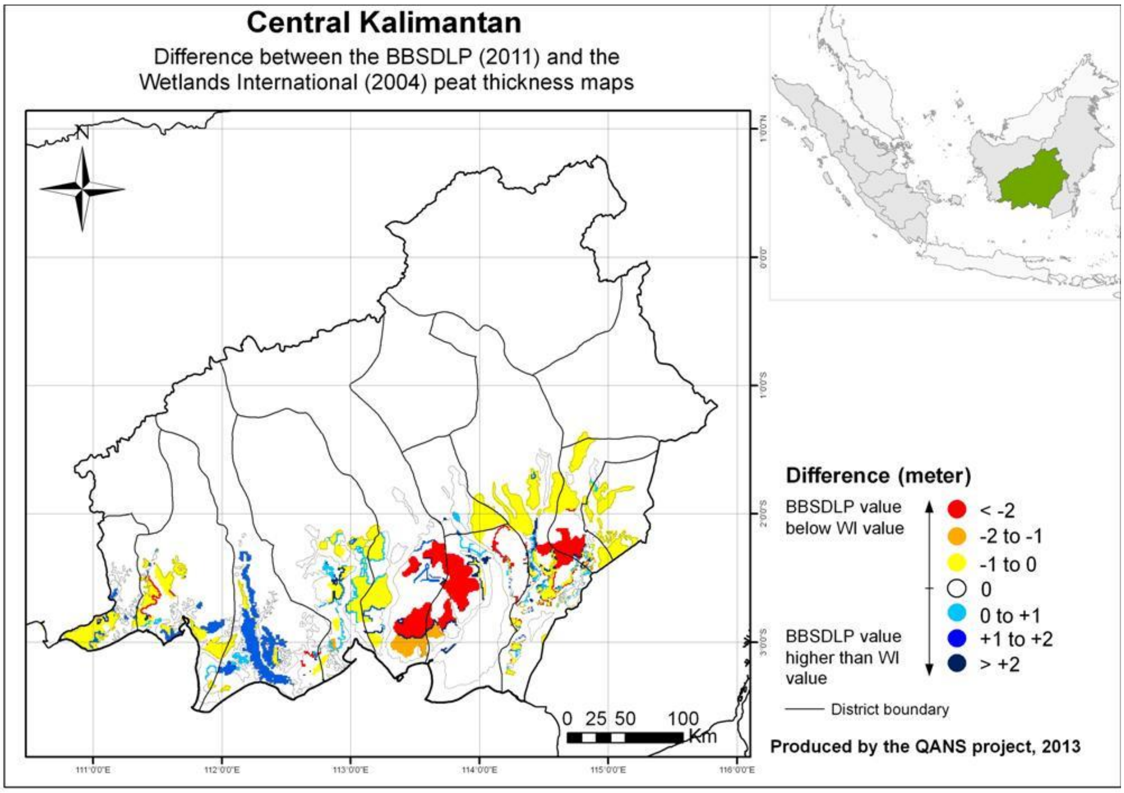
Difference between the BBSDLP and Wetlands International peat thickness maps for Aceh, Jambi, South Sumatra, West Sumatra, Central Kalimantan, East Kalimantan and South Kalimantan. For Riau and West Kalimantan see Figure 7.

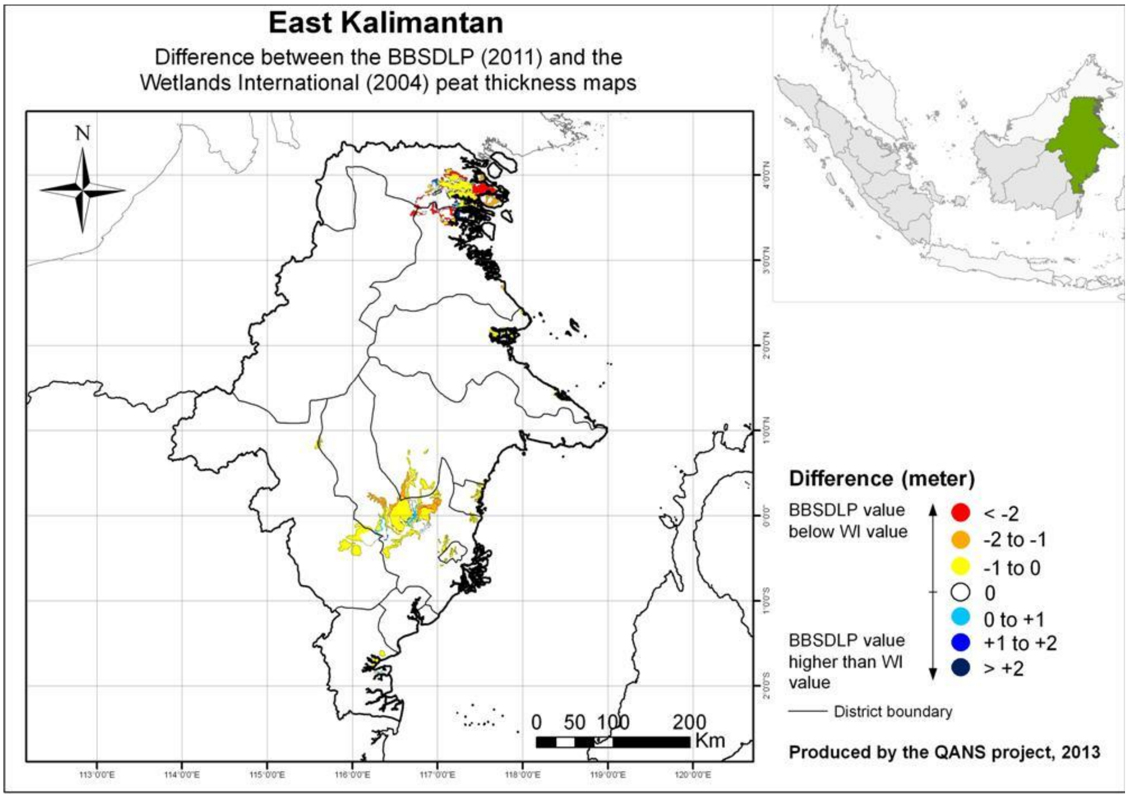


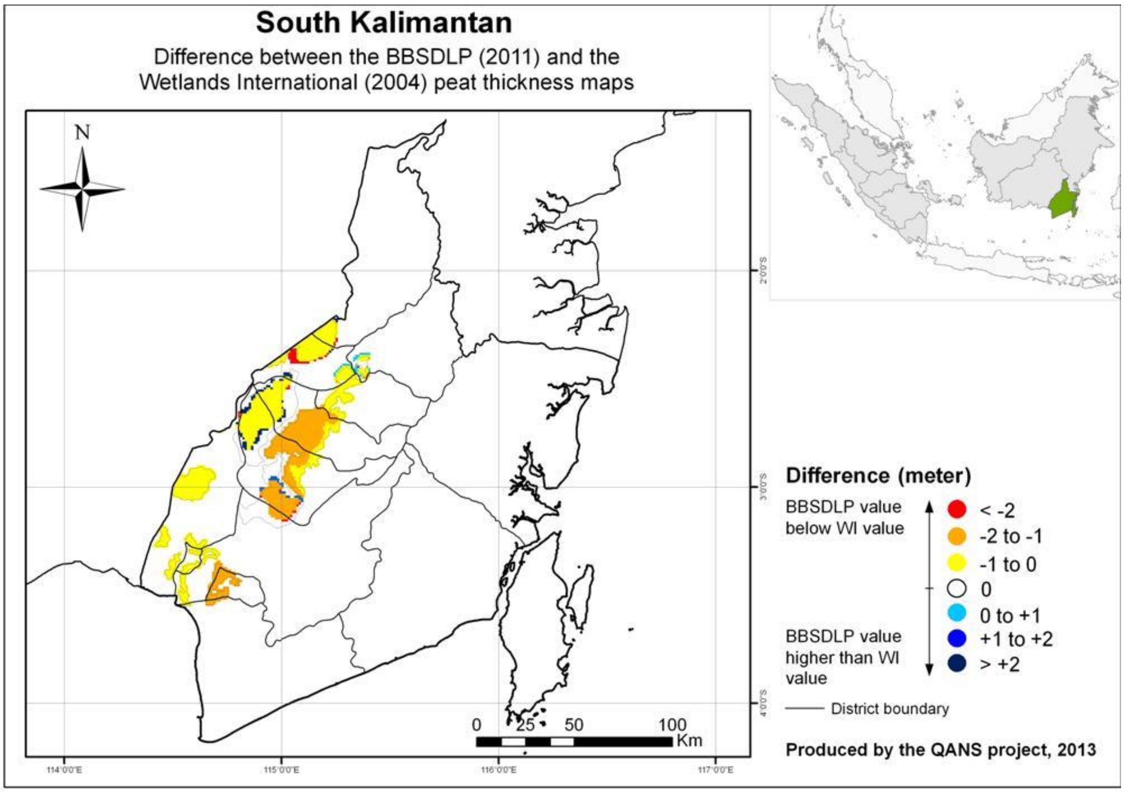

Jambi
Difference between the BBSDLP (2011) and the Wetlands International (2004) peat thickness maps
N
Difference (meter)
BBSDLP value below WI value
< -2
-2 to -1
-1 to 0
0
0 to +1
+1 to +2
> +2
BBSDLP value higher than WI value
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013


South Sumatra
Difference between the BBSDLP (2011) and the Wetlands International (2004) peat thickness maps
N
Difference (meter)
BBSDLP value below WI value
< -2
-2 to -1
-1 to 0
0
0 to +1
+1 to +2
> +2
BBSDLP value higher than WI value
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013


West Sumatra
Difference between the BBSDLP (2011) and the Wetlands International (2004) peat thickness maps
Difference (meter)
BBSDLP value below WI value
BBSDLP value higher than WI value
< -2
-2 to -1
-1 to 0
0
0 to +1
+1 to +2
> +2
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013


Central Kalimantan
Difference between the BBSDLP (2011) and the Wetlands International (2004) peat thickness maps
Difference (meter)
BBSDLP value below WI value
BBSDLP value higher than WI value
< -2
-2 to -1
-1 to 0
0
0 to +1
+1 to +2
> +2
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013


East Kalimantan
Difference between the BBSDLP (2011) and the Wetlands International (2004) peat thickness maps
N
Difference (meter)
BBSDLP value below WI value
< -2
-2 to -1
-1 to 0
0
0 to +1
+1 to +2
> +2
BBSDLP value higher than WI value
District boundary
0 50 100 200 Km
Produced by the QANS project, 2013


South Kalimantan
Difference between the BBSDLP (2011) and the Wetlands International (2004) peat thickness maps
N
Difference (meter)
BBSDLP value below WI value
< -2
-2 to -1
-1 to 0
0
0 to +1
+1 to +2
> +2
BBSDLP value higher than WI value
District boundary
0 25 50 100 Km
Produced by the QANS project, 2013