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LOCATING AND DELINEATING PEATLANDS AND ORGANIC SOILS IN THE TROPICS

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SUMMARY

Deforestation and drainage of organic soils stop their ability to sequester carbon and lead to the emission of huge amounts of greenhouse gases both through microbial oxidation and fire. The development of oil palm plantations is one of the main trigger for clearance and drainage of organic soils in the tropics. Drained peatlands are - even when emissions from peat fires are excluded - responsible for 5% of the global anthropogenic greenhouse gas emissions, which is almost double the amount of CO_2 emissions from aviation (Wetlands International 2015). Rewetting drained peatlands has therefore a large GHG mitigation potential. According to the High Carbon Study (Raison *et al.* 2015; Barthelmes *et al.* 2015), all tropical organic soils with more than 20% soil organic matter or more than 12% soil organic carbon and 15 cm depth of the organic layer should be excluded from development. This study outlines the state-of-the-art information and introduces practical guidance on locating and delineating organic soils (incl. peatlands) in West Africa and Southeast Asia, where expansion of oil palm plantations is expected. Unfortunately, adequate geospatial data on location, extent and land use of peatlands and organic soils are not available and incomplete for West Africa and Southeast Asia. Illustrating examples from Indonesia and Sierra Leone, the use of legacy soil and suitable proxy data (e.g. hydromorphic soils, wetlands, wetland vegetation, depressions, floodplains), and up-to-date remote sensing approaches on different scales will be illustrated to identify organic soils in the Tropics. Mapping for the local (concession) scale needs to be accompanied by a thorough field survey, whereas the indication of large tracks of organic soils as ‗no-go' areas for oil palm plantations at regional scale may be done using legacy data and remote sensing solely.

Keywords: *peatland mapping, tropics, high carbon study, remote sensing, legacy soil maps, proxy*

INTRODUCTION

Current estimates indicate that the total area of tropical peatland is in the range of 30-45 million ha (approximately 10-12% of the total global peatland resource), constituting one of the largest near-surface pools of terrestrial organic carbon (Solomon *et al.* 2007, Sorensen 1993). Deforestation and drainage of peatlands stop their ability to sequester carbon and lead to the emission of huge amounts of greenhouse gases both through microbial oxidation and fire (Page *et al.* 2002, Ballhorn *et al.* 2009, Hooijer *et al.* 2010, 2012). Especially in the tropics, conventional land use systems are degrading land, water and biodiversity on a large scale. Concurrently, the rising global demand for biofuels (e.g. palm oil), raw materials and other exportable agricultural products enhance deforestation (DeFries *et al.* 2010, Foley *et al.* 2011). The establishment of oil palm plantations is one of the main trigger for the development of organic soils and peatlands. Overall, an urgent need exists to identify the location of peatlands and organic soils, to protect them against any drainage, and to rewet already drained areas in order to decrease greenhouse gas emissions and to prevent hazardous peat fires.

The High Carbon Consulting Study 5 (‗Practical guidance on locating and delineating peatlands and other organic soils in the tropics', cf. Barthelmes *et al.* 2015) defined a carbon threshold that automatically excludes all tropical organic soils with more than 20% soil organic matter or more than 12% soil organic carbon and 15 cm depth from the development for oil palm. This approach merely has to identify the presence of a peat layer of 15 cm depth and can refrain from assessing the total carbon stock of peatlands and other organic soils (cf. Raison *et al.* 2015). This study focused on West Africa, Indonesia and Papua New Guinea, where the expansion of oil palm is expected in near future.

Unfortunately, geospatial data on location and extent of peatlands and organic soils is very rare in most countries of the tropics. Also the rapidly developing remote sensing technologies do not manage to fill this gap, because the large diversity of peatlands worldwide and the multitude of land use types prevent the extrapolation of local results to the global scale. High quality remote sensing based peatland mapping use among others LiDAR technology at local scale - that implies high costs. Therefore, continental and global peatland mapping continues to depend on the aggregation of already existing, local and national data (Montanarella 2014). We give the methodology how to derive organic soil maps for sub-national/regional scale and concession/local scale while integrating existing soil and proxy data and using up-to-date remote sensing.

METHODS

The identification of peatlands and organic soils can be conducted while integrating already existing geospatial data (cartography) under consideration of landscape ecological constrains of their genesis, and/or the use of remote sensing technology. The mapping of larger tracks of peatlands and organic soils might rely on cartography and/or remote sensing, whereas the exact delineation of them at local or concession scale needs a sound ground survey.

A - Cartography

The approach is mainly based on the extensive collation of geo-data and other information. Considering the lack of available data on peatland and organic soil distribution it is appropriate to include proxy data, that indicate areas characterized by persisting high water levels (e.g. wetlands, hydromorphic soils, wetlands vegetation) as suitable environments for the development of organic soils (cf. Barthelmes *et al.* 2015).

Spatially explicit soil and proxy information is available in great numbers in open access online archives, e.g.:

1. ISRIC (World Soil Information; http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/indexes/access.htm);

2. JRC (Joint Research Centre; http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/indexes/access.htm;

3. FAO Corporated Document Repository (http://www.fao.org/documents/en/docrep.jsp);

4. SPHAERA (Base de données Sphaera du service Cartographie; http://www.cartographie.ird.fr/sphaera/)

While evaluating the collated data, the understanding of underlying concepts and definitions and the identification of relevant terms is crucial. For example, synonyms for areas with possibly organic soils in West Africa are Marigot, Bas-Fonds, Boli, Fadama, Poto-Poto, Loluda, Vida and Uswalo. Much more terms are relevant if considering divers proxy data (cf. Barthelmes *et al.* 2015). Proxy data that appreciates the landscape ecological constraints of peatland and organic soil occurrence are, e.g. Digital Elevation Models or a Topographic Wetness Index. The available maps often display organic soils or suitable proxy information at small scale or cover only parts of the considered area or country. Therefore, it is necessary to to downscale low resolution information to high resolution organic soil probability maps (using additional proxy data as e.g. wetland and wetland vegetation or topographical maps), and to extrapolate spatially restricted peatland/organic soil information to adjacent areas. These procedures are described in detail in Barthelmes *et al.* (2015). Furthermore, two decision support trees are provided for the identification of peatlands and organic soil areas for different scales while predominantly using legacy maps and available proxy data.

B – Remote Sensing

Since most tropical peatlands are highly inaccessible, field mapping of peatlands is a considerable challenge, at regional, national and global scales (Ballhorn *et al.* 2011, Jaenicke *et al.* 2008). The combination of field measurements and remote sensing could provide map products on peatland extent with an optimal balance of covering a region comprehensively, reasonable accuracy and quantifiable uncertainties (Lawson *et al.* 2014).

Lawson *et al.* (2014) identified four key factors that distinguish tropical peatlands from surrounding terra firme (dry-land) forest and that are detectable with the help of airborne and space born remote sensing data: (a) low diversity of vegetation, (b) distinctive vegetation structure, (c) distinctive topography, and (d) high water tables. Which key features of tropical peatlands can theoretically be detected by which sensor type and which sensor in practice is feasible to detect certain key features is address in Barthelmes *et al.* (2015).

Generally, the optical imagery from medium spatial resolution sensors (e.g. on board the Landsat satellites) has been the primary and most successful tool for peatland mapping. It is recommend to use multiple remote sensing products in combination (including passive and active sensors; ‗Multisensor approach', Lawson *et al.* 2014).

any tropical peatlands are degraded by e.g. drainage, forest clearance, or fire and lose most of their key features for remote sensing based mapping. Therefore, the acquisition of remote sensing data from pre-degradation stages is essential. LiDAR data imply high costs and are generally only available as discrete point measurements or thin stripes of data, rather than a full coverage. To interpolate between LiDAR measurements other data sources are needed (e.g. L-band RADAR and/or field inventory data on forest structure; e.g. Mitchard *et al.* 2012). As with every remote sensing approach, also peatland distribution mapping from remote sensing needs to be validated with ground reference data.

Barthelmes *et al.* (2015) recommend remote sensing approaches to identify peatlands and organic soils at a sub-national / regional scale and to derive peatland and organic soil maps at local/concession scale.

RESULTS

Carthography

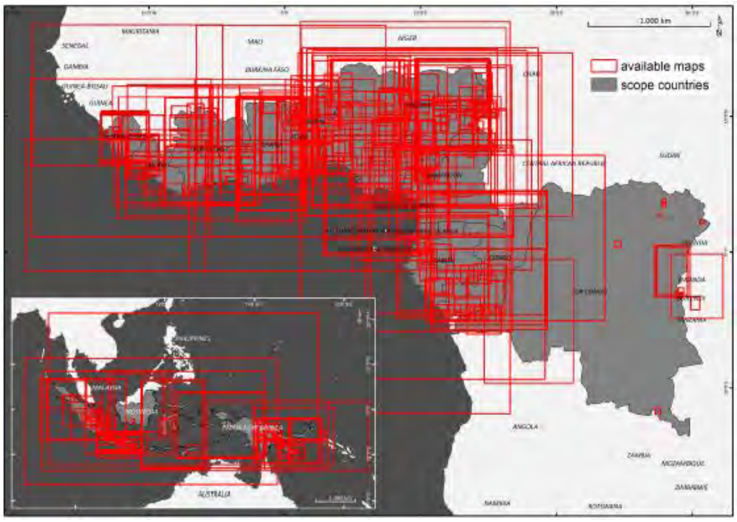

Figure 1: Suitable maps for the indication of organic soils or useful proxies available for West Africa, Indonesia and Papua New Guinea (cf. Barthelmes *et al.* 2015).

A surprisingly large amount of predominantly legacy soil and proxy maps could be collated and analysed.
Figure 1 shows all maps that are useful for the indication of organic soils or suitable proxies as e.g. hydromorphic soil, wetlands, wetland vegetation or inundated areas for West Africa, Indonesia and Papua New Guinea.

A - Mapping example from cartography (Coastal organic soils in Sierra Leone)

Similar to Southeast Asia, organic soils prevail in West Africa along the coastlines in lagoons, river deltas and other estuarine environments. The integration of available data led under use of satellite imagery to the identification of areas with organic soils at sub-national/regional scale. Sierra Leone has undergone a reconnaissance land survey carried out by the FAO in the 1970s. The elaborated map ‗Land Systems o Sierra Leone‘ at scale 1:500,000 indicate land systems with ‗highly organic soils‘ or ‗organic top soils‘ in estuarine swamps and alluvial plains (land systems ‗Tasso‘ and ‗Torma Bum‘; Figure 2A; cf. Barthelmes *et al.* 2015). Figure 2 shows the data integration to derive an organic soil probability map (Figure 2D).

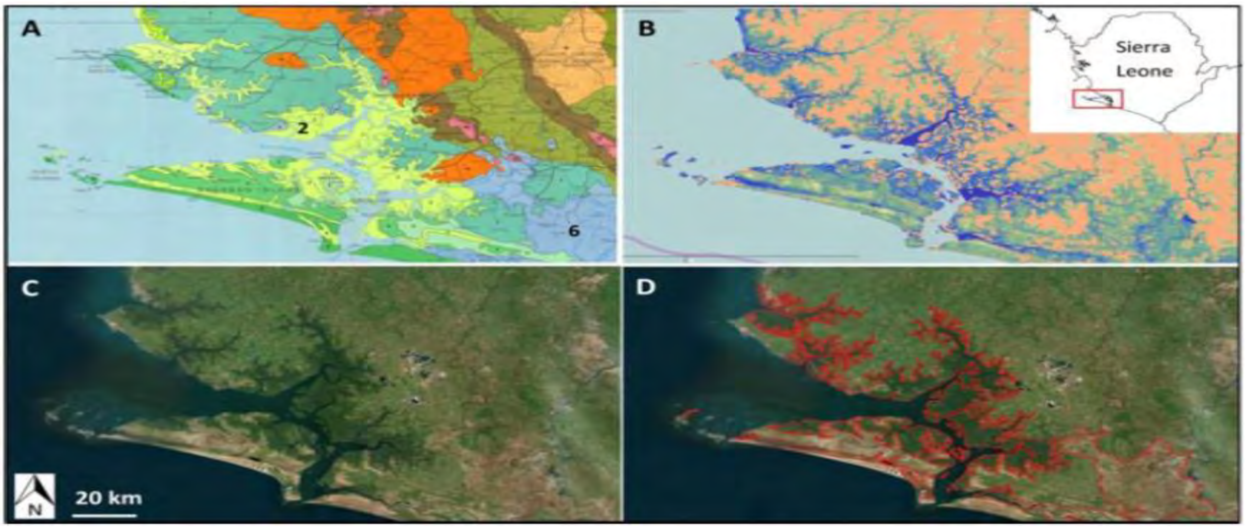

Figure 2: Detail of the coastal lowlands along the Sherbro River Delta: A - land system map with indicated organic soils (signatures ‗2‘ and ‗6‘; Birchall & Bleeker 1980); B - remote sensing derived wetland map (cf. Gumbricht 2012); C - satellite image of the area; d) delineated organic soil map (red).

B - Mapping example from remote sensing

To improve the local accuracy of the Wetland International peatland map (Wahyunto *et al.* 2004) different information sources (airborne LiDAR data, aerial ortho photos, historical satellite imagery and the different land cover maps) were compared visually in an iterative integral approach. This approach not only mapped one peatland key feature but as many as possible. No field data for validation of the mapping results were available.

Figure 3 demonstrates the multisensor approach. The upper three images display Landsat satellite data (bands 5, 4, 3; spatial resolution of 30 m) from a subset of the investigated peatland area in Central Kalimantan (years 1991, 1997 and 2000). The first lower image displays a RapidEye image (bands 3, 2, 1; spatial resolution of 5 m) of the area (year 2010). Superimposed is the Wetland International peatland map (brown outline; Wahyunto *et al.* 2004). These first four images clearly demonstrate the importance of historical imagery as considerable land cover change occurred within this area, which complicates peatland mapping. The second lower figure displays how the use of SRTM elevation data (90 m spatial resolution; lighter grey are areas of higher elevation) can be used to enhance this peatland map (yellow outline). Finally the last figure shows to what detail airborne LiDAR elevation data (DTM; one meter spatial resolution; here also lighter grey represents areas of higher elevation) can contribute in improving this peatland map even more (red outline).

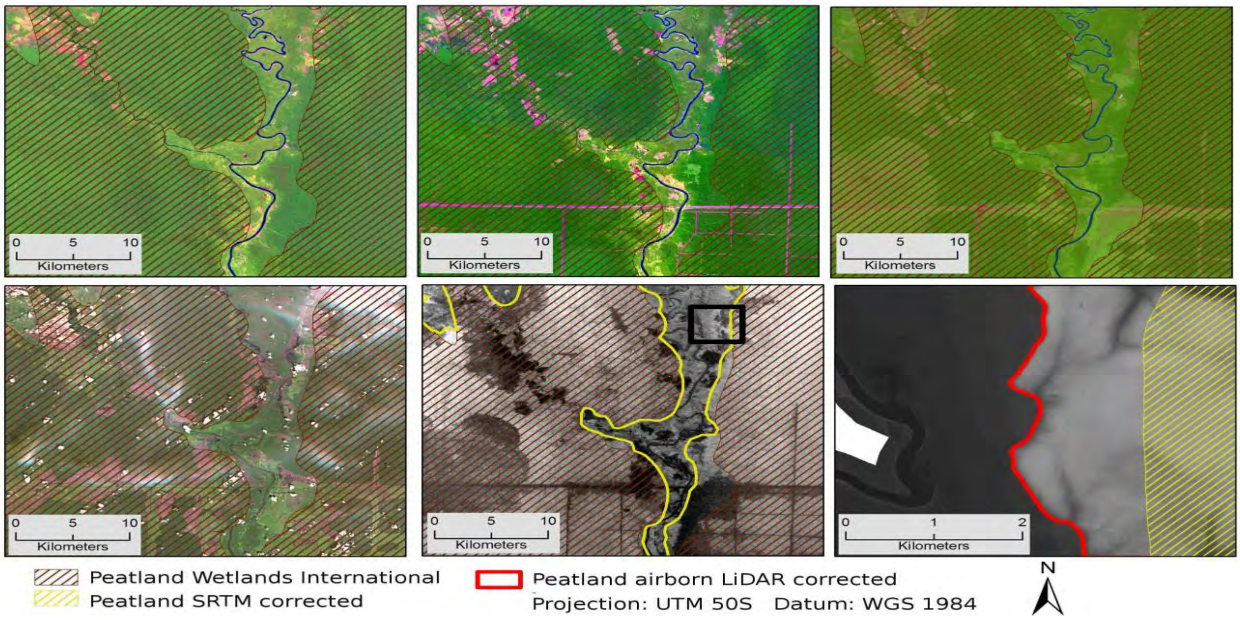

Figure 3: Example of how an existing peatland map (Wetlands International) can be enhanced through the integration of different remote sensing sensors (multi-senor approach), especially airborne LiDAR data.

DISCUSSION

For the identification of peatlands and organic soils with the cartographic approach, it has to be kept in mind that several of the maps are older than 30 years and that organic soil occurrences may have disappeared due to e.g. flooding of reservoirs, or that they may have expanded due to terrestrialization processes in shallow lakes or turned into mineral soils in decades of drainage-based land use. Landscape ecological knowledge of organic soil and peatland constraints and occurrences is needed to interpret these older maps while using modern satellite imagery. The general accuracy of soil and proxy maps provided from online archives is often good, if considering the position of recognizable landmarks as rivers, lakes or mountains in the landscape - which can be assessed using satellite imagery in the GIS software. The maps derived by this method can be regarded as a first indication of areas with high probability of organic soil occurrence. If the background data are reliable, the mapping results are convincing, and organic soils are identified in corresponding landscape settings, this approach can be applied for delineating ‗no-go‘ areas for development at sub-national/regional scale.

To map peatlands and organic soils at local/concession scale the additional use of remote sensing is necessary, at best following the multisensor approach inclusive airborne LiDAR. It is important to note that peatland detection and delineation based on remote sensing data is more or less an iterative process through incorporating different sensors types. The interpreter has to be an expert with a deep background in tropical peatland ecology, have local knowledge of the area under investigation and have a profound understanding of the different remote sensing sensors applied. As with every remote sensing approach, also peatland distribution from remote sensing needs to be validated with ground reference data. Especially in tropical peatlands ground reference data collection is often difficult (accessibility) and expensive. Therefore ground truthing campaigns need to be planned carefully to maximize the output.

CONCLUSION

Increasing land use pressure, growing populations and degradation of agricultural land endanger peatland and organic soil to become developed, especially for oil palm plantations. Therefore, it is necessary to locate them prior drainage and clearance take place. The integration of the huge amount of already existing information like legacy maps on peat, organic soil or suitable proxies enables in many areas of West Africa, Indonesia and Papua New Guinea the identification of larger tracks of organic soils or at least of permanent inundated areas that likely include organic soils. Available remote sensing data and derived tools, like Digital Elevation Models and Topographic Soil Wetness Index enhance the organic soil area delineation, and enables downscaling and extrapolation in case of only small scale maps for a certain area, or their incomplete coverage.

On local/concession scale, the multisensor approach including airborne LiDAR, accompanied by sound field surveys can deliver high quality peatland and organic soils maps. However, cost constraints might hamper the implementation of this approach for assessing extensive tropical lowlands.

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