Tropical Peatland Restoration Report: the Indonesian case

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Tropical Peatland Restoration Report: The Indonesian Case

Berbak Green Prosperity Partnership/ Kemitraan Kesejatheraan Hijau (Kehijau Berbak)

Millennium Challenge Account Indonesia

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5 February 2018

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List of Abbreviations

APL	Areal Penggunaan Lain (non-Forestry government land)
APP	Asia Pulp & Paper (company)
BAU	business as usual
BD	bulk density (property of peat, expresses in g/cm³)
BGPP	Berbak Green Prosperity Programme
BRG	Badan Restorasi Gam but (Indonesian Peatland Restoration Agency)
C	carbon
CH4	methane
CIMTROP	Center for International Cooperation in Sustainable Management of Tropical Peatland (of the University of Palangkaraya, Central Kalimantan)
CKPP	Central Kalimantan Peatland Project (completed in 2009)
cm	centimetres
CO_2	carbon dioxide
COP	Convention of Parties
DOC	dissolved organic matter
DTM	digital terrain model
EMRP	Ex-Mega Rice Project [failed 1 million ha rice scheme in Central Kalimantan on deep peat]
FORDA	Forest Research & Development Agency (aka Puslitbang Kehutanan)
GHG	greenhouse gas
GWL	ground water level
ha	hectare
ICRAF	International Centre for Research in Agroforestry (aka as the World Agroforestry Centre)
IDR	Indonesian Rupiah
IPCC	Intergovernmental Panel on Climate Change
K	potassium
KLHK	Kementrian Lingkungan Hidup & Kehutanan (Ministry of Environment and Forestry)
MCA	Millenium Challenge Account
Mha	million hectares
MoEF	Ministry of Environment & Forestry
n.a.	not applicable
NGO	non-governmental organization
NH_4	ammonium
N_2O	nitrous-oxide
NP	National Park
NTFP	non-timber forest product
P	Phosporous
pF	water retention capacity
PLG	Proyek Lahan Gambut
POC	particulate organic matter
PP	Peraturan Pemerintah (Government regulation)
PROSEA	Plant Resources of South East Asia (a long-running programme)
PSF	peat swamp forest

REALU	Reducing Emissions from All Land Uses (a now completed programme of ICRAF)
RESTORPEAT	Restoration of tropical peatland to promote sustainable use of renewable natural resources
RRR	Rewetting, Revegetation & Revitalisation [approach of BRG]
RSPO	Roundtable on Sustainable Palm Oil
SIPEF	Société Internationale de Plantations et de Finance (Belgian agro-industrial company)
TAHURA OKH	Taman Hutan Raya (Grand Forest Park) Orang Kayo Hitam (located in Jambi)
tC	tons of carbon
tCO_2	tons of carbon dioxide
Tg	teragram (10^{12} grams or a million metric tons)
TOC	total organic matter
TPC	total phenolic content
TRGD	Tim Restorasi Gambut Daerah
TTI	PT Tolan Tiga Indonesia (an oil palm company, member of RSPO and SIPEF)
UGM	University Gajah Mada (in Yogyakarta)
UNFCCC	United Nations Framework Convention on Climate Change
UPTD	Unit Pelaksana Teknis Daerah (Local Technical Implementation Unit)
USD	United States dollars
WTD	water table depth
WWF	World Wide Fund for Nature
ZK	Zona Koleksi (Collection Zone)
ZP	Zona Permanfaatan (Use Zone)

Foreword

As per the Project Implementation Document, BGPP is to assist the national peatland restoration agency (BRG) in managing and planning donor coordination, which includes the channelling of donor funds towards promising avenues of peatland restoration. Via briefing notes, BRG is to be provided with the latest technical updates on best approaches and techniques. However, rather than producing a series of separate briefing notes, the Consultant has chosen to provide these in one document (this report) that covers all areas of rewetting, revegetation and revitalisation.

Indonesia has more than half of the known tropical peatlands in the world, and until fairly recently (the mid-1980s, when the first author began working in Indonesian wetlands) most of these were largely forested and a valuable refuge for lowland wildlife on the lush islands Sumatra and Kalimantan. The logging and subsequent conversion of these forests to commodities such as oil palm and *Acacia* (for pulp) has brought lots of wealth to the country, but this has come at a cost. While the rapid destruction of these habitats has been sad from an ecologist's point of view, overall environmental costs are high. Drainage of these peatlands has led to very significant carbon emissions that become even higher when fires are rampant, especially in El Niño years. These peatland fires also have significant economic and human health costs, and lead to regular political issues with neighbouring countries (Singapore, Malaysia) that are more affected by peat fire smoke and haze than the national capital Jakarta. If the current drainage-based land use continues then the outcome is even bleaker: peat will continue to oxidise and the land will subside until most peatland is no longer drainable and will be too flooded for any further economic use. This problem is already emerging and will extend over vast areas in the coming 30-50 years under a business as usual scenario. Under such circumstances, pumping will not be an option in most cases as rainfall is high (2000-3000 mm per annum in most areas) and the value of extensive tree crops is too low to economically justify pumping.

While the issues are great, the solutions are fairly simple. If the drainage canals are closed and drainage prevented, peat will become wetter and reach a new equilibrium after a number of years, so that emissions are greatly reduced and peat fires will become a rare event. Closing canals in peatland has its challenges, but a lot of experience has been gained over the past 10 years. Re-establishing a tree cover is very useful to keep the newly rewetted peatland moist and the air humid, and the most suitable species to plant in rewetted areas are those belonging to the original peat swamp forest flora. As areas need to contribute to local livelihoods, one may plant useful species that belong to the original peat swamp forest flora that provide economic benefits. Such species have been identified and are being promoted. Alternatives for oil palm and *Acacia* are also likely to be developed on rewetted peat, as the peat swamp forest flora also includes species that combine characteristics of rapid growth and good pulping properties, while others produce edible oils. People are to be part of the solution, and programs to revitalize local communities and livelihoods based on holistic programs that include rewetting and revegetation are being developed.

Although solutions are within easy grasp, various challenges remain. Large companies have invested significantly in their plantations and downstream processing plants, and while they see fires as an issue needing to be tackled, longer term problems such as flooding are beyond the planning horizon of most corporate managers. Villagers may be more inclined to make changes in what they cultivate, but they need to see viable examples as they have too little financial leeway to test untried options. Also, there are legal hurdles as well, as some (e.g. non-timber forest product) options that appear viable are hampered in their development by regulations requiring permits for harvest, handing and trade of these products and impose a heavy tax, all on the assumption that these products have been harvested from natural forests. These challenges lead to pushback and continuation of business as usual, and many ostensibly 'sustainable' ongoing projects on peatland are actually 'business as usual', with suboptimal rewetting and continued planting and cultivation of dryland species. The necessary transition will have to take place, but it will not do so without addressing current impediments.

The straightforward approach outlined above has been embraced by the Indonesian Peat Restoration Agency (Badan Restorasi Gambut or BRG) in its triple-R (RRR) program of Rewetting, Revegetation and Revitalisation. This report is an attempt to assist BRG by summarizing current (scientific) knowledge in these RRR fields. Although contracted via MCA-Indonesia to support BRG, the views and statements made remain the responsibilty of the authors and are not to be seen as the official view of the BRG.

The authors would like to thank Sara A. Thornton of Leicester University, who has just submitted her PhD thesis[1] on blackwater fisheries in Central Kalimantan, for contributing a vast part of the section on peatland fisheries (4.5) in this report. Special thanks also to those who kindly provided comments on various drafts of this report, especially Dr. Sue Page of Leicester University (comments on whole document), Dr. Henk Wösten of Wageningen University and Research (comments on rewetting) and Dr. Kevin Jeanes, freelance environmental consultant (comments on revegetation).

Jakarta, February 2018

Wim Giesen

&

Eli Nur Nirmala Sari

[1] Thornton, S.A. (2017). (Un)tangling the Net, Tackling the Scales and Learning to Fish: An Interdisciplinary Study in Indonesian Borneo. Thesis submitted for the degree of Doctor of Philosophy at the University of Leicester, U.K.

Executive Summary

Over the past 2-3 decades most of Indonesia's peat swamp forests in Sumatra and Kalimantan have largely been logged, drained and converted to plantations or lie idle in a degraded state. While logging and plantations have brought wealth, the transition has come at a cost, and peatland development has led to a significant increase in emissions, and peatland fires that have major economic and health impacts. As drainage leads to peat oxidation[2] and land subsidence, these peatlands are likely to become more and more subject to flooding in the coming decades, potentially leading to a major loss of productive land. To address these issues, the Indonesian President Pak Joko Widodo established the national Peatland Restoration Agency (Badan Restorasi Gambut or BRG) in January 2016. BRG has developed a 3-R approach towards tackling the problem based on a program of rewetting, revegetation and revitalisation. This document aims to summarize current knowledge on each of these 3-R topics.

<u>Rewetting</u>

Anything short of full rewetting (i.e. hydrologically rehabilitating a peatland to a near natural state) means that oxidation will continue. In that respect, current regulations that prescribe retaining 30% of a peat dome in plantation concessions as a source of water in the dry season, and limiting drainage to a maximum ground water table (GWT) level of -40 cm, may contribute to a reduction in fire incidence, but will not stop enhanced carbon emissions or peat oxidation and land subsidence. When peat is drained, it first consolidates and shrinks/compacts, and this leads to an initial subsidence of 1-1.5 m in the first few years. After that biological oxidation remains as a key factor, leading to an average subsidence of about 4 cm per year. Fires lead to increased land subsidence of about 20-30 cm after a first fire and less for subsequent fires. Emissions of drained peat swamp forest are around 4-7 tC/ha.yr and this increases to 11-20 tC/ha.yr if converted to plantations. In Central Kalimantan, fires are linked to GWTs below -20 cm and maintaining a GWT above -5cm may be needed to prevent fires.

Rewetting is carried out by blocking canals, and there are three main methods: i) box dams (i.e. wooden structures filled with sand [or peat] bags, usually with a spillway of -30-50 cm), ii) compacted peat dams, and iii) infilling, in combination with palisades (spaced poles to prevent peat being washed away). Compacted peat dams and infilling require the use of heavy equipment (i.e. excavators) and is usually carried out by plantation companies, while box dams are usually implemented by government agencies, NGOs and local communities. Each method has its pros and cons. Compacted peat dams are significantly cheaper than box dams, all material is available on site (e.g. a borrow pit near the canal), they require little maintenance, lead to full rewetting and last relatively long. However, they can easily be destroyed (e.g. people wanting to re-open waterways) and are not easily passable by boat. Box dams create local employment and allow ready passage of boats. However, they are relatively expensive, take longer to construct, last only 2-5 years, require lots of material that has too be brought in (timber, sand bags), and the spillways means that some drainage continues (to -40cm on average).

[2] In the peat context, oxidation is the term usually used by chemists and soil scientists when describing the process of decomposition of peat whereby it releases CO_2. This process takes place when peat is drained and oxygen is available, and is (largely) carried out by micro-organisms. Throughout this document the term 'peat oxidation' is used but is synonymous with decomposition.

Study is required on effectiveness (in raising water tables) of the canal blocking types, and how long these last as maintenance is often lacking. Effectiveness depends to some extent on the history of drainage; as subsidence is greater closer to canals, the end result after 1-2 decades of drainage are mini-domes between canals, and subsidence will continue even after complete blocking of a canal until a new equilibrium is reached. Deep well establishment does not lead to rewetting of peatland, but can only be regarded as a possible (but not always effective) tool in tackling peat fires. Creating easy modes of access in fully rewetted peatland, as a more sustainable alternative to keeping canals open, need to be tested and tried; possible alternatives include walkways (e.g. wood, compacted peat), rail systems, and large wheeled motorcycles or quads.

Revegetation

Restoring degraded peatland will require establishing a vegetation cover as this will raise humidity, lower temperatures and decrease fire risk. The approach to revegetation depends on the state of degradation that has been reached. If remnants of original peat swamp forest remain, hydrological rehabilitation may be sufficient for the forest to regenerate naturally, provided that the area is protected against logging and fires. However, if few trees remain then enrichment planting will be required as there is little or no seed bank available in peat swamps for natural regeneration. If fires have taken place over most of the area then ecological rehabilitation involving full hydrological rehabilitation (i.e. full rewetting) and replanting of large areas will be required. Depending on the fire history, degree of flooding, and level of disturbance, various combinations of species belonging to the original peat swamp forest flora are available. Adjacent and in protected areas (kawasan konservasi) species that are of ecological importance should also be included in the mix of species.

A common pitfall in peatland areas near communities is continuing with commonly used species such as aloe vera, pineapple, buah naga, coffee, cocoa, durian and so on that are dryland species and require at least some drainage; this is then facilitated by box dams equipped with spillways that lower the GWT to -40 cm or more. This approach is unsustainable (as oxidation, subsidence, fire risks and ultimate flooding continue) and also unnecessary, as viable alternatives based on full rewetting are readily available. Revegetation programs near communities should focus on peat swamp species that can provide economic benefits – studies show that 80+ species are potentially of economic importance, and the cultivation of swamp species on rewetted peat is called paludiculture. Some species such as sago, swamp jelutung, gelam and gemor are well known, while others such as ketapang, tengkawang, kemiri, manggis and daun salam first need to be tried and tested. Most paludiculture species are trees, which will take time before production (e.g. of fruits, nuts, latex) is reached; in the meantime, fast growing herbaceous swamp species could be cultivated in the first years, including purun, kangkung, paré and various pakis species.

Revitalisation

The paludiculture approach described under revegetation is one of the key approaches that should be undertaken in revitalisation programs, as this can be conducted in combination with full rewetting programs. However, much still needs to be done as few examples exist at present and many species need to be tried and tested first. Also, certain paludiculture crops such as swamp jelutung will require further support (as the past market and related value chain has collapsed) in order to redevelop the market, and also for overcoming regulatory barriers (e.g. regulations established to curb harvest from natural forests now prevent cultivation). Harvesting of non-timber forest products from restored or regenerated peat swamp forests may also add to local livelihoods, but developing this will take time as most peat swamp forests are currently under threat and/or severely degraded. Eco-tourism in remaining peat swamp forests provides a limited opportunity for adding to local livelihoods, as the infrastructure for this at present is not well developed and remaining areas are often poorly accessible.

Peat swamp fisheries do present a potentially significant opportunity, both for food production and ornamental fish species (ornamental fish species are abundant in peatland waters). At present, though, many stocks are depleted in these degraded peatland systems; however, once restored, it is expected that the fish populations will bounce back and these could then contribute to local livelihoods. As the use of fire for land preparation has been banned (also in peatland), local communities often struggle to find an alternative. However, a number of trials show that zero burning cultivation of rice (on shallow peat) is possible, using the application of biological decomposers to the cleared vegetation prior to planting (e.g. of rice). Also, these trials indicate that a relatively high production level is possible. The impact on peat emissions and subsidence need to be measured, however, as that has not happened to date. Livestock rearing in pens is another possible avenue, as a range of peatland species can provide palatable and relatively nutritious fodder, although supplementary minerals may need to be provided to prevent deficiencies. Beekeeping also holds potential, especially in combination with widespread revegetation with certain species such as gelam (*Melaleuca cajuputi*), which in other peatland areas (e.g. Mekong Delta, Vietnam) has proven to be successful.

1. Introduction

Indonesia has about 20-21 Mha of peatland (Wahyunto et al. 2003, 2004 & 2006; Page & Rieley 2016) including 13 Mha in Sumatra and Kalimantan (Table 1). Most of these peatlands are near coastal and occur along the east coast of Sumatra and in the southern and western coastal regions of Kalimantan. Indonesian peat soils are characterized by a low pH of 3-5 (surface: 3.1-4.6, subsoil: 3.0-4.2 Yonebayashi et al.1997; 2.9-4.0 Yule 2010) and low nutrient levels (Yonebayashi et al. 1997). These peatlands are relatively young, most having been formed about 5,000-10,000 years before present (Neuzil 1997, Dommain et al. 2011), although some inland peatlands such as at Danau Sentarum NP in West Kalimantan are over 30,000 years old (Anshari et al. 2001). Originally these areas were covered with peat swamp forest (photos 1 & 2), but since the 1980s Western Indonesian forests have been intensively logged and large parts have been drained and converted to other land use or are degraded (Figure 1, photos 3 & 4). Dohong et al. (2017) confirm that the main drivers for peatland degradation in South-East Asia are logging, conversion to industrial plantations, drainage, and recurrent fires. Over the past two decades the main driver has been conversion to oil palm and *Acacia* (pulp) plantations (Miettinen et al. 2016) and by 2015 6.3 Mha of peatland in Western Indonesia had been converted, of which 3.2 Mha for industrial plantations and 3.1 Mha by smallholders (4.8 Mha of these are in Sumatra and 1.5 Mha in Kalimantan). Of the remainder, 2.9 Mha of peatland in Sumatra and Kalimantan is (severely) degraded and deforested, and lies idle (Miettinen et al. 2016).

Table 1 Peatland in Sumatra & Kalimantan (Mha)

	Sumatra	Kalimantan
Wahyunto et al (2003, 2004 & 2006)	7.2	5.77
Hooijer et al (2010)	6.9	5.8
Posa et al (2010)	8.3	6.8
Osaki et al (2016)	6.44	4.78
Miettinen et al 2012b)	7.2	5.87
average	7.2	5.8

Photo 1. Peat swamp forest of Sebangau NP, Central Kalimantan

Measuring more than 500,000 ha, Sebangau NP is the largest peatland protected area in Kalimantan. Prior to gazettal in 2004 (SK.423/Menhut-II/2004) it was widely logged.

Photo W. Giesen (2008)

Photo 2. Primary peat swamp forest in Danau Sentarum NP, Central Kalimantan

The peat swamp forest that extends over 1/6th (20,000 ha) of Danau Sentarum NP is found on the oldest peatland in Indonesia, being dated at >30,000 years BP (Giesen & Anshari 2016).

Photo W. Giesen (2017)

Photo 3. Logging raft on the Siak Kecil River, Riau, Sumatra

The hey days of logging activities in peat swamp forests occurred in the 1980s and early 1990s, when vast amounts of valuable timber were extracted from these forests.

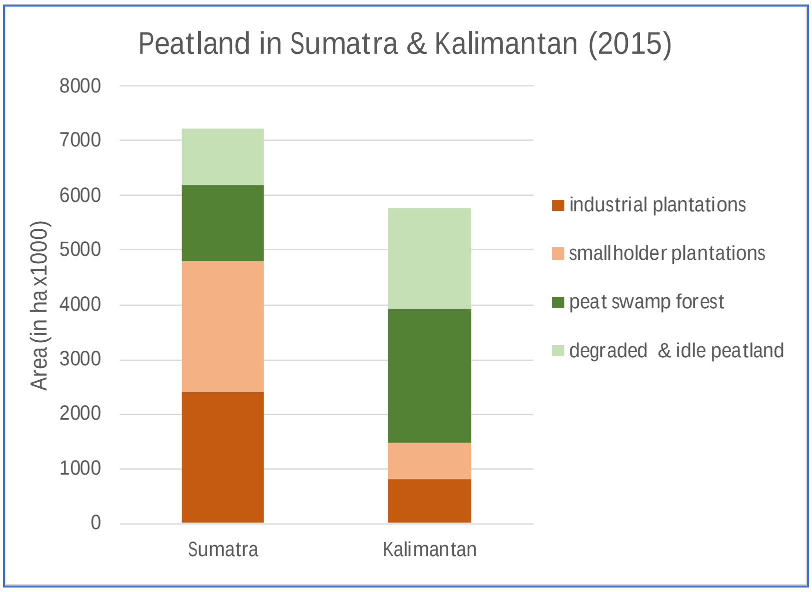
Photo W. Giesen (1991)

Photo 4. Peat swamp forest converted to plantation in South Sumatra

Peat swamp forests have been felled and converted to plantations such as here in South Sumatra, where Acacia has been felled and the land prepared for a subsequent planting.

Photo W. Giesen (2016)

Figure 1 Peatland conversion in Sumatra & Kalimantan



Note: data from Miettinen et al. (2016)

Three basic kinds of organic soil materials are distinguished, namely fibric, hemic and sapric, which are distinguished according to the degree of composition of the original plant material, with fibric being least least decomposed, sapric most decomposed and hemic being intermediate. Bulk density is highest for sapric (>0.2 g/cm³) and lowest for fibric (<0.1 g/cm³)[3]. Indonesian peatland mainy consist of sapric and hemic-sapric peat, rich in lignin (65-93%) and cellulose (<10%), without traces of hemi-cellulose or protein (Sabiham 2010). Peat closer to the coast, i.e. peat with marine influence, have a higher ash and cellulose content, and a higher pH than freshwater peat (Sabiham 2010).

As tropical peat largely consists of water (with 10% organic matter, bulk density of 0.07-0.1 g/cm³; Hooijer et al. 2010, 2011; Jauhiainen et al. 2005), draining of peatland results in peat drying out, and this leads to peat subsidence, oxidation and enhanced carbon emissions (Hooijer et al. 2006, Page et al. 2011). The latter are particularly significant as carbon emissions from drained peatlands contribute as much as 45% of Indonesia's total carbon emissions, surpassing that of deforestation (35% of total; Hooijer et al. 2006).

In the El Niño year 2015, about 81% of the emissions were calculated to originate from peatland fires (Pribadi & Kurata, 2017). As a result, Indonesia is one of the world's leading emitters of carbon (position no. 3-5 depending on timing of calculation; see WRI[4]). In the dry season the desiccation of drained peat increases the risk of fires and this is of particular concern during prolonged El Niño droughts when large areas of peatland may burn. During the latest El Niño in 2015 about 850,000 ha of peatland in Sumatra and Kalimantan was burnt, including in commercial plantations, areas managed by smallholders and in degraded peat landscapes. One of the consequences was that Indonesia's daily carbon emissions in September-October 2015 was greater than the fossil fuel CO_2 release rate of the European Union (Huijnen et al. 2016). Peat smoulders rather than burning completely and hence a lot of smoke is produced. This smoke is a major health hazard and massively contributes to the 'haze' problem that leads to closing of airports, major economic losses and issues with neighbouring countries (Singapore, Malaysia). As a result of the 2015 fires about 500,000 persons were hospitalized for respiratory tract illnesses, economic losses in Indonesia were estimated to total at least USD 16 billion[5] (World Bank 2016) and perhaps as much as USD 47 billion[6], and 11.3 Tg of carbon was released to the atmosphere (Huijnen et al. 2016).

[3] FAO: http://www.fao.org/docrep/x5872e/x5872e07.htm
[4] http://www.wri.org/our-work/project/forests-and-landscapes-indonesia/climate-change-indonesia
[5] http://www.worldbank.org/en/news/feature/2015/12/01/indonesias-fire-and-haze-crisis
[6] http://www.straitstimes.com/asia/47b-indonesia-counts-costs-of-haze

In response to the damaging 2015 peatland fires, the National Peatland Restoration Agency (*Badan Restorasi Gambut* or BRG) was established by Presidential Decree in January 2016 (PerPres No. 1/2016), with the mandate to coordinate and facilitate the restoration[7] of 2.0 Mha of degraded peatland in a period of 5 years (2016-2021). In its peatland restoration efforts BRG applies three integrated types of intervention, namely rewetting, revegetation and the revitalization of livelihoods (the 'RRR approach').

Part of the "Support to BRG" component of the MCA-Indonesia funded Berbak Green Prosperity Programme (BGPP) project consists of provision of training to TRGD (*Tim Restorasi Gambut Daerah*) members in six of the seven targeted peatland provinces (Papua is excluded). This present report is intended as input to this training programme, and will form part of knowledge management and capacity building in general. This report follows the RRR approach, with three chapters covering rewetting, revegetation and revitalisation. Each chapter provides a description of common mistakes and information that is incorrect, followed by a summary of what is known and proven, along with best practices, to the best of our knowledge. Where appropriate, case studies and real life examples are provided, and each section ends with a summary of gaps in our knowledge, indicating where further study is required.

There remains a need, both within BRG and the Government of Indonesia, to define when a peatland area can be regarded as 'restored'. Degraded peatland cannot (on a human timescale) really be restored, only rehabilitated to an improved level that this is as 'near natural' as possible. This is because once drainage has occurred, peat has been lost (e.g. to oxidation) and subsidence has occurred, and this cannot suddenly reappear. Peat formation takes time, so once rehabilitated, it may restore on a timescale of at least many hundreds of years, if not longer. Rehabilitating degraded peatland to a 'near natural' state can be defined as restoring a more or less natural hydrology and establishing a vegetation cover to protect it; i.e. a tree cover (not sedges/ferns) that will lower fire risks, increase biodiversity, and perhaps bring socio-economic benefits (e.g. via agroforestry or paludiculture).

In a narrow sense, one may call a rehabilitated peatland as 'near natural' as possible if you completely rewet it, replant it with tree seedlings (e.g. where no parent trees remain nearby as a source of seed), and wait a few (minimal 5-10) years until you have some kind of forest/tree cover. However, in many cases you cannot fully rewet, for example, in *daerah budidaya* where you will have groundwater levels of -40cm due to spillways in canal blocks, and so on. Also, revegetation is very expensive and you cannot wait until you have a forest cover, as even with fast growing pioneer species this can take at least 5-10 years. In terms of 'physical restoration criteria', we may therefore need to recognize categories 'fully restored', 'partially restored' and 'not restored', with the following criteria:

i. Fully restored: near natural groundwater levels, plus assisted revegetation where needed (cover is underway and appears guaranteed)
ii. Partially restored (transitional stage): partially raised groundwater levels (to -40cm) with (some) assisted revegetation if needed.
iii. Not restored: areas with groundwater levels (well) below -40cm, areas devoid of tree cover.

Note that this only concerns physicial restoration: Revitalisation, as a third criteria for restoration, remains more elusive and in many cases may take many years after physical restoration has been achieved.

[7] Habitat restoration means restoring back to an original state; in degraded peatlands this is, strictly speaking, not possible as in most cases peat has been lost due to oxidation following drainage, and the best one can hope for achieving is habitat rehabilitation. However, as 'restoration' is the most commonly used and understood term, it will be used in this report rather than 'rehabilitation'.

2. Rewetting

Rewetting is defined as the raising of ground wate
r levels in drained peatland. In order to preserve peat this rewetting should result in a peat hydrology that is as "near natural" as possible, but there are pressures from various sides (but especially the plantation industry) to keep ground water levels low. The sections below describe the common pitfalls (2.1), discusses drainage and subsidence issues (2.2), flooding (2.3), carbon emissions in drained peat (2.4), fires, peat loss and carbon emissions (2.5), rewetting approaches (2.6) and knowledge gaps (2.7). Best practices are summarised where action is required or prescribed.

2.1 Common pitfalls re rewetting

Eco-hydro model

Peatland policies in Indonesia have been strongly influenced by the so-called "eko-hidro" approach, a peatland management model developed (but now publicly disavowed) by the pulp and paper company Asia Pacific Resources International Limited (APRIL) with large concessions in peatlands. The "eko-hidro" model was claimed to provide a sustainable form of drainage-based peatland management and consists of three elements:

1) A core conservation area on top of peat domes covering roughly 30 % of the peat area. This conservation area would operate as a natural 'water tower' that would help keep water levels in the lower-lying plantations from falling too low in the dry season.
2) A controlled drainage system with water levels in plantations managed at between 0.5 to 0.8 m below the peat surface to minimize peat loss and thereby reduce carbon emissions and land subsidence.
3) Buffer zones between plantations and conservation forest, of 1.2 to 1.6 km wide, where water levels are kept at a progressively higher level from the plantation to the forest.

The management prescription to protect 30 percent of the peatland landscape as proposed by 'eko-hidro' also appears in the 2014 Government Regulation for the protection and management of peatland ecosystems (PP71/2014). According to Wetlands International and Tropenbos (2016), the basis for this appears to be flawed, for the following reasons:

- Flow from conservation areas (with a size ±30% of dome) yields <5% of the water volume required to significantly mitigate the fall in dry season water levels in surrounding plantations, and a much larger part of the peatland must be protected to meet the goal of this approach.
- Using the conservation area as a source of water for the production area will have a major impact on peat and forest health and compromise the 'conservation' status of the forest.

40 cm drainage level

A level of 40 cm of drainage in peatland is prescribed in Government Regulations (PP71/2014 and PP57/2016), and land use managers are required not to drain to levels below this depth, from the peat surface. The goal of this policy is (at least in part) to prevent or reduce the risk of extensive land fires. If this level of drainage is exceeded, then the peat land is considered damaged and the peat land user is obliged to restore the affected peat land. In practice, draining to -40 cm means that in dry seasons water levels will be well below this level (possibly well over 1.0 m below the surface) dependent on position in the peat landscape. The basis for setting drainage to -40 cm is a pragmatic one, but there are various issues. Firstly, while in natural peat swamp forests groundwater levels may drop to -40 cm or lower during the dry season, this is a lowest level attained under natural circumstances, while PP71 sets this as a target that will often not be achieved (in dry months). Secondly, groundwater levels of below -40 cm (i.e. >40 cm below the surface of the peat) have been linked to increased fire risks (e.g. Wösten et al.2008); this seems accurate, but the relationship between degree of drainage and soil moisture (as expressed in pF curves; see 4.2) depends on the type of peat (sapric, hemic, fibric) and is therefore site specific, and the relationship found by Wösten et al. (2008) was for one location only (Sebangau NP, Central Kalimantan); in fact, it was a 'modelled' relationship and not based on field data.

Less than 100% rewetting

Anything less than full rewetting – whereby the natural hydrology[8] of a peatland is restored as much as possible – will mean that peat subsidence and enhanced carbon emissions will continue. At best, raising water levels from -65-80 cm to -40 cm or using the 'eko-hidro' approach will slow down the rate of peat loss, but that may not amount to a significant improvement. Calculations show that raising water tables in *Acacia* plantations in the Kampar Peninsula to -40 cm reduces subsidence by only 26% (Wetlands International & Tropenbos 2016). As worded by Evers et al.(2017): "Current research clearly shows that the actual debate should be focused not on how to develop drainage-based plantations sustainably, but on whether the sustainable conversion to drainage-based systems is possible at all."

Pumping of groundwater

The pumping of groundwater using either portable or fixed pumps in peatland areas is often regarded as a form of 'rewetting' of peat. However, while this approach can certainly play a role in degraded peatland, especially when extinguishing fires (albeit not without risk), the overall impact is not that of rewetting but a vertical recirculation of water (see deep tubewells 2.7.2). There is no impact on oxidation not associated with fires, and subsidence will continue unabated.

Both conservation and drainage based agriculture on the same peat dome

Officially, all peat with a depth of 3m of more is protected – that means that peat with depths of less than 3m can legally be developed where this is allowed by land status (e.g. in APL areas). This leads to practices whereby centres of domes may be protected, but the perimeter can be legally drained and developed. Due to high hydraulic conductivity of tropical peatlands (Box 1) it is wiser to manage peat domes as single hydrological units and treat the edges of these domes (with peat depths <3m) accordingly, i.e. acknowledging that they are part of the dome and cannot be drained without impunity. Using the concept developed over the past 5-10 years, these dome edges are to be termed "adapted management zones" and their hydrological management is to be such that it does not affect the overall dome.

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[8] In a natural peat swamp forest the hydrology is such that ground water levels may drop to -75cm in the dry months to +20 cm in the wet months (Takahashi & Yonetani 1997).

Box 1. Hydraulic conductivity of tropical peat

Tropical peatlands have a highly saturated hydraulic conductivity of approximately 30 m/day[9], which is due to the relatively coarse textural nature of the often little decomposed peat material (Wösten et al. 2008). This hydraulic characteristic of tropical peatlands makes it very difficult to combine peatland conservation (i.e. without any drainage) with agricultural use of peatlands that requires drainage within the same hydrological unit. These contrasting drainage requirements call for a separation of the conservation and agricultural function of peatlands, preferably in independent hydrological units. Combining the conservation and agricultural function in the same hydrological unit will lead to suboptimal conditions for both functions (pers. comm. H. Wösten 2017). In a study in Panama, Baird et al. (2016) found that ombrotrophic tropical peat domes have unexpectedly high permeability, similar to that of gravel (varying from 8m to several hundred metres per day). They also found that high permeability has little effect on natural peat dome water tables because of low hydraulic gradients, and in these areas flow is largely controlled by surface topography. In contrast, the impact on drained peat domes is high as the gradients are steep and almost 100% of rainfall leaves the site via subsurface flow.

Peat compaction

Peat compaction is promoted by some (notably in Sarawak) as improving conditions in oil palm plantations, and there are indeed advantages such as increased soil moisture content and improved rooting stability for plantation crops. However, this approach also results in higher GHG emissions as there is more peat carbon in the oxic zone, and it is likely to also lead to higher losses of DOC. Compacted peat has a higher bulk density (BD) than non-compacted peat, and studies indicate a strong correlation between BD and methane emissions when the peat burns, i.e. the higher the BD the higher the methane emission; there is also a similar correlation between BD and carbon monoxide, but this is not as pronounced (Smith et al., 2017).

2.2 Drainage & subsidence

When peat is drained it will subside due to a combination of three processes: consolidation, compaction(/shrinkage) and oxidation (Wösten et al. 1997, Jauhiainen et al. 2011).

Consolidation: the compression of saturated peat below the water table owing to loss of buoyancy of the top peat, increasing the strain on the peat below. Primary consolidation is caused by loss of water from pores in the peat; it occurs rapidly when groundwater is quickly removed, especially where a dense drainage system is implemented in peat of high permeability. Secondary consolidation is a function of the resistance of the solid peat material itself to compression; this is a slow process that makes up only a small fraction of total consolidation (Hooijer et al. 2012).

Compaction and shrinkage: volume reduction of peat in the aerated zone above the water table depth (WTD). Compaction results from the pressure applied on the peat surface by heavy equipment; shrinkage occurs through contraction of organic fibres when drying (Hooijer et al. 2012). In practice, the two cannot be separated, and the net result is the volume reduction of the peat above the WTD and an increase in the soil bulk density (BD). In the drained layer, BD can be 0.1-0.15 g/cm^3 while below the WTD this averages at 0.07-0.08 g/cm^3 (Couwenberg & Hooijer 2013). Oxidation causes subsidence of peat above the WTD due to the loss of organic matter through decomposition (by bacteria, actinomyces & fungi), fires, and losses as dissolved or solid organic matter[10] (DOC and POC; see box 2; Hergoualc'h and Verchot 2011, Hooijer et al. 2012, Farmer et al. 2013, Couwenberg & Hooijer 2013). Of the three processes contributing to subsidence, only oxidation results in GHG emissions into the atmosphere.

[9] Simply put, this means that water moves horizontally through a peat layer at an average rate of 30 metres per day.

[10] These losses as POC and DOC can be treated as (slightly delayed) oxidation; total amounts are significant, and these are exported via fluvial processes to coastal waters where they are rapidly oxidised (see Box 1).

Box 2. DOC and POC fluxes from peatland

A further complication is the fairly recent realization that soluble and physical removal of carbon (as dissolved organic matter DOC or particulate organic matter POC) via flowing water (surface or groundwater) also plays a role in peatland. DOC exports via blackwater rivers can be significant and the Siak River in Riau, for example, with DOC concentrations from 560-2594 mmol/litre was calculated to export 0.3 Tg C/year (Baum et al. 2007). Increasing temperatures may lead to a rise in DOC exports, and in the UK a 65% increase in DOC concentration was found in waters draining from peatland from 1988-2000 (Freeman et al. 2001). DOC leaching from intact peat swamp forest (PSF) derives mainly from recent primary production, whilst DOC from disturbed PSF is predominantly comprised of much older (centuries to millennia) carbon from deep within the peat column (Moore et al. 2013). TOC (i.e. POC and DOC) losses from disturbed peatland were 88-105 gC/m².year, while from intact peatland the loss was 63 gC/m².year (Moore et al. 2013). Including fluvial losses, carbon losses resulted in a 22% higher estimate than was previously inferred from gaseous exchange measurements alone (Moore et al. 2013). However, Rixen et al. (2016) determined that 38% of DOC originated from decomposing peat in degraded peatland, while 62% originated from decomposition of labile leaf matter of secondary vegetation. They also found that DOC leaching from degraded and drained peatland under secondary vegetation increased nearly threefold, from 62 to 183 gC/m².yr. DOC draining from degraded peatland can lead to oxygen deficiencies in nearby blackwater streams. DOC and POC exported to the sea via blackwater streams is likely to be rapidly oxidised and therefore contributes to overall carbon emissions (Freeman et al. 2001, Moore et al. 2013). Wit et al. (2015), however, show that river outgassing fluxes in Southeast Asian rivers (including Musi, Batanghari, Siak & Indragiri on Sumatra) are moderate and suggest that 53.3±6.5% of carbon entering the freshwater system is decomposed and emitted back to the atmosphere as CO_2, which is in line with the 5th Assessment Intergovernmental Panel on Climate Change/IPCC report (2013). This means that just over half is (rapidly) oxidised and that the rest is assimilated or otherwise trapped.

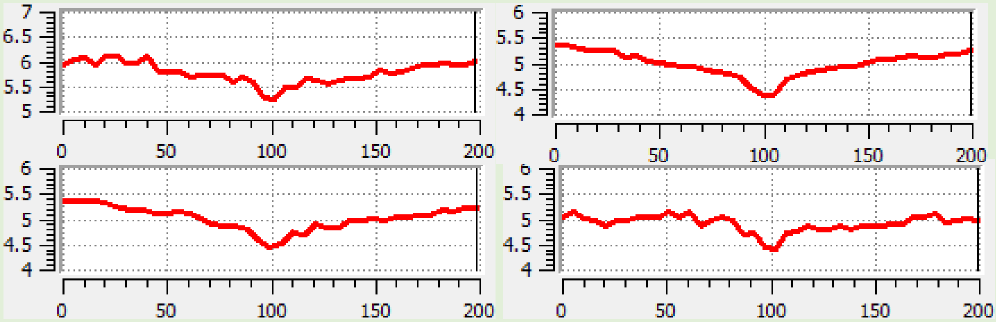
Combined, consolidation, compaction/shrinkage and oxidation result in an initial subsidence of 1-1.5 metres in the first few years following drainage. Consolidation and compaction taper off after about five years, and the relative contribution of oxidation to subsidence increases, with subsidence averaging at about 4 cm per year (Table 2). The subsidence rate also depends on the degree of drainage, and Wösten and Ritzema (2001) provide the following relationship for this that holds following the initial (2-3) years of consolidation: subsidence rate (cm/year) = 0.1 x water table depth (in cm). In peatland areas with a grid of drainage canals subsidence is found to be greatest nearest the canals and the end result can be a series of 'mini-domes' with highest levels in the middle of each grid block (see Box 3).

Oxidation (mainly biological) contributes less to subsidence during the first few years of drainage (45% according to Farmer et al. 2013), but increases to 60-75% after five years of drainage (Wösten et al. 1997, Hooijer et al. 2012, Farmer et al. 2013), increasing to 92% after 18 years of drainage (Hooijer et al. 2012, Farmer et al. 2013). Itoh et al. (2017) measured oxidative peat decomposition in peatland with various levels of disturbance and found that decomposition was determined both by groundwater levels and the type of disturbance (e.g. heavily drained PSF, drained and burned ex-PSF). The differences they found in the relationship between peat decomposition and groundwater level indicate that separate estimations are required for each type of land. Anshari et al. (2010) found that as peat was drained and degraded by logging and/or converted (to agriculture or oil palm), pH, dry bulk density and total nitrogen of peat all tend to increase, while water content, loss on ignition and total organic carbon tended to be more constant.

[Note: The initial subsidence phase dominated by physical processes (consolidation and compaction/shrinkage) is often called primary subsidence, while the following phase dominated by biological oxidation is often called secondary subsidence.]

Box 3. Drained peatland 'mini-domes'

In peatland areas with a grid of drainage canals such as in the Taman Hutan Raya (Tahura) Orang Kayo Hitam to the west of Berbak NP in Jambi, Sumatra, subsidence is found to be highest close to the canals and decreases with increasing distance. The end result can be a a series of 'mini-domes' with highest levels in the middle of each grid block between canals. Below are a number of cross-sections across canals in the Tahura (distances and heights are in metres). In these examples, the height difference can be as much as 1m over a distance of 100m, over a period of about 20-25 years following the start of drainage.



Adapted from a presentation by Deltares (2016); y-axis indicate peat height in metres; x-axis indicates horizontal distance in metres

Table 2 Subsidence in South East Asian peatland

References	Consolidation & compaction (cm)	Longer term subsidence (cm per year)	Notes
Radjagukguk (1997)	not mentioned	2-5	"...immediately after drainage and clearing, a relatively rapid subsidence of the peat layers generally occurs, subsequently slowing down to 2-5 cm per year."
Wösten et al. (1997)	20-50 (initially per year)	2.0-4.6	Malaysian peat swamps. Subsidence up to 20-50 cm/year is possible for first years prior to 1960; from 1960-1974 there is an average loss of about 13 cm/year; followed by a period (1974-1988) with an average subsidence of 4.6 cm/year, while more recent subsidence (post 1988) averaged at 2.0 cm/year.
Wösten & Ritzema (2001)	100 in first 2 years	5	100 cm in first two years is because of consolidation, after that 5.0 cm/year in years 3-10 due to combination of consolidation, shrinkage and oxidation. Subsidence (in cm/yr) = 0.1 x water table depth (in cm)
Dradjad et al. (2003)	shrinkage 0.5-2.2 cm / year	2.5-5.3	Highly variable, from 1-9.7 cm/year; measurements in South Kalimantan, from 1972-74 show 5.5 cm/year
Hooijer et al. (2012)	142 cm in first 5 yrs	5	After 142 cm loss in first five years this stabilizes at around 5cm per year for subsequent years; after 5 years of drainage 75% of cumulative subsidence was caused by peat oxidation, while after 18 years this was 92 %.
Couwenberg & Hooijer (2013)	not mentioned	4.2	Oil palm and Acacia plantations that had been drained for 5–19 years
Wakhid et al. (2016)	1.5 cm due to oxidation	5.96	Rubber plantation in Jabiren, Central Kalimantan

2.3 Flooding in peatland

While peatland may increasingly be flooded due to waters entering these areas from rivers with degraded/deforested watersheds (e.g. peatlands adjacent the lower Batanghari/Kumpeh rivers in Jambi, Sumatra; see Box 4), of major concern is the flooding of peatland due to peat subsidence. The two processes often occur simultaneously, with one exacerbating the impacts of the other. Flooding is most readily observed along blackwater rivers in peatlands that have been affected by fires. The string of lakes along the Siak Kecil River in Riau in the Giam-Siak Kecil Biosphere Reserve have developed after burning had removed (part of) the peat layer nearest to the river (Giesen and van Balen, 1991). This feature is surprisingly old as topographic maps dating from the late 19th century also display the same string of lakes. More recently, similar lakes have developed along the Air Hitam Laut River in Berbak NP in Jambi, Sumatra, where 17,000 ha of (deforested) peatland was burnt along this river in the 1997-98 El Niño fires (Giesen 2004, van Eijk et al. 2009).

Peat will disappear due to drainage and oxidation, and it has been calculated for plantations in Sarawak (East Malaysia) that the “lifetime of peat” (i.e. time until peat is lost) under oil palm (OP) (drained to -50 cm) or sago (drained to -25 cm) was <10 to 30 years for 2.5 m deep peat under OP and <20 to 60 years for sago (Wösten & Ritzema 2001). In practice, however, peat may not be entirely lost but the process of subsidence may continue until it stabilizes at a level at which natural (gravity) drainage is no longer possible and the peatland is often flooded. The Rajang Delta in Sarawak, East Malaysia, is a 850,000 ha area dominated by a deep peat, with industrial oil palm plantations that increased from 6% in 2000 to 47% in 2014 (Deltares 2015). Under a business as usual scenario (assuming no further expansion of plantations and using a conservative subsidence rate of 3.5 cm/year for drained areas) it is predicted that reduced drainability (which already affected 29% of plantation areas in 2009) will affect 42% of plantations by 2034, 56% in 2059 and 82% by 2109. According to Deltares (2015), “Eventually, nearly all peatland in the area is expected to be lost for production, much of it within decades and most within the next 100 years.” A similar study in Central Kalimantan on Blocks A and B of the Ex-Mega Rice Project Area (EMRP or PLG) shows that after 100 years, in the oil palm scenario (i.e. with continued drainage), about 67% of peat in this area will be subject to regular flooding (Sumarga et al. 2017; see Figure 2).

The conversion of PSF from secondary peat swamp forest to mature oil palm plantation may seriously compromise carbon storage and, through its impact on peat physical properties (such as bulk density and porosity), also seriously affect the water holding capacity of these peatlands (Tonks et al. 2017). This process may further aggravate flooding.

Box 4. Flooding in the Tahura peatland, Jambi

The Taman Hutan Raya (Tahura) in Jambi consists of almost 20,000 ha of drained and heavily disturbed peatland. Originally part of Berbak National Park this area was excised from the Park in the early 1990s, logged, and subsequently degraded further by a combination of drainage, further logging, fires and attempts at conversion for agriculture (esp. oil palm). Much of the Tahura consists of deep peat (3-8m deep), but there is a gradient towards the north where this declines to less than 1.5-2m depth. As a consequence of subsidence, the land surface in the area west of the Tahura is now less than 0.5 m above average river water level as measured during the 2013 survey. This renders the area difficult to drain most of the time, and prone to frequent flooding from the Kumpeh/Batanghari rivers, and rain water plus discharge from the Tahura/Berbak peat dome. At present (2017), more than 90% of the land surface to the west of the Tahura is below the 2012 river flood level. This flood level is thought to occur at least once every five years.

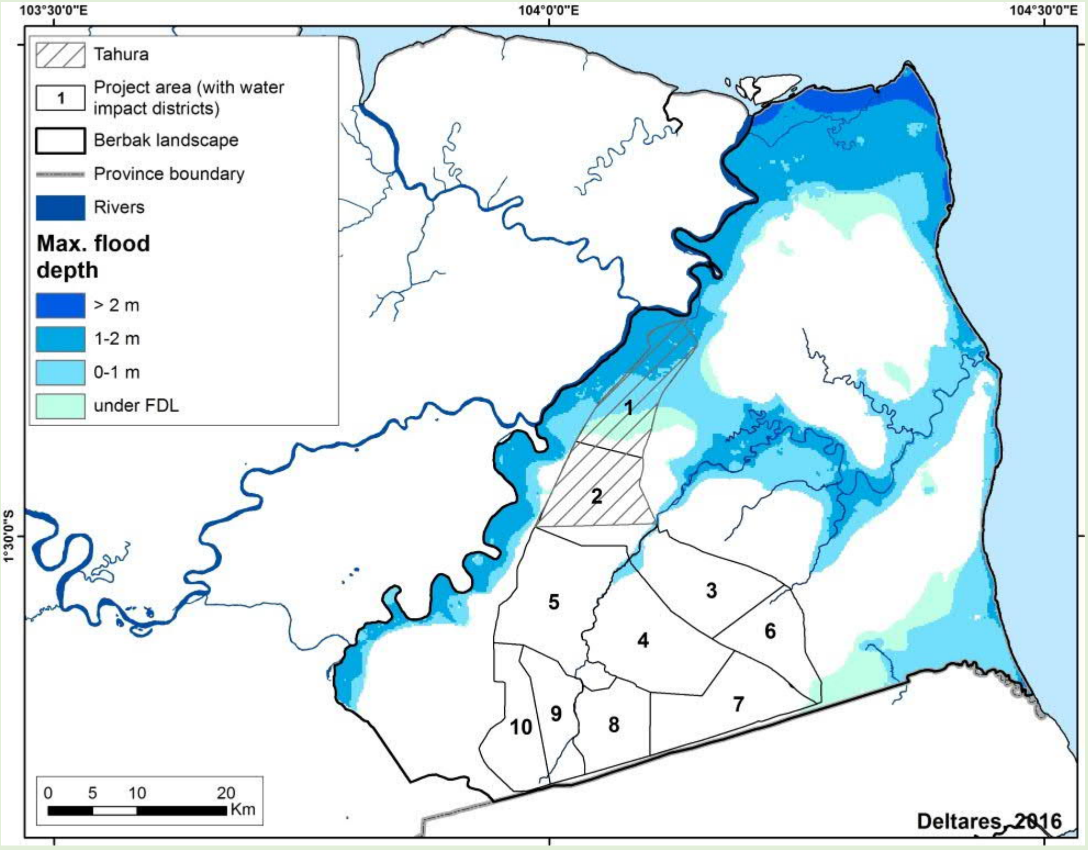
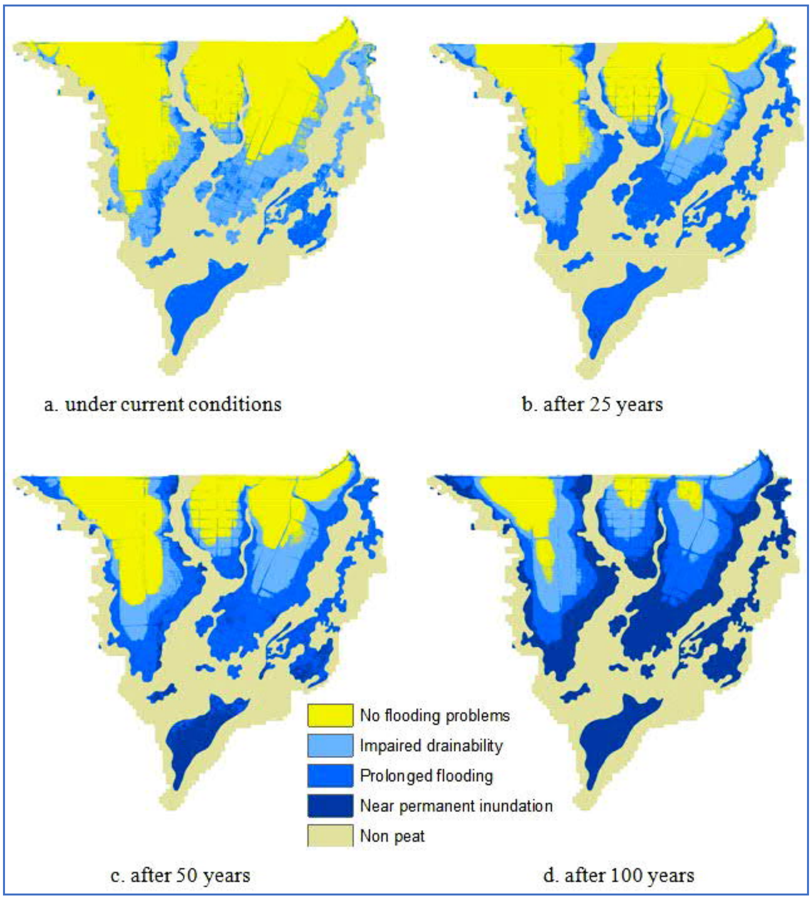


Figure 2 Flood risk maps for the Ex Mega Rice Project Blocks A and B peatland areas.



Blocks A and B peatland areas under (a) current (2011) conditions and after (b) 25, (c) 50, and (d) 100 years of subsidence applying the free drainage limit, high water level, and low water level drainage limits for the oil palm scenario. Note: Taken from Sumarga et al. (2017).

2.4 Carbon emissions in drained peat (without fires)

There has been significant debate about carbon emissions from peatlands, particularly about the methodological approach for determining these. The emphasis in these discussions is on emissions from heterotrophic processes (e.g. bacterial or fungal decomposition) that are greatly increased due to peatland drainage, rather than emissions from autotrophic processes (e.g. root respiration) which are always present. Basically, there are two approaches: i) mass balance approach (using fluxes) and ii) subsidence approach.

Mass balance approach. The IPCC guidelines originally (2006) focused on 'mass balances' that depended on approaches to estimate carbon stock changes in any pool, namely the 'gain-loss' approach and the 'stock-difference' approach[11]. However, while of great scientific interest this approach is fraught by many unknowns, although in the long-term following this approach may result in better insight into underlying processes (Carlson et al. 2015).

[11] The "gain–loss" approach includes all processes that bring about changes in a pool. Gains can be attributed to growth (i.e., biomass increases) and to transfers of carbon from another pool. Losses can be attributed to transfers of carbon from one pool to another or transfers out of the system. The "stock-difference" method is an alternative approach, which can be used where C stocks in relevant pools are measured at two points in time to assess C stock changes and an average gain or loss rate is determined over the time interval between measurements (Murdiyarso et al. 2010).

Subsidence approach. The key issue with linking subsidence to emissions is that not all factors leading to subsidence also lead to emissions. Consolidation, compaction and shrinkage do not contribute to emissions, while oxidation (such as biological decomposition and fires) does; fluvial removal (of POC and DOC) also contributes to emissions (by about 2-5%, depending on conditions) and can be regarded as slightly delayed oxidation (see Box 2). As mentioned in 2.1, after five years of drainage 60-76% of subsidence is due to oxidation, while after 18 years this increases to 92%.

Average emission depends on the level of disturbance (see table 3). In drained (primary and secondary) peat swamp forest carbon emissions are in the range of 4-7 tC/ha.yr, while if this peatland is also converted (e.g. to oil palm or *Acacia crassicarpa* plantation) this increases significantly to between 11-20 tC/ha.yr (11 tC/ha.yr for OP, 20 tC/ha.yr for *Acacia*; IPCC 2013). This range of emissions values is explained by the degree of drainage, groundwater levels and land management practices. Couwenberg et al. (2010) found a relationship for converted peatland of 2.45 tC/ha.yr per 10 cm of drainage, i.e. with 40 cm of drainage this would be almost 10 tC/ha.yr, while for 65 cm drainage this would be 16 tC/ha.yr. Similarly, Hirano et al. (2009) found that “The CO_2 emissions from tropical peatland ecosystems were strongly controlled by groundwater level. In the nondrained swamp forest, soil CO_2 emissions decreased largely when the WL rose over -0.2 m. In the drained swamp forest, on the other hand, soil CO_2 flux increased when the WL fell below -0.7 m.” According to Hirano et al. (2012), “relationships suggest that annual CO_2 emissions increase by 79–238 gC m^{-2} every 0.1 m of GWL lowering probably because of the enhancement of oxidative peat decomposition.”

Fertilizers are usually applied in plantations on drained peat, and these can increase microbial respiration, decomposition and carbon emissions. According to Murdiyarso et al. (2010) “Because most of these peat systems are ombrotrophic, and thus tend to be nutrient-limited, nutrient additions are likely to significantly increase both oxidation of soil organic matter, leading to increased CO_2 emissions, and N_2O emissions in the case of N fertilizer. These effects could be persistent and affect rehabilitation efforts.” However, the responses may vary depending on which compounds are added. In Florida, for example, addition of phosphorous (P) led to increased microbial respiration in peat with naturally low or medium P levels, but not in peat with higher P levels. Addition of ammonium (NH_4), on the other hand, inhibited microbial growth in most peat soils (Amador and Jones 1993). In tropical peatlands of Indonesia, however, Jauhiainen et al. (2014), found that added nitrogen availability in fertilised peat increased both N_2O emission average rates and flux variation. Hartill et al. (2017) found that fertilizer application in oil palm plantations resulted in an increase of 2.5-4.5x of N_2O emissions, and that conversion of PSF to oil palm plantations also resulted in a increase of 2.7x in N_2O emissions. In terms of CO_2 eq/ha.yr, Oktarita et al. (2017) found that emissions from drained and fertilized peatland were 5-10x that of natural PSF.

2.5 Fires, peat loss & carbon emissions

In Indonesia, natural peat swamps are forested and rarely affected by fires unless these spread from adjacent heavily degraded land (Hope et al. 2005, Page & Hoscilo 2016). Peatland fires are mostly started by farmers as part of land clearance activities, and by private plantation companies and government agencies as the principal tool for clearing forest before establishing crops (Page et al. 2002, Page & Rieley 2016). In Kalimantan and Sumatra more than 70% of the 13 Mha of peatland has been affected by drainage and logging and is heavily degraded (section 1; Miettinen et al. 2016), while only a small percentage remains in a relatively ‘pristine’ (2-7 %) condition. This means that >70% of peatland is highly susceptible to fires. As described by Langner et al. (2007), fire is highly correlated with land cover changes and most fires occur in degraded forests.

Wösten et al. (2008) found a correlation between the occurrence of fires and groundwater tables in peatlands in the vicinity of the Sebangau NP in Central Kalimantan, namely that fires tended to occur when these levels dropped to below -40 cm. Water retention curves (pF) show that if one has a 40 cm vacuum (corresponding to a groundwater level of -40 cm), coarse peat (i.e. with large pores) loses all of its water leaving a dry peat layer of 40 cm that can easily burn. pF curves of peat with varying levels of decomposition (e.g. hemic, fibric, sapric) are very likely to vary considerably as their pore structure differs, and measuring pF curves of these various peat types would provide more clarity about actual vulnerability. However, taking peat samples and measuring pF reliably in these peatlands is notoriously difficult (pers. comm. Wösten, August 2017).

Putra et al. (2016) studied the occurrence of peat fires in 2010-2012 in the Ex-Mega Rice Project area in Central Kalimantan and their results "showed that most of fires occur in areas with a ground water level (GWL) less than -20 cm, indicating that fire is coincident with lower GWL. This result also strongly illustrates the importance of maintaining high GWL, of more than 5 cm, to reduce fire risk and prevent degraded peatlands from experiencing surface peat fires and further devastating deep peat fires."

During the 1997/98 El Niño-induced drought peatland fires in Indonesia may have released 13–40% of the mean annual global carbon emissions from fossil fuels (Page et al. 2002, Ballhorn et al. 2009). The large range in estimates is caused by a lack of understanding of how much peat is combusted by fire – this has been targeted by various studies over the past two decades. In the 1996-97 El Niño related fires it was estimated that about 50 cm of peat had been consumed on average (Page et al. 2002), while during the less severe 2006 El Niño related fires an average of 33 cm (±18 cm) were consumed (Ballhorn et al. 2009). Simpson et al. (2016) found in an assessed 5.2 ha area in Jambi, Sumatra, that peatland 'depth of burn' levels ranged from 0-1.0m and averaged at 23 cm (±19cm). In an extensive study in the Ex-Mega Rice Project area in Central Kalimantan, Konecny et al. (2016) found lower figures for peat combustion (i.e. burn scars), and also that subsequent fires led to less peat being consumed. During a first fire 17 cm of peat was lost, on average, while during 2nd, 3rd and 4th successive fires 10, 6 and 2 cm of peat were consumed. This corresponds to carbon losses of 114, 64, 38 and 13 tC/ha (Konecny et al. 2016). That the level of fire damage is determined by groundwater levels is illustrated by the correlation with the distance from drainage canals: at a distance of up to 200-300 m from canals fire scars are on average 40cm or more deep, while at a distance of 800 m or more the fire scars are generally <20cm deep (Page & Hooijer 2016).

The use of fires for the clearing of land was banned in 2016 by means of Presidential Decree No. 57/2016 on *Protection and Management of Peat Ecosystems*, but this regulation made an exception for the use of fire by smallholders with less than 2 ha of farmland. Following the 2015 El Niño related fires, when it became clear that many fires were directly related to smallholders, the use of fire for (peat-)land clearing has been banned for all farmers including smallholders.

Miettinen et al. (2017) found that 78% of emissions from peatlands in Southeast Asia (in 2015 estimated at around 146 Mt Cyr^{-1}) were either from plantations (44%) or smallholders (34%), i.e. from managed and drained peatland. At the same time, emissions from fires were on average 122 Mt Cyr^{-1}, hence they conclude that the "... results emphasise that whilst reducing emissions from peat fires is important, urgent efforts are also needed to mitigate the constantly high level of emissions arising from peat drainage, regardless of fire occurrence."

2.6 Rewetting to curb peat loss

The most important requirement for the preservation of peat is permanent saturation by water (Page et al. 2009, Dommain et al. 2010, Evers et al. 2017), and to curb peat loss in peatlands affected by drainage it is essential that peat is rewetted and peat hydrology is restored to near-natural conditions. The relationship between groundwater levels and emissions is relatively well understood, and as mentioned earlier Couwenberg et al. (2010) found a relationship for converted peatland of 2.45 tC/ha.yr[12] per 10 cm of drainage. Simple measures such as raising groundwater tables by operation of tertiary gates can already significantly reduce carbon emissions, and Imanudin and Susanto (2015) found that raising levels in Tanjung Jabung Timur district in Jambi from -47 cm to -23 cm resulted in a halving of emissions, from 11.4

[12] 2.45 tC/ha.yr is equivalent to 9 tCO_2/ha.yr.

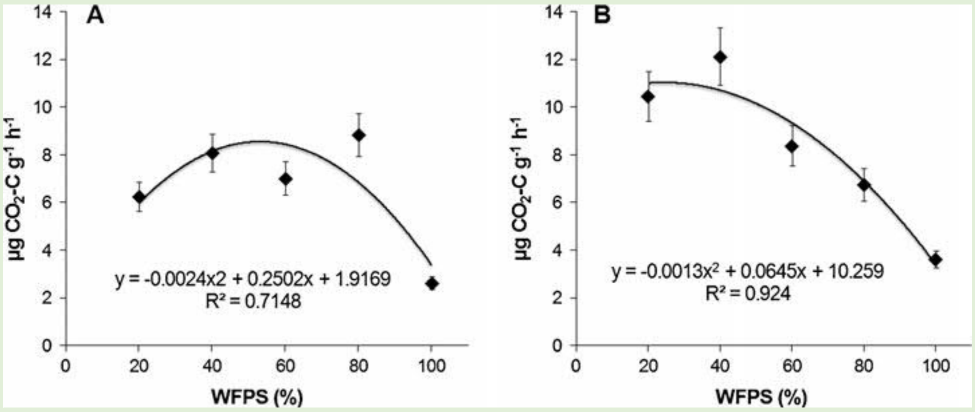
to 5.6 tC/ha.yr[13]. Furakawa et al. (2005) found that carbon loss from lowland rice paddies was one-eighth of that of other crops (cassava, coconut, pineapple), although the Global Warming Potential was almost the same level as that of other crops because of CH_4 emissions from these rice paddies. Emissions were found to be lowest in undrained swamp forests. Soil and air temperature play a secondary role in CO_2 emissions compared to soil moisture levels, and emissions are clearly largely determined by groundwater levels in peat (Marwanto & Agus, 2013). While it is well known that rewetting of peat reduces peat loss there are few studies in Indonesia that focus on the relationship, and a recent study by Husen et al. (2013) is presented in Box 5.

The blocking of canals and drains not only reduces respiration and emission losses of carbon but also reduces the fluvial export of organic matter from peatlands (as dissolved organic matter or DOC), as elevated water levels presumably lower the production and/or release of DOC into peat waters (Wallage et al. 2006, Worrall et al. 2007).

One aspect of rewetting that remains a challenge is that excessive desiccation of tropical peat may result in hydrophobicity (e.g. of the peat surface layer). This not only makes it much more difficult to rewet but also renders peatland much more susceptible to surface waterlogging and erosion (Andriesse 1988, Notohadiprawiro 2006, Rieley 2007). The resistence to rewetting appears to be related to bulk density, and the lower the bulk density the more difficult peat can be rewetted; on the other hand, higher bulk densities can usually be readily rewetted (Andriesse 1988).

Box 5. Peat soil moisture & respiration

A recent laboratory study by Husen et al. (2013) demonstrates that saturated conditions are more effective in reducing microbial activity than dryer soil conditions, confirming that water saturation is effective in reducing peat emissions (figure below). If surface peat is desiccated further (figure A, below left) then respiration slows down, although still almost 3x higher than 100% rewetted peat. Note that the peat in this study was relatively disturbed, as bulk density was 0.13 g/cm³ for subsurface peat and 0.19 g/cm³ for surface peat, while for undisturbed peat this is 0.07-0.1 g/cm³ (see introduction). Results are likely to be more pronounced in undisturbed peat.



Adapted from Husen et al. (2013). Effect of changes in water filled pore space (WFPS) on peat respiration at a) surface peat samples (0–20 cm), and b) subsurface peat samples (30–50 cm).

Rewetting prevents (or at least slows down) peat decomposition by reducing microbial decomposition of peat organic matter. This is partly because of lower oxygen availability and anaerobic processes are inherently slower (Jauhiainen et al. 2016). However, it has also emerged that the total phenolic content (TPC) of peat plays an important role in inhibiting microbial growth and peat decomposition (Fenner & Freeman, 2011). At the same time high phenolic content in peat soils also has a negative influence on

[13] Note that these figures are low compared to what is usually found in drained peatland (see Table 2).

plant growth and mineral availability within soils (Sabiham et al. 1997). Wet, anoxic conditions limit in microorganisms the activity of phenol oxidase, the enzyme responsible for the breakdown of phenolic compounds. Drainage introduces oxygen into the peat, thereby stimulating phenol oxidase and peat decomposition. TPC levels are directly related to rewetting, and according to Yule et al. (2016) "waterlogged conditions preserve the concentration of phenolic compounds in peat, and that even [peat swamp forest] PSF that has been previously logged but which has recovered a full canopy cover will have high levels of total phenolic content (TPC) in peat. High levels of TPC in peat and in the flora are vital for the inhibition of decomposition of organic matter and this is crucial for the accretion of peat and the sequestration of carbon." In their study on phenolics in mahang *Macaranga pruinosa* and associated peat, Lim et al. (2017) found that TPC increased significantly at the peat surface and during the wet seasons. They found that "TPC of mature leaves were significantly higher during the wet season. This implies that either plants synthesize phenolic compounds in response to flooding, or phenolics are more readily available during the wet season due to increased detrital leaching and plants can absorb phenolics via their roots."

Challenges in rewetting drained and degraded peatland are summarized by Dommain et al. (2016) and include the following aspects:

- <u>Peat dome fragmentation</u>, which may offset any rewetting efforts in restoration areas. Peat domes need to be managed as single hydrological units, but domes are often under fragmented land use and management, with varying approaches to hydrological management (see pitfalls, 2.1 & box 1).
- <u>Regional seasonality and drought</u> may affect rewetting. Large-scale deforestation and drainage in Kalimantan might have already exacerbated drought severity while the long-term climate effects of deforestation in South East Asia certainly include reduced precipitation.
- <u>Subsidence</u>, especially along canals, may affect rewetting as the impact of canal blocks may not sufficiently extend to areas further away from the canals (i.e. 'mini-domes' may occur between canal grids). Close to blocked canals groundwater levels may be, say, -40 cm in the dry season but further away this may drop to well below -100 cm.

2.7 Approaches to rewetting

2.7.1 Canal blocking and infilling

There are three main types of canal blocking applied in peatland restoration in Indonesia:

1. <u>Box dams or coffer dams</u>. These consist of box-like structures usually made of wood and infilled with (woven plastic) bags filled with sand or manually compacted peat. Mostly these are constructed using local labour and have a (lined) spillway to prevent damage by overtopping and facilitate the passing of small boats. This type of dam has mainly been constructed by NGOs and universities. A manual on their construction has been produced by Wetlands International (Suryadiputra et al. 2005). Examples are provided by Dohong & Lilia (2008) and Ritzema et al. (2014; see Box 6 below).
   Advantages are:
   a. Technique is reasonably well-known locally and 'does the job' (provided that the 'box' frame extends into the mineral sub-soil).
   b. Waterways remain passable for small boats.
   c. Creates (temporary) local job opportunities.
   Disadvantages are:
   d. Relatively expensive (e.g. IDR 45 million million for a dam across a 4-6m wide canal, IDR 70 million for one 6-10m wide[14]).
   e. Without maintenance they do not last long (often only 2-3 years).
   f. Require lots of fairly large timber (long enough to extend into the mineral subsoil).
   g. Take long to construct (compared to other canal block types).
   h. Easily damaged by persons wanting to re-open waterways.
   i. Do not lead to full rewetting, because of the spillways.

[14] Information from WWF Indonesia on the Londerang restoration project in Jambi.

2. Compacted peat dams. These dams consist of peat taken by an excavator from (shallow) borrow pits adjacent or near the canals and compacted by the excavator driving across the top (Box 7, Box 8). A typical compacted peat dam is usually 6-8 m across the top, which is constructed so that it is higher than the surrounding peatland to prevent dam overtopping. These have mainly been constructed by plantation companies and are then often constructed with a by-pass (of -50 cm depth) so that water levels in the plantations are not too high for oil palm or *Acacia* production; this also facilitates passing of the dam when water levels are sufficiently high. However, this does not constitute full rewetting and for full rewetting no by-pass should be made. A manual on their construction has been produced by APP and Deltares (2016).

   Advantages:
   a. Technique well understood by plantation companies and their sub-contractors.
   b. Small environmental impact, as there is no need for timber; excavators (*alat berat*) do not damage the peat when used in dry months (only 2-3 cm impression of peat layer).
   c. Are relatively cheap (e.g. IDR 5.3-7.5 million for a dam across a 6-8m wide canal, based on excavator rental, labour and fuel; APP & Deltares 2016)[15].
   d. Can be rapidly constructed, as a skilled excavator operator can construct at least one dam per day.
   e. When well-compressed, these dams are effective and last much longer than box dams (at least 5-10 years, probably much longer).

   Disadvantages
   f. Less use of local labour, less local involvement..
   g. Waterways do not remain readily passable, although slides may be added to facilitate the passage of small boats.
   h. Easily damaged by persons wanting to re-open waterways (e.g. using chain saw); this can be curbed to some extent by adding a layer of cement to deter chainsaws.

3. Canal infilling (or backfilling) with peat. This is a method usually not applied as ‘stand alone’ but carried out in combination with either box dams or (more usually) compacted peat dams. There are not many examples available of this, but in theory this approach will greatly retard the flow of water and also facilitate the growth of vegetation, which further adds to the slowing down of water flow. There is no manual on this process (although described, for example, in Euroconsult Mott MacDonald & Deltares 2009), but as it is very simple this should not be a problem for implementation. To keep peat in place infilling is usually combined with the placing of (wooden) palisades. As large volumes of peat need to be moved this cannot be done manually by local communities, but will require the use of excavators (*alat berat*).

   Advantages:
   a. Can greatly slow down flow of water in canals and raise groundwater tables.
   b. Low cost compared to other methods (depending on volumes moved).
   c. Prevents access to peatland, and this can be beneficial in protecting peatland conservation areas such as national parks.

   Disadvantages:
   d. Needs to be carried out in combination with dams, otherwise flooding may result in removal of much of the peat.
   e. Less use of local labour, less local involvement (although local labour is required for placing of palisades to keep peat in place).
   f. Needs a lot of material, so borrow pits are required that are ideally placed well away from the canals to avoid erosion and other issues.
   g. Not much experience exists with this process yet and although it seems straightforward some unforeseen issues may arise.
   h. Lack of access will be perceived as negative in some areas/conditions.
   i. Fish rearing in canal sections is no longer an option following infilling.
   j. May not be long lasting (as not as compacted/solid as a compacted peat dam).

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[15] Costs on BGPP indicate that these costs are higher: USD 600 for a 4m wide canal, USD 1,000 for 8m, USD 1,400 for 10m and USD 5,000 for a 20m wide canal.

Box 6. Box dams in Central Kalimantan

Canal blocking was carried out in heavily degraded peatland in the ex-Mega Rice Project area in Central Kalimantan from 2004-2009 by the RESTORPEAT project in cooperation between CIMTROP (University of Palangkaraya) and Wageningen University, the Netherlands (Ritzema et al. 2014). These were box dams consisting of Melaleuca cajuputi *(gelam) poles using manually compacted peat for infilling. They concluded:*

- *Dams can permanently raise the water table in a degraded peat dome, reducing subsidence and* CO_2 *emissions. The average water table was raised from -1.12 m to -0.37 m, although in the dry season this still fell to below -1 m. Vegetation rapidly established on dams & in canals, slowing water flow.*
- *These dams built with locally available construction material (i.e. peat & gelam poles) faced problems as: i) gelam poles are generally too short (need to go into mineral subsoil) and ii) (manual) compaction of the peat is difficult, especially when (underlying layer of) peat is wet. Seepage flow underneath/alongside the dams presented a major threat which resulted in the collapse of (some) dams.*

A lesson from the early RESTORPEAT dams: because the gelam *poles did not extend into the mineral subsoil, the dam was subsequently undermined by seepage and collapsed.*

WWF Indonesia constructed box dams on canals in and around Sebangau NP in Central Kalimantan. The design was much more robust (and expensive) than the RESTORPEAT dam, having learned from these earlier attempts. The large spillway allows access , but also means that full rewetting is not being attained.

Photos: W. Giesen (both 2008)

Rewetting practicalities: permeability & location of dams

Dams as water retarders rather than as water blocks. When constructing canal blocks it should be realized that these blocks do not have to be water impermeable, but rather have a permeability that is comparable to the saturated hydraulic conductivity of the surrounding peatlands, which is often as high as approximately 30 m/day (Wösten et al. 2008) and may be as much as several hundred m/day in degraded peatland (Baird et al. 2016; see Box 1). Under these conditions, creating impermeable dams would only increase the risk of dam failure due to high hydraulic pressure on these impermeable dams while water will bypass these dams by flowing through the surrounding peatlands. In practise, dams should function as water retarders rather than as water blocks. Water retarding in drainage canals is essential to restore the hydrological integrity of peatlands as it helps to clog up the system by stimulating vegetational regrowth as well as siltation of the drainage canals to a degree that the area as a whole maintains the natural, relatively high saturated hydraulic conductivity (pers. comm. H. Wösten, 2017).

Cascade of dams. In connection with the above item in which dams function as water retarders rather than as water blocks it should be realized that the optimum difference in water levels upstream and downstream of the dam should be limited to approximately 20-30 cm. This will reduce pressures on the dam and increase effectiveness in raising water levels. The practical consequence of this is that a cascade of a number of dams is required to overcome a certain water level difference. Insight in the slope of drainage canals (e.g. on a digital terrain model or DTM) provides guidance as where to best locate these dams thereby optimizing limited resources for the relatively expensive construction of dams (pers. comm. H. Wösten, 2017).

From upstream to downstream. In constructing dams it is advisable to start building dams at the most upstream part of the canals. This has various practical reasons, including access (rewetted areas will become less accessible), but also because canals in the upstream area are most likely to be small compared to those further downstream and construction of these relatively small dams will be relatively easier and cheap. At the same time starting building dams in the upstream area reduces water pressure in the downstream area, thereby reducing costs of dam construction and reducing risk of dam failure (pers. comm. H. Wösten, 2017).

Recommended dam types & access to rewetted peatland

BRG recommends the construction of compacted peat dams (plus canal infilling in some areas) in conservation/protection areas (*Daerah Lindung*), and the construction of box dams in areas in use by local communities (*Daerah Budidaya).* However, this recommendation is mainly because of concerns regarding access by local communities, and it would be wise to also consider alternative approaches for maintaining access in rewetted peatland. Possible options include methods for passing compacted peat dams (without by-passes or spillways), such as slides or ramps, or modes of transport on the rewetted peat rather than via the canals. The latter may include options such as (moveable wooden, plastic, etc...) tracks, adding a thin layer of cement to the top of the peat (e.g. Huat et al. 2005) or using specially developed equipment such as used in northern temperate peatlands (Dubowski et al. 2014). Logging companies (HPH) use moveable rail systems in peatland, but these are expensive and require a significant investment; another option is a 'kuda-kuda' simple rail system using poles as used by smaller logging companies. An ideal method of access should: i) be compatible with full-rewetting (i.e. not include spillways); ii) be relatively inexpensive; and iii) have a low environmental impact (e.g. not require large amounts of timber).

Box 7. Compacted peat dams in Sumatra I: on APP's concessions

Asian Pulp and Paper (APP) is one of the largest pulp and paper companies in the world. The company receives pulpwood from its suppliers' pulpwood concessions in Indonesia, many of which are located on peatland. After the 2015 El Niño fires the company aimed to block perimeter canals around their suppliers' concessions, and the aim was to construct a total of 7,500 compacted peat dams following the design explained in APP & Deltares (2016). Construction started in South Sumatra in August 2015, Kerumutan, Riau in October 2015 and subsequently upscaled to other concessions. By 8 January 2016 2,323 blocks had been constructed in Riau alone, and altogether >6,000 blocks were constructed in Sumatra by APP in 2015-2016. The canal blocks are designed to include a bypass spillway with a depth of -50 cm, so that water levels are not too high in the plantations.

Aerial view of a compacted peat dam with a lateral spillway or bypass (at -50cm), in one of the APP related concessions in South Sumatra. In full rewetting a bypass is not desirable.

Box 8. Compacted peat dams in Sumatra II. BGPP's dams in the TAHURA OKH

As part of the peatland restoration component of the MCA-Indonesia funded Berbak Green Prosperity Partnership project's activities in Jambi, Sumatra, canals were blocked with compacted peat dams in the Taman Hutan Raya Orang Kayo Hitam (TAHURA OKH), a heavily degraded 18,200 ha peatland in the bufferzone of Berbak NP. These compacted peat blocks varied from 2-3m wide, to >20m wide. Because of delays, works had to be carried out in the wet season, which meant that blocks were constructed in two steps, with time in between to allow peat to settle and consolidate before being further compacted by excavators.

Compacted peat block over a 2-3m wide canal

Compacted peat block over an 8m wide canal

Compacted peat block under construction across the 20+ metre wide canal that runs along the western boundary of the TAHURA OKH.

Photos by W.Giesen (top 2) & Nasrul Ichsan (bottom, using drone), 28 January 2018

2.7.2 Deep well establishment

In 2016-2017 a lot of emphasis has been placed on the rapid and inexpensive installation of deep wells in peatland areas, and the aim (e.g. of BRG) is to place one deep well in every 3 ha area of peatland vulnerable to fires. In all, about 5000 deep wells are to be installed via the BRG program in the coming years (i.e. up to 2020); drilling alone has been budgeted at about Rp. 6 million per well, which does not include pumps. While such a system can in theory be useful in preventing or extinguishing fires in vulnerable peatland, and there are a number of disadvantages to this approach. Firstly, wells (and sprinkling of water on peat) does not mean that peat is really rewetted – there is a (very temporary) vertical circulation of water, but overall if a peatland is drained this means that peat oxidation and subsidence will continue unabated in spite of the presence (and temporary operation) of wells. Secondly, pipes are installed down to depths of up to 40 m and these are often uncased, which means that they will easily corrode and become blocked and soon become much less useful or effective. Thirdly, the use of pumps depends on correct judgement, on when to employ, and will be vulnerable to availability of funds (e.g. for fuel and maintenance) and willingness of people to take the risk to operate pumps in peatland threatened by fires. Lastly, the hydrological impact of deep wells (if employed at large scale) is not known. Slightly dampened peat (e.g. dampened by water from wells), if it ignites, can produce higher emissions from smouldering than drier peat (because damp(er) peat contains less oxygen); damp peat is not an advantage, it needs to be fully saturated (pers. comm. S. Page 2017).

2.8 Knowledge gaps

Effectiveness of canal blocks

Most canal blocks consist either of box dams constructed by NGOs (or their partners) as part of projects, or are compacted peat dams constructed by companies on their concessions. In both cases there is a lack of reporting on long-term success:

- projects are usually short-term (i.e. <4-5 years) and when the projects end the dams are only 2-3 years old and still in a reasonable condition; and
- companies generally conduct internal reporting only and there is no requirement to inform outsiders.

What is needed is an unbiased assessment of how dams constructed in the past 10-12 years have performed, so that 'lessons learned' are based on more solid footing. This should include an assessment of dam type (box, compacted peat), dam condition, maintenance received (if any), costs, and the degree to which water tables have been raised (hydrological effectiveness) and subsidence has been slowed.

Reduction of emissions & subsidence by raising ground waterlevels to -40 cm

Recent regulations call for raising ground water levels in plantations up to -40 cm, which is up from current levels of -65 cm or lower. This is expected to have positive effects by reducing carbon emissions and subsidence (but not stop these processes), but exactly by how much is unclear and requires detailed study. [Wetlands International & Tropenbos (2016) suggest that raising GWLs to -40cm will result in a reduction in sudsidence of 26% only, but this is disputed by others who regard this as too low a figure and say that it might be closer to 50% (pers. comm. Dr. Sue Page, Sept. 2017).]

pF curves for various peat types & conditions

Water retention (or pF) curves indicate that when ground water levels in peat are drawn down to ± -40 cm, peat (which is coarse and has lots of pores) will lose its water content and a dry peat layer will remain that is vulnerable to fires. This critical level (± -40 cm) depends very much on the level of peat decomposition and pF curves will therefore probably vary considerably between the various peat types (sapric, fibric and hemic peat) and therefore also per location. It is therefore suggested that field and/or laboratory studies be carried out on pF / water retention in a range of peat types, so that the relationship is better understood. Also included could be the effect of peat compaction, such as carried out in Malaysian oil palm plantations.

Note that a better understanding of pF curves has direct implications for policies, such as the current drainage depth of -40 cm (as specified in PP71/2014 and PP57/2016).

Fate of DOC & POC that leaves peatland

The loss of carbon as POC and DOC from (degraded) peatlands is not well understood in the Indonesian context, nor is much known about the fate of POC and DOC, especially after it is removed from the peatland (blackwater) system and enters the sea. Wit et al. (2015) show that just over half is rapidly outgassed from these blackwater rivers by the time they reach the coast, but the fate of the remainder is unknown and other mechanisms may also play a role (e.g. rapid assimilation or trapping).

3. Revegetation

3.1 Types of Revegetation

Revegetation is the second important tenet of peatland restoration after restoration of the hydrology (rewetting), as maintaining a vegetation cover on peat increases humidity in the soil and air, slows peat decomposition and decreases fire risks. Without a vegetation cover peat dries out rapidly and becomes highly vulnerable to fires, especially in dry months. Revegetation must be embedded in a (peat-)landscape approach in order to be successful (Box 9).

Box 9. Landscape approach to peatland management

A note needs to be made at the outset that revegetation alone will not lead to preservation of the peatland. The peatland is primarily a wetland, and as noted above, before any consideration of land cover and forest management, i.e. revegetation, is made, the plans and zonation to support the restoration and management of the peatland landscape hydrology should already be in place. The key tenet of wetland conservation is the management and preservation of the supporting peatland wetland hydrology, and this can only be managed effectively with a landscape approach. The peatland landscape also comprises of two differing wetlands, with differing hydrology and requiring differing management effort to support landscape/wetland conservation. The peat dome has its own peat swamp hydrology, and requires active hydrology restoration efforts to bring about a re-wetting to reduce the fire incidence and the rate of peatland subsidence due to drying and oxidation. The adjacent river floodplains on the peat dome edges, fall under the larger river basin hydrology, and most normally require key effort to develop flood-adapted community livelihoods – in order that local communities in the buffer zones of the peat dome are not forced to shift onto the higher drier peat dome areas due to crop and plantation failure due to the ever-increasing river flood peaks.

The type of revegetation planned should in the first step support the above plan and zonation for peatland landscape management, and be adapted in terms of seedling survival and follow-up production or restoration sustainability, to the over-arching peat dome rewetting program (i.e. water tables at the peat surface for most of the year and no drainage allowed), and the supporting buffer zone program of river flood adapted community livelihoods. The type of revegetation required should secondly be adapted to the level of degradation and the current status of, and intended plan, for the area (i.e. *daerah budidaya, daerah konservasi*). Current GOI legal guidelines[16] already suggest a clear division of revegetation effort between ecological restoration and forest conservation effort for peatlands with peat layers 3 m or greater depth, and potential community forestry and paludiculture on shallower peats.

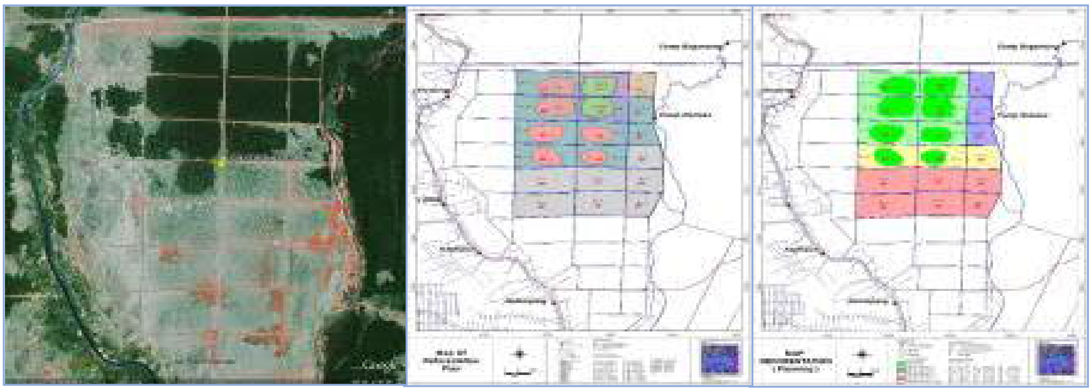
The types of interventions that can be considered are summarized in Table 3, with interventions varying from (assisted) peat swamp forest regeneration in moderately degraded PSF, to ecological rehabilitation of severely degraded peat swamps. The restoration and regeneration of moderately degraded peat swamp forests (degradation types A1, A2) is largely the responsibility of the Ministry of Environment and Forestry (MoEF) and forest concessions, while the mandate and focus of BRG is largely on degradation types B, C and D; the interventions for these latter types are briefly described below. However, given its potential, paludiculture is described in more detail in 3.2, while ecological

[16] Presidential Decree Nr. 32/1990 on protected area management (Art. 10) generically states that peatlands with a depth of 3 meters or more in swamps and are located upstream (of a river) must be defined as conservation areas.

rehabilitation is elaborated further in 3.3. For the other types of intervention – largely outside BRG's mandate - one may refer to existing literature (e.g. Wösten et al. 2008, Page et al. 2009, Giesen & van der Meer 2009, van Eijk et al. 2009, Euroconsult Mott MacDonald et al. 2009, Gunawan et al. 2012, Graham et al. 2016, Gunawan & Kobayashi 2016).

It should be noted that interventions need to be tailored to site conditions, and that mapping of such conditions should be the starting point. The assessment of site conditions and cause(s) of degradation should guide the choice of interventions needed to address the conditions and cause of degradation (e.g. canal blocking, choice of species to be planted, planting densities), and this should be mapped out at a manageable scale (Figure 3).

Figure 3 Mapping of degradation level to determined type of intervention needed



Example from Blok A, EMRP/PLG area, Central Kalimantan
Level of intervention indicated in righthand map: Green = areas that will regenerate by themselves; purple = areas requiring low intervention methods; yellow = areas requiring high intervention methods; red = areas requiring full re-vegetation. From presentation on 'Targeted appropirate and efficient revegetation of tropical peatlands' by Dr. Laura Graham, at the 2nd International Peatland Restoration Research Alliance (IPRRA) in Jakarta, 2nd November 2017.

Peat adapted Agro-forestry (B1)

Peat adapted agro-forestry is recommended in *daerah budidaya* areas that are moderately to largely deforested (tree cover 5-20%), with most PSF tree species remaining. These area are drained by (past logging) canals and have sometimes also been burnt, but usually the impact of fires is very local. Hydrological rehabilitation (canal closure/rewetting) is a prerequisite, along with fire detection and prevention measures. In terms of revegetation, enrichment planting of economically desirable species is recommended. In community managed forests (e.g. *hutan desa*) these should preferably be NTFP species, to avoid tree felling and exposure/desiccation of peat.

Peat swamp forest restoration (B2)

Peat swamp forest restoration is recommended in *daerah konservasi* areas that are moderately to largely deforested (tree cover 5-20%), with most PSF tree species remaining. These area are drained by (past logging) canals and have sometimes also been burnt, but usually the impact of fires is very local. Hydrological rehabilitation (canal closure/rewetting) is a prerequisite, along with fire detection and prevention measures. In terms of revegetation, significant enrichment planting of ecologically desirable species is recommended – these can include fruit species that are attractive for wildlife (e.g. figs, wild jambu or nutmegs) or emergent canopy species (e.g. *Koompassia malaccensis*).

Paludiculture (C1)

Paludiculture is recommended for *daerah budidaya* areas that are mostly deforested (with a tree cover 1-5%). These areas are drained and have often burnt one to several times. There may be some occasional flooding, but this should not be too deep or prolonged. Hydrological rehabilitation (canal closure/rewetting) is a prerequisite, along with fire detection and prevention measures. Paludiculture is defined as the cultivation of peat swamp species for economic benefit, linked in a programme of peatland rehabilitation (i.e. in rewetted peatlands). These economically beneficial species can be planted either as monocultures or in mixed planting settings. See 3.2 for more details.

Ecological rehabilitation (C2, D1, D2)

Ecological rehabilitation is recommended for *daerah konservasi* areas that are mostly deforested (with a tree cover 1-5%; C2), and in severely degraded areas with a tree cover usually <1% that have often burnt many times, long history of drainage and subsidence, and are subject to frequent flooding and seasonal ponding and lake formation (D1, D2). Hydrological rehabilitation (canal closure/rewetting) is a prerequisite, along with fire detection and prevention measures. Revegetation is required for larger areas, using mainly fast growing and hardy pioneer species that can tolerate flooding and exposure to drought (in D1 and D2), in combination with hardier ecologically desirable species (in C2). The latter should include fruit species that are attractive for wildlife.

Table 3 Peat swamp interventions

Level of degradation:	**A. Moderately degraded peat swamp forest**	**B. Degraded peat swamp forest**	**C. Severely degraded peat swamp forest**	**D. Severely degraded peat swamp**
Description of degradation	Forest disturbed by logging and logging canals, but with largely closed canopy, usually not burnt.	Logging canals present, moderately to largely deforested (tree cover 5-20%), with most PSF tree species remaining, sometimes burnt, but very local.	Mostly deforested (tree cover 1-5%), often burnt multiple times (1-3x), history of drainage >10 years, occasional flooding	Areas severely degraded, tree cover usually <1%, often burnt ≥4-5x, long history of drainage and subsidence, frequent flooding, seasonal ponding/lakes
Visual examples:				
Types of intervention recommended in ***daerah budidaya***	**A.1 Peat-adapted silviculture** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, possibly enrichment planting of desirable timber (or other) species, timber harvesting using rail systems.	**B.1 Peat-adapted agroforestry** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, enrichment planting of economically desirable species.	**C.1 Paludiculture** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, planting of desirable, economically beneficial peat adapted species, either as monocultures or mixed planting.	**D.1 Ecological rehabilitation** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, planting of pioneer PSF species that grow rapidly and cope with flooding, drought & heat stresses.
Types of intervention recommended in ***daerah konservasi***	**A.2 Peat swamp forest regeneration** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, possibly local enrichment planting of ecologcically desirable species (e.g. fruit species for wildlife).	**B.2 Peat swamp forest restoration** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, signifcant enrichment planting of ecologcically desirable species (e.g. fruit species for wildlife).	**C.2 Ecological rehabilitation** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, replanting of large areas with PSF species, both pioneers & ecologically desirable species.	**D.2 Ecological rehabilitation** Hydrological rehabilitation (canal closure/rewetting), fire detection & prevention measures, planting of pioneer PSF species that grow rapidly and cope with flooding, drought & heat stresses.

3.2 Paludiculture

Paludiculture is a swamp cultivation approach developed in northern temperate areas as a means of rehabilitating degraded peatland, while making these economically useful at the same time (Wichtmann & Joosten 2007, Schäfer 2011). Although still a very new concept in Indonesia it has been developed internationally over the past 1-2 decades, particularly in northern Europe and North America and the basic approaches are explained in detail in Wichtmann et al. (2016). These temperate systems are simpler, however, and paludiculture at these latitudes is based on usually a few products (e.g. *Phragmites communis* reeds, *Alnus glutinosa* alder wood, several berry producing species). Also, these temperate peatlands are largely *Sphagnum* bogs which present fewer challenges (e.g. in terms of accessibility) than tropical peatlands with a large wood content. However, similar principles can be applied.

3.2.1 Misunderstanding about paludiculture in Indonesia

The need for full rewetting in peatland restoration and paludiculture is often ignored, and many programmes involving peat 'restoration and replanting' in reality involve partial rewetting only, and the planting of dryland species. The promotion of dryland crop and plantation species in regional peatland areas, according to national policy and central government research recommendations, is also leading to long term community livelihood and private sector economic failure in the buffer zone floodplains which border the peatlands due to rising river flood peaks (i.e. leading to peatland encroachment to escape the floods).

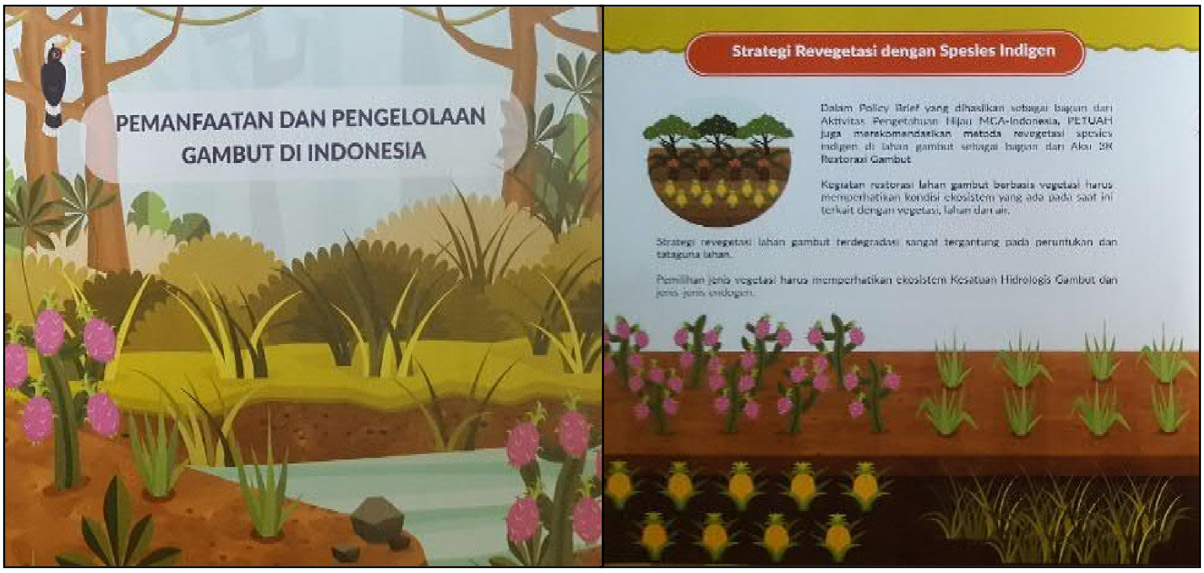
Peatland restoration programmes in Indonesia usually include some form of replanting or cultivation, but in many cases, however, rewetting carried out on these programmes is less than full rewetting, for although canals are blocked, ground water levels are kept artificially low (to -40cm or even -65—80 cm). Under such circumstances, most dryland species can be cultivated and project proponents often promote species such as (Liberica) coffee, cocoa, pinang, coconut, bananas, cempedak, jengkol, corn, duku, durian, oranges, pepper, pinang, pineapple, red ginger, rubber and dragonfruit. These commodities all need drainage to survive and will therefore not perform well on fully rewetted peat, hence their cultivation is unsustainable in the long-term and does not really constitute paludiculture.

What has not been helpful is that in the past official Government programmes have inadvertedly promoted these dryland species in peat restoration programmes (Figure 4), as they have done also in flood prone floodplain areas adjacent the peatlands. Fortunately, for peatlands this has since been rectified to some extent, and lists of species that are truly peat adapted have been appended in Permen 16/2017 (Min. KLHK) on *Technical guidelines on recovery of peat ecosystem functions.* Also contributing to the problem is the -40 cm drainage level set in PP71/2014 and PP57/2016[17].

What is also apparent is that the management of peatlands should be landscape-based. Managing the peatlands alone will not meet the conservation and sustainability objectives for the peatland landscape. All areas of conservation focus require a buffer zone programme, to create a 'social fence' to protect the 'core area' of management focus, and to reduce the outside pressures on peatlands by provision of alternative livelihood and economic options for the buffer zone communities and the private sector. The case of re-vegetation and paludiculture should support this proven and tested approach, with program implementation also extended into the peatland buffer zones, and possibly off the peats, to reduce the external pressures on the peatlands.

[17] The case for the river floodplains adjacent the peatlands is not so progressive, with no new policy or legal instruments arising in recent years to support the practice of paludiculture and flood adapted agriculture.

Figure 4 GOI brochure inadvertedly promoting dryland species on restored peat



A number of projects, programmes and initiatives have recently been undertaken to reduce emissions from cultivation. These include initiatives by private companies to rewet areas of plantation, and projects/programmes by government agencies to promote cultivation of peatland using non-burning techniques. While an improvement compared to business as usual (BAU), these approaches fall short of full rewetting (see example on raised water tables in *Acacia* by Sumitomo) or do not involve rewetting at all although the rate of emissions from peat is reduced by phasing out burning. These examples are described below:

<u>Raised water tables in *Acacia,* West Kalimantan</u>

The *Acacia* plantation company PT. Wana Subur Lestari (concession jointly held by the Sumitomo Corporation & PT Alas Kusuma) extends over 40,000 ha in West Kalimantan, south-southeast of Pontianak. Their water management basically follows the eco-hidro principles (see 2.1), i.e. with secondary canals following the contours of the peat dome, a forested conservation area (8,000 ha) as a water reservoir, and a system of active water level management (via a system of sluices and flap gates). Water management aims at keeping water levels as close to -40 cm as possible. The peat dome largely consists of peat with a depth of 8+ metres, of which the mineral subsoil is below mean sea level. Subsidence is measured at 3.5 cm/year. Production of *Acacia* is in year-4 of its first cycle, but it is estimated that production levels are good and comparable to what is attained elsewhere with greater drainage (pers. comm. Sumitomo, 7 Sept. 2017).

<u>Raised water tables in oil palm plantation, Riau</u>

The oil palm company PT Meskom Agro Sarimas manages a 4,000 ha plantation on the island of Bengkalis in Bengkalis district, Riau. Ground water levels are kept higher (in part, higher than -40 cm) than in usual OP operations where -65 cm is the norm, and according to the company in spite of this production is only 9% lower than usual. However, according to Dr. Azwar Maas (Laboratorium Pedologi Jurusan Tanah, Fakultas Pertanian UGM Bulaksumur, Yogyakarta,) who is an advisor to BRG and the chair of BRG's Kelompok Ahli, water management is uneven, with groundwater levels also at -60 cm to -80 cm, and as trials having been ongoing for less than a year it is premature to make statements about impacts on production.

Non-burning *demplot* Pulang Pisau, Central Kalimantan
In 2017, a trial on non-burning agriculture was carried out with BRG support in a 1.0 ha demonstration plot (*demplot*) in Desa Sebangau Jaya, Pulang Pisau District, Central Kalimantan. Previously, the local community used burning as a tool to clear peatland scrub and weeds in preparation for rice planting, and the yield was around 2.8 tons per hectare. However, following the ban on the use of fire for clearing villagers were reluctant to replant and the area was fallow. In the trial approach, the area was cleared using machetes and sprayed with a decomposer mixture (*biang kompos*), and the trial yielded 4.5 tons for the one ha area. There are now plans to upscale the trial to 10ha and expand it with a further 16 ha in adjacent Desa Mekar Jaya. [note: additional information about the peat is lacking, as those involved on the trial did not have a peat auger, and the trial was too brief (one season only) to assess the impacts on subsidence. However, as rice does not perform well on deep peat it is assumed that peat depths are shallow or moderately deep, i.e. 1-3 m]

Non-burning demplot Teluk Meranti, Riau
Non-burning demplot in Desa Gambut Mutiara, Kec. Teluk Meranti, Riau. Farmers in this area normally use fire for clearing peatland in preparation for maize cultivation; this resulted in an average maize production of 0.5-0.8 tons/ha.year. The non-burning demonstration plot project carried out by Balai Penelitian Pertanian Lahan Rawa Banjarbaru involved the clearing of peatland without using fire, plus the application of dolomite (to reduce acidity) and fertilizer (N,P,K). Production figures raised to 3-5.5 tons/ha.year and there were plans for upscaling this significantly (Ar-Riza et al. 2010). [However, there are questions about the impacts of fertilization on emissions and peat loss (see 2.4), including an increase in N_2O emissions. Also, the study makes no mention of rewetting and it is likely that the peat area in this study was drained.]

3.2.2 Potential for paludiculture in Indonesia

The potential for paludiculture in Indonesia was assessed by Giesen (2015) who used his database of indigenous peat swamp forest plant species in Southeast Asia as a starting point and compared this with useful species as recorded by PROSEA (Plant Resources of Southeast Asia[18]), a programme that ran from 1990-2004 and set out its findings in 19 volumes. The results, which are summarized below, indicate that Indonesia's indigenous peat swamp flora holds a very significant potential for paludiculture. Since then, a guidebook on a limited number of key species has been produced by MoEF (FORDA) and Wetlands International (Box 10).

Summary of the assessment by Giesen (2015):

- 1376 higher plant species have been recorded in lowland Southeast Asian peat swamp forests
- 534 species (38.8% of total) have a known use
- 222 produce useful timber
- 221 are known to have a medicinal use
- 165 are used for food (e.g. fruits, nuts, oils), and
- 165 have been assigned "other" uses (e.g. latex, fuel, dyes).

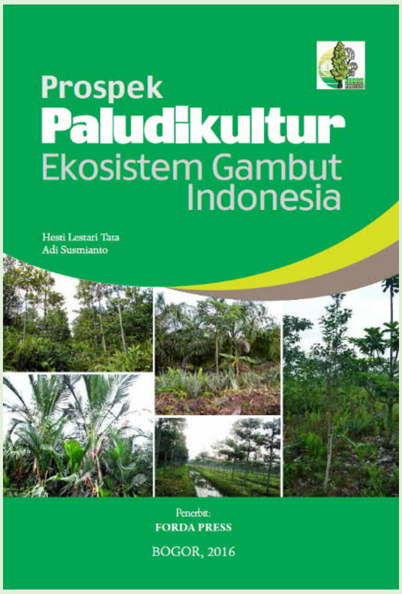
Many are known to have multiple uses and 81 non-timber forest product (NTFP) species have a 'major economic use' (as reported by PROSEA; reproduced here in Appendix 1). An initial economic assessment indicates that based on returns, some indigenous peat swamp forest species are potentially competitive with oil palm and *Acacia crassicarpa*. Also, swamp jelutung (*Dyera polyphylla*) is potentially an attractive alternative for local communities as the return on labour may be greater than for oil palm (Sofyuddin et al. 2012). However recent market studies indicate that this would need to be re-established for jelutung as the existing market folded following the steep decline in harvest from natural forests.

[18] http://www.prosea.nl/

A further assessment by the BGPP project (Kehijau Berbak 2017) of these 81 NTFP species with a potentially 'major economic use' assigned these species to four categories:

- 'quick gain' species (6 species), which are mainly herbaceous species that produce quick results (but have a lower unit value, although the overall market may be good); species include *Eleocharis dulcis* (purun or water chestnut), *Ipomoea aquatica* (kangkung or water spinach), *Momordica charantia* (paré or bittergourd), *Uncaria gambir* (gambir or gambier, a climber), and *Nephrolepis biserrata* and *Stenochlaena palustris* (both pakis, edible ferns).
- proven commercial species (6 species), namely *Aquilaria beccariana* (gaharu, which produces incense after inoculation), *Melaleuca cajuputi* (kayu putih or gelam, that produces poles, honey, oils), *Metroxylon sagu* (sagu, producing flour/starch), *Dyera polyphylla* (jelutung, producing latex) and *Nothophoebe coriacea* and *Nothophoebe umbelliflora* (gemor, that produce bark used as insect repellent). These species have products of a known commercial value and are known to perform on (rewetted) peat.
- commercial species that require performance tests on peat (11 species), namely *Garcinia mangostana* (manggis or mangosteen), *Nephelium lappaceum* (rambutan), *Syzygium aqueum* (jambu air), *Shorea stenoptera, S. pinanga, S. seminis, S. macrophylla* (tengkawang or illipe nut), *Aleurites moluccana* (kemiri or candlenut) *Pometia pinnata* (kasai or matoa) *Syzygium polyanthum* (salam, daun salam) and *Terminalia catappa* (ketapang). These species have products of a known commercial value and occur in natural peat swamp forest, but their performance (e.g. fruit production, growth rate) on peat is unknown.
- rest species: many uncertainties: market studies, ecological studies (58 species); the remaining species have many uncertainties at present, but warrant further study as they appear to hold potential.

Box 10. Handbook on paludiculture in Indonesia



A guidebook on paludiculture (in Indonesian) was published jointly by FORDA (MoEF) and Wetlands International – Indonesia Programme in 2016 (Tata & Susmianto 2016). This describes a small number of key species in relative detail, namely sago (*Metroxylon sagu*), nipah[19] (*Nypa fruticans*), jelutung rawa (*Dyera polyphylla*), ramin (*Gonystylus bancanus*), belangiran (*Shorea balangeran*), gemor (*Alseodaphne coriacea, Nothaphoebe sp.*), gelam (*Melaleuca cajuputi*), tengkawang (*Shorea* species) and purun tikus (*Eleocharis dulcis*).

[19] It is somewhat unusual that nipah is included in this booklet on paludiculture, as it does not occur in peat swamps but is confined to estuaries and brackish water coastal areas, and almost always on mineral soils. Note that the booklet does mention estuaries as being the natural habitat of this species.

Pulp species. In addition to these NTFP species, the cultivation of pulp species that do not require drainage is an area that is currently being tested by the Indonesian pulp and paper industry. Promising species are likely to be included among the 155 fast growing pioneer and secondary forest species recorded in Indonesian peat swamp forests by Giesen et al. (2017, submitted). These need to be tested for pulping properties (e.g. fibre length) and actual performance on rewetted peat. They are unlikely to perform as well as *Acacia crassicarpa* that on peat may reach harvesting maturity in only 4-5 years, but it must be noted that the latter has benefitted from many decades of domestication and optimisation (Thomson et al. 2001) and even if 'fast tracked' a new pulp species will probably require at least 5-10 years of trialling and optimisation before reliable production is attained.

3.2.3 Cases of paludiculture in Indonesia

Although the term 'paludiculture' was unknown until recently, the practice of paludiculture has been carried out, in some cases more than 100 years, and these examples need to receive attention. These include smallholder sago plantations in Riau, a medium-scale jelutung plantation in Jambi, and tengkawang (illipe nut) in West Kalimantan. These are described in brief below and summarised in Table 4.

***Metroxylon sagu* (sago)** is cultivated in various parts of Indonesia and is especially popular in Papua and parts of Sumatra (Aceh, Riau). In Riau sago cultivation is concentrated in Kepulauan Meranti District (Pulau Padang, Pulau Rangsang, Pulau Tebingtinggi) and Pulau Bengkalis, where it is cultivated on peat of 1-3 m depth, and the strait between Bengkalis and Padang islands is locally renown as the 'pusat sagu' (centre of sago cultivation). On Pulau Padang, sago was observed to be cultivated on moderately deep peat (1-3m, av. 2.3 m[20]) that was slightly drained (10-20 cm) to facilitate easy access on foot, although for growth this is not necessary. For harvesting, trunks were cut into sections of about 1.5-2 metres and rolled out along a simple makeshift rail system made out of poles (Photo 5; Giesen, 2013). Old topographic maps indicate that sago plantations have occurred in this area more than 100 years. Economic studies on Pulau Padang (Sonderegger & Lanting, 2011; Karyanto, 2012) show that sago appears to be a lucrative business, as the three small factories operating on the island, all using sago from deep peat, have a combined gross income of about 1.4 million USD (IDR 15 billion). The average revenue per hectare was about USD 510 (IDR 6.7 million), based on extensive plantations with low inputs. Not all areas are equally productive, and studies funded by JICA in Riau show that sago requires potassium (K^+) in order to be productive on deep peat (pers. comm. Prof. Osaki, 1 November 2017).

***Dyera polyphylla* (jelutung)** was cultivated near Sungai Aur village, Tanjung Jabung Timur district, in Jambi, by the company PT Dyera Hutan Lestari, from 1991-2004 and by 2004 a total of about 2,000 ha had been planted and latex tapping already occurring (Muuss 1996, Giesen 2004; photo 6). However, there were problems with peat desiccation as the hydrology had not been rehabilitated and fires destroyed most, especially in 1997, and the plantation has subsequently been abandoned. By 2013 all that remains was the DHL nursery at Sungai Aur, which supplied seedlings to projects and villages (pers. comm. ICRAF 2013). Various projects and programmes in Jambi have continued with the planting of jelutung, including the ICRAF programme on Reducing Emissions from All Land Use (REALU) and programmes by the Forestry Department (Sofiyuddin et al. 2012), and jelutung can now be regarded as well on the road to domestication (Tata et al. 2016). The planting of jelutung has not been without problems, though, as the areas planted with jelutung have often not been hydrologically rehabilitated and planted areas subsequently burnt. Also, the market for jelutung collapsed when the production of jelutung from natural forests dwindled as forests disappeared, and regulations put in place to control harvesting of jelutung from natural forests now hampers jelutung production from planted areas (Tata et al. 2016; see 3.2.5).

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[20] Whether sago does well on deep peat (e.g. 4-8 m depth) is not well established, and it seems to perform best at riverine margins of peatland rather than in dome areas. It has recently been established that sago performs better if peat is more humified (Sim et al. 2017).

***Shorea* spp. (tengkawang or illipe nut)** consists of a group of about a dozen dipterocarp species (mainly *Shorea*) that produce nuts that produce a valuable oil/butter that can be used as a substitute for cocoa butter. Trials were carried out at Segedong-Samandaka, West Kalimantan, by Inhutani and UGM from 2003-2009, and a total of about 2,200 ha were planted along lines. Species planted are mainly *Shorea pinanga* and *S. macrophylla and S. stenoptera,* but also *Shorea guiso, S. teysmanniana, S. compressa, S. balangeran* and *Vatica mangachapoi*. Tengkawang are not known from peat soils and these trials were initially accidental; however, these species perform well on (moderately) deep peat of 2m to more than 3m deep, and have been planted in lines in peat swamp forest that had been previously logged but undrained (Photo 7, Giesen, 2013). Surveys in 2012 indicate that all species appear to be performing well, although the nuts have yet to be harvested (mast fruiting had yet to occur). Mast fruiting[21] can be an issue, but there are also reports of cultivars (e.g. of *Shorea stenoptera*) that display annually flowering and fruiting (Coolen 2014).

Photo 5. Sago on Pulau Padang, Riau

Sago on Pulau Padang is of a relatively small size; trunks are cut into sections of 1.5-2m length and rolled out of the peatland on a makeshift rail made out of poles.

Photo W. Giesen (2012)

Photo 6. Jelutung plantation of PT Dyera Hutan Lestari, Jambi

Swamp jelutung Dyera polyphylla *was cultivated in a commercial plantation at Sungai Aur until 2004. Trees were being tapped after 7-8 years (see photo). However, the hydrology was not rehabilitated and the area was vulnerable to fires that affected the area in 1997 and 2004.*

Photo W. Giesen (2003)

[21] Mast fruiting can be defined as a mass-seeding phenomenon exhibited by some species of plants, which can be defined as "synchronous production of seed at long intervals by a population of plants" (Janzen 1976).

Photo 7. Tengkawang planted by UGM & Inhutani on deep peat in West Kalimantan

Tengkawang is not known to occur in peat swamp forest, but was found to perform well on undrained peat of 2-3m depth. Ferns are due to open nature of areas cleared around planted trees.

Photo W. Giesen (2012)

Table 4 Existing & planned paludiculture in Indonesia

No.	Name & location	Species	Area (ha)	Notes
1	PT Dyera Hutan Lestari, Sei Aur, Jambi	jelutung (plus some pulai)	2000	Active from 1991-2004; abandoned after repeated fires. Muuss (1996), Giesen (2004)
2	Bengkalis & Kepulauan Meranti, Riau	Sago	Several 10,000	These are traditional, extensive sago plantations that have existed >100 years. Giesen (2013) & Sonderegger & Lanting (2011)
3	Inhutani / UGM, Segedong-Samandaka, W. Kalimantan	Various tengkawang: Shorea pinanga, S. macrophylla, S. stenoptera, S. guiso, S. teysmanniana, S. compressa, S. balangeran & Vatica mangachapoi	2220	The location is not actively managed, and the paludiculture trials were 'accidental', from 2004-2008. Requires follow-up studies and management input. Giesen (2013)
4	CKPP location Central Kalimantan	jelutung, plus a variety of PSF species (40 in all)	1500	Wetlands International – Indonesia Programme. Project ran from 2005-2009. (Wetlands International – Indonesia Programme 2008).
5	Sebangau NP, Central Kalimantan	Natural species (jelutung, pulai, kahui, etc...)	n.a.	From 2005-2009 176 box dams were constructed, and areas on and around the dams planted with a mix of PSF species. WWF website[22]
6	Conoco Phillips, Tahura, Jambi	jelutung, pulai, gelam, pinang, bintangur, tengkawang	200	200 ha planted in 2016-2017; 300 ha planned by 2018; pinang, bintangur & tengkawang failed (died after rewetting). (this report)

[22] http://d2d2tb15kqhejt.cloudfront.net/downloads/wwf_id_mitigasisebangau_v3screen.pdf

7	Balai Litbang LHK Palembang, South Sumatra	jelutung, ramin, punak (Tetrameristа glabra), kahui (Shorea balangeran), pineapple	20	20 ha planted in demplot, from 2012-2014; initially without rewetting (as not necessary at the time, drainage was constructed in plantations around the plot after the plots were already revegetated), but with BRG assistance this is now scheduled to happen, along with establishing agrosilvofishery in an adjacent 10ha plot; Bastoni et al. (2016 & pers. comm. 2017).
8	LESTARI project, with various sites in Indonesia including Pulang Pisau district, Central Kalimantan	As yet not determined.	30,000 planned	USAID funded programme. Peat dams for 30,000 ha of Blok C to be constructed by PU via contractors in 2018. LESTARI support for Hutan Desa as well as agroforestry. Pers. comm. C. Bennett (2017).
9	Tri Pupa Jaya plantation in South Sumatra (part of APP / Sinarmas)	pulai Alstonia scholaris, jelutung Dyera polyphylla, Palaquium burckii and Shorea leprosula. (limited area only)	2000	The idea behind the retiring plantation areas of Acacia crassicarpa on deep peat is to create a bufferzone between plantations and adjacent protected areas. In 2016 APP decided to retire a total of 7,000 ha, including 3,400 ha in the Tri Pupa Jaya plantation in South Sumatra, adjacent the Sembilang National Park. By September 2016, about 2,000 ha had been rewetted by means of compacted peat dams, and Acacia had been clear-felled and removed, and there had been some limited planting of PSF species.
10	Tanjung Leban, Bengkalis restoration site University of Riau	jelutung, meranti, rubber	2.25	2008, with five (5) box dams lined with geotextile, filled with sand & peat; spillway -25 cm. (pers. comm. H. Gunawan, 2017)
11	Katingan Peatland Restoration and Conservation Project, Central Kalimantan	gelam, jelutung, pulai, kahui (Shorea balangeran), for fire break, not harvest	1.23	Katingan is being implemented as an ecosystem restoration project by PT. Rimba Makmur Utama. Monitoring & Implementation Report June 2016[23]. Planting is per June 2015.
12	Tanjung Leban Bengkalis Permanent Research plots, Riau	mainly jelutung planted in the 1 ha PSF mix plot	3	CIFOR, University of Riau, Global Landscapes Forum; established 3x 1ha plots in 2016-17, one with rubber, one with OP, and a third with mix PSF species. No hydrological rehab, only sluice-gate. (Murdyarso et al. 2017)

[23] PT RMU (2016). www.v-c-s.org/wp-content/uploads/2016/06/CCB_IMP_REP_1477_13JUN2016.pdf

13	Londerang site, Jambi, WWF funded by MCA-I, Jambi	Plan to replant 200 ha: 75% with jelutung, 25% with jackfruit, mango, durian, rambutan and cempedak. [note: these are not adapted to full rewetting]	12,600	MCA-Indonesia funded project in HL Gambut: 70 box dams including 10 large (>6m) and 60 small (partly completed). Planting of 200 ha planned with the 12,600 ha area; by 25th October 2017 25ha completed. Antara News[24] & pers. comm. WWF
14	TAHURA Orang Kayo Hitam, Berbak GPP MCA-Indonesia funded, Jambi	60,000 seedlings jelutung (2/3s), gelam, sago, tembesu rawa, meranti rawa	8,000	125 compacted peat dams planned in the uncontested southern part of the 18,200 ha Tahura. By 31 Jan. 2018 48 canal blocks had been completed (30) or underway (18). A total of 53 ha had been planted by sub-contractor.
15	PT Tolan Tiga Indonesia, Sungai Barumun, Riau	Meranti & tengkawang species: Shorea stenoptera, S. pinanga, S. seminis, S. leprosula & S. selanica	10	This is a trial, conducted in 2017 with mainly tengawang species; first results shhow high mortalities, mainly due to seedling size and lack of experience. New trials planned.
16	Asia Pulp & Paper, Siak, Riau	Melaleuca cajuputi, Campnosperma coriaceum, Cratoxylum arborescens, Shorea balangeran.	16	Alternative species for pulp production being tested, as an alternative to Acacia crassicarpa; 2016-2017; ongoing.

A number of small scale trials (demplots) in peatland are underway (2017) in Central Kalimantan, under programs by CIFOR and Universitas Muhammadiah Palangkaraya (UMP), for example, a 30 ha plot (of which 5 ha to be planted in January 2018) at Kalampangan Village, Sebangau Kota Sub-district, Pulang Pisau District, a 2 ha area in Buntoi Village, Kahayan Hilir Sub-district, Pulang Pisau District, and a 2 ha Education Forest in Mungku Baru, Palangka Raya (by Kerjasama Kemitraan Penelitian dan Pengembangan Pertanian Nasional/KKP3N, Ministry of Agriculture). However, in most cases inappropriate species are being planted, such as:

- kaliandra (*Calliandra calothyrsus*) and gamal (*Gliricidia sepium*): these are both exotic dryland species from Central America, unsuited to rewetted peat; as they are legumes and nitrogen fixers, they will also 'fertilize' the soil and speed up peat decomposition.
- kemiri sunan (*Reutealis trisperma* (Blanco) Airy Shaw; formerly *Aleurites trispermus*); this species naturally occurs in Indonesia, but is a drylandf species unsuited to rewetted peat (it requires significant drainage).

The only species being trialed at present by CIFOR and UMP in Kalampangan Village (Sebangau Kota Sub-district, Palangka Raya), Central Kalimantan that may be suited to rewetted peatland is nyamplung (*Calophyllum inophyllum*) on 5 ha, and mempari (or malapari, *Pongamia pinnata*[25]) on 3 ha; however, the degree of adaptation to rewetted peat may depend on the provenance of the seeds/seedlings, as nyamplung also occurs in coastal areas (on sandy soils) and a number of other dryland habitats, while mempari may also occur in many habitats, including coastal areas.

[24] http://jambi.antaranews.com/berita/319181/wwf-indonesia-siapkan-70-sekat-kanal-di-jambi

[25] Recent taxonomic revisions suggest that this species may be renamed as *Millettia pinnata* (see: https://en.wikipedia.org/wiki/Millettia_pinnata)

3.2.4 Mycorrhizae & PSF species

It has emerged over the past two decades that many (but not all) peat swamp forest species engage in symbiosis with mycorrhizae (Tawaraya et al. 2003). These are fungi (or fungi-like) species that live in the rhizosphere (i.e. around or in the root system of the trees or shrubs) and can play an important role in nutrient uptake (Sulistiyanto, 2005) and/or reducing infections with less desirable or detrimental microorganisms. There are predominantly two types of mycorrhizae: ectomycorrhizae that live around on the outside of the (cortical cells of the) roots, while arbuscular mycorrhizae penetrate the cortical cells of the roots of a vascular plant. According to Tawaraya & Turjaman (2016) mycorrhizal fungal diversity is higher in tropical forests than in other forests, and colonization of PSF tree roots by mycorrhizal fungi improves plant growth of many tree species grown in the tropical forests. Also, the survival rates of colonized seedlings of tree species are higher than those of non-colonized seedlings.

In peat swamps arbuscular mycorrhizae have been identified in at least 53 common PSF tree species (Appendix 2), while ectomycorrhizae are common in most dipterocarp species, including in peatland dipterocarps. This means that PSF dipterocarps may be colonized by both arbuscular and ecomycorrhizae. A common PSF tree species in which mycorrhizae have not been identified to date is *Combretocarpus rotundatus* (Tawaraya & Turjaman 2016).

When collecting wildlings (i.e. PSF seedlings germinating in the wild) these should be collected along with the peat surrounding the root ball in order to reduce root damage and encourage development of symbiotic mycorrhizal relationships as these fungi will already be present naturally (Tawaraya et al. 2003). According to Tawaraya & Turjaman (2016), the inoculation of mycorrhizal fungi at the nursery stage is a useful technique for largescale remediation programs of degraded tropical forests. Selection of appropriate combinations of PSF tree species and mycorrhizal fungal species is also important for successful colonisation and effectiveness of the symbiotic relationship.

3.2.5 Regulatory obstacles for paludiculture in Indonesia

In spite of the overall potential and a number of promising examples (e.g. sago, jelutung, tengkawang), paludiculture has not really expanded much over the past five years. The area under paludiculture cultivation remains limited (see Table 4) and is not expanding as rapidly as one might expect. The reasons for a lack of expansion of paludiculture are various, but include knowledge gaps (see 4.2.5), market vagaries, and the lack of a supporting regulatory environment. Markets for some paludiculture species such as jelutung collapsed when production from natural forests (where this was being harvested) ceased, and resuscitating these markets will require investment (see section on revitalisation).

Importantly, the regulatory environment affecting the development of NTFP cultivation on rewetted peat is complex, time-consuming and far from supportive. These regulations were developed in order to regulate and control the harvesting and sale of NTFPs from natural forests, but now serve as a major obstacle to the development and domestication of these products. For example, according to Tata et al. (2016), taxation on jelutung was established because until recently most jelutung was still derived from natural forest stands and the regulation was meant to curb pressures on natural stocks. In the meantime, natural jelutung stocks have depleted to the point that they are not longer being harvested, but the deterrent now hampers the development of cultivated jelutung. Some key regulations affecting the development of NTFPs are described below.

- Co-operation between communities & MoEF. Social forestry and cooperation with local communities is not possible in most types of state forestry land, except in the case of Hutan Desa (Village Forest) and Hutan Kemasyarakatan (Community Forest), where this can be allowed on the basis of *Peta Indikatif Areal Perhutanan Sosial* PIAPS (= indicative maps of social forestry areas).

- Permits required for harvesting NTFPs. Government Regulation No.41/1999 and No.6/2007 (on harvesting of NTFPs in Indonesian state forests) call for the issuing of permits (*Izin Pemungutan Hasil Hutan Bukan Kayu* – IPHHBK). This is also stipulated in the Ministerial Regulation of the Forestry and Environment Department No.46/2009 and No.54/2016.
- Permits required for processing NTFPs. To further process NTFPs, an NTFP Primary Industrial Business Licence is required (Izin Usaha Pemanfaatan Hasil Hutan Bukan Kayu - IUPHHBK) which may be obtained by individuals, firms and cooperatives as per Regulation No.6/2007.
- Permits to trade NTFPs. To trade NTFPs derived from state forests, Forestry Ministerial Decree No.55/2006 requires permit holders to present NTFP freight invoices. In practice, obtaining such freight invoice requires going through cumbersome official procedures; NTFP extraction permit holders need to produce NTFP production reports, which needs to be followed up with a legalization appeal to the official certifier at the provincial level and the head of the district agency.
- Taxation of certain NTFPs (such as jelutung). Once the NTFP production report (see previous) is certified, it is used to calculate a forest resource provision payment as per Trade Ministerial Decree No.12/2012, which states that for Jelutung latex, IDR60.000/kg needs to be paid. It also covers products such as rattan, resins and jernang (dye from certain rattans).

3.2.6 Paludiculture and degree of flooding

Paludiculture is not a panacea for rehabilitating all areas of degraded peatland, as areas that are very severely degraded and subject to regularly and/or prolonged floods (Types D1 and D2 in Table 3), this approach would not be possible as the flooding is too severe for most paludiculture species. However, in degradation type C1 (Table 3) one will also have to differentiate between areas that are rarely or not flooded and other areas that may be regularly flooded, as each paludiculture species will respond differently, and gradients in degree of flooding are likely to be encountered. The list of promising economically beneficial paludiculture species provided in Appendix 1 have been tentatively assessed as to their flood tolerance, and this is provided in Appendix 3.

3.2.7 Knowledge gaps re paludiculture

Performance of potential NTFP species on rewetted peat

As mentioned in 4.2.2, many species have been identified as having potential for paludiculture programmes, as they occur naturally on peat (i.e. peat without drainage) and have a known economic value. However, usually very little is known about how these species perform on peat and this lack of knowledge of many promising species on rewetted peatland leads to an understandable reluctance of farmers to invest in these commodities. Out of the 81 species short-listed by Giesen (2015), only 12 are reasonably well known and can be trialled – the remaining 69 species all require further study as to how they perform on peat. [What is also poorly understood for many species is their markets and value chains; however, this is part of the revitalisation component of RRR and is dealt with in chapter 4.2.]

Impact of NTFP cultivation on peat hydrology

Peat adapted NTFPs will have different impacts on the hydrology of rewetted peat, depending on various factors such as planting density, potential for intercropping, growth rates, methods for harvesting, evapotranspiration rates, and so on. Some NTFP crops are likely to have a more positive impact on the hydrology of rewetted peat than other NTFP crops. Similarly, intercropping/mixed agroforestry approaches are likely to be more beneficial for peat hydrology than monocultures, as humidity is likely to be higher if the vegetation has various layers/strata. In any case, such impacts can only be guessed at at present and require further study, in order to optimize NTFP cultivation so that positive impacts on peat are maximized.

Low impact access to rewetted peatland

Once peat hydrology is restored (by canal blocking) and the rewetted peat is replanted with promising, peat-adapted NTFP species, the major challenge to the success of maintaining such a system is providing low impact access so that NTFPs can be harvested. On many past and existing programmes, this issue has been ignored, or dealing with the issue postponed. However, this can jeopardize the entire system as was seen in the case of the jelutung plantation in Sei Aur; in this area rewetting was not carried out as the canals were used to provide access, and in the end the 2000 ha plantation succumbed to repeated fires that killed >90% of the trees (see 4.2.3). Current programmes and practices shy away from the problem by promoting the construction of box dams with spillways that allow the passage of small boats (Box 6), but this needs to change as dams with spillways are less than 100% effective in rewetting and are unsustainable in the long-term. Basically there are three main approaches for facilitating of access in fully rewetted areas, namely alternatives for crossing canal blocks, trail systems and adjusting the timing of harvest; these are described in more detail below. *However, none are optimal at present, and practical studies are required to develop a low cost, low impact approach for accessing rewetted peat*.

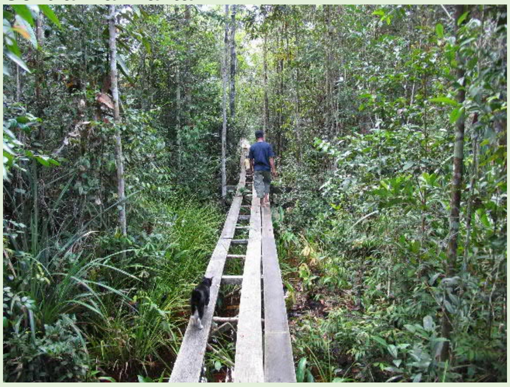
- Alternatives for crossing canal blocks. Canal blocks without spillways can be passed by other means; one way is moving the goods from one boat to another at each block, which is time consuming and requires investment in extra boats. Another way is using a ramp or slipway as common in Europe and North America (this can involve smooth timber or simple rollers); the main issues are size of the boat and the maintenance of the slipway. Another consideration is that canal blocking may directly involve canal infilling, or full rewetting may result in the gradual infilling of the canal if it is not maintained. In both cases canals can no longer be used for transport.
- Trail systems. Trails can be constructed out of wooden planks, consist of planks on the ground, or of crude wooden rails (Box 11). One could also consider more durable systems such as metal rails as used by the logging industry, or walkways constructed out of durable plastics. The main issues here are investment costs (esp. for the durable types), and high environmental impacts and maintenance required for wooden varieties. A possibility is also creating a ‘crust’ out of cement, although this does not last long and has its own (localized) impacts on peat.
- Adjusting the timing of harvest. Certain products may only require harvesting once or twice a year, and if this could be timed during the dry season then access on foot may be sufficient, especially if the products are low volume/high value.

Box 11. Examples of trail & rail systems in peatland

Logging rail in use in Jambi

Kuda-kuda rail used by illegal loggers in Central Kalimantan

Simple 'rail' used for moving sago trunks, Riau



Wooden walkway, Mawas, Central Kalimantan

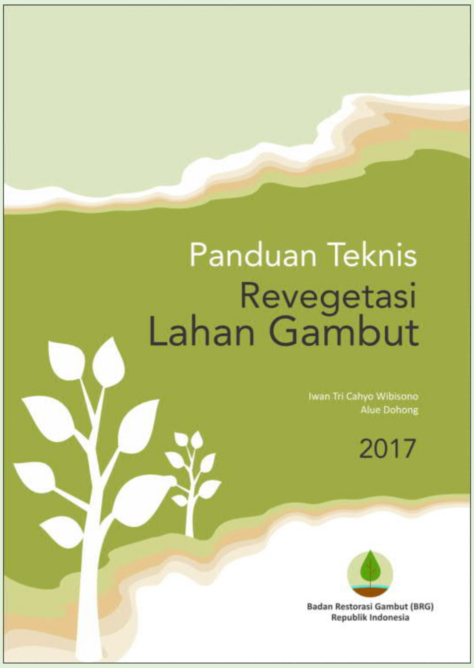
Photos W. Giesen (clockwise starting top-left: 2003, 2008, 2008 & 2012)

3.3 Ecological restoration

3.3.1 Guidelines for ecological restoration

A very practical technical guideline for revegetation of peatland areas has been drafted for BRG by Wibisono and Dohong (2017). This booklet (Box 12) covers all practical aspects related to the establishing of nurseries, the sourcing of seeds of PSF species, peat land preparation prior to planting, tending of planted seedlings and monitoring of the results. It also provides a list of PSF species that could be considered for such replanting programmes. It does not cover paludiculture species for economic benefit, nor does it cover costs or the application of mycorrhizae (fungi) for improving performance of planted seedlings. What is covered are a wide range of practical aspects for revegetation of (semi-) natural degraded peat swamp areas.

Box 12. Technical handbook on revegetation of peatland



A practical guidebook on the revegetation of degraded peatland areas (in Bahasa Indonesia) by Wibisono and Dohong (August 2017).

As elaborated in 3.1, ecological restoration is to focus on two types of areas, namely:

1. areas that are severely degraded with <1% tree cover, and subjected to extensive and prolonged flooding, are burnt many times, have a long history of drainage and subsidence, and are subject to frequent flooding and seasonal ponding and lake formation (D1 and D2 in Table 3), and
2. areas that are severely degraded, but still have 1-5% tree cover, have a conservation status *daerah konservasi* and are not as severely flooded (C2 in Table 3).

Hydrological rehabilitation (canal closure/rewetting) is a prerequisite, along with fire detection and prevention measures. Revegetation is required for larger areas, involving the planting of mainly fast growing and hardy pioneer species that can tolerate flooding and exposure to drought (in D1 and D2), in combination with hardier ecologically desirable species (in C2). The latter should include fruit species that are attractive for wildlife, such as wild figs (*Ficus* species), wild nutmegs (*Knema & Myristica* species), and jambu (*Syzygium* species). Note that seed banks are practically non-existent in peat swamp forests. Even in undisturbed PSFs the number of seeds per m^2 are lower than in other lowland rain forest forest types and the period of seed viability is often short-lived (Graham & Page 2017); after a major disturbance (forest clearing, drainage), this drops dramatically and after fires becomes zero (Graham et al. 2016). Seed dispersal plays a role in limiting regeneration. Distance to the forest edge plays a role and after a modest distance (100-200 m) seed dispersal for tree species depends on facilitation by wind, water or animals. In the tropics, animals are responsible for the dispersal of seeds of 50-90% of tree species with birds being most important. Graham and Page (2011) tested how effective bird perches were in assisting regeneration of peat swamp forest species, but found that while this approach resulted in increased numbers of seeds there was no increase in recruitment. Importantly, only degraded area tree species appeared aided and not species of primary forests.

Blackham et al. (2014).in their study of natural regeneration of PSF in Central Kalimantan found that along their transects in deforested areas, most woody species found in their plots also grew in mature forest, but “regrowth was dominated by a few abundant wind-dispersed species (particularly *Combretocarpus rotundatus*) and most other species were potentially dispersed by bulbuls

(Pycnonotidae) and other small- to medium-sized birds. Most regeneration reflects the availability of dispersal agents, with additional woody species probably sprouting from vegetative remnants of the previous forest cover, although a role for additional dispersal agents cannot be ruled out." They conclude that "Continuous woody canopy cover is probably achievable by unassisted regeneration in degraded peatlands, but it will be slow and patchy with low species diversity. We recommend enrichment planting with species from intact peat swamp forest, but only after an initial survey of the existing regrowth."

Giesen and van der Meer (2009) provide lists of PSF species that are adapted to various flooding depths, and for the deeper flooding regimes, these are summarized in Table 5. In the most severely degraded areas that are flooded much of the year, only a few options are available, namely rasau, bakung and sedges that can float, retard water flow and cause infilling of canals and shallow depressions (type 1 flooding areas). In flooding types 2 and 3 more tree species could be used. [note that this list is not exhaustive, but indicative]. Wibisono and Dohong (2017) provide lists of species suited for various levels of degradation (i.e. types of cover), and this is summarized in Table 6. Means of propagation of various PSF species for ecological restoration, as provided by Wibisono and Dohong (2017) is summarized in Appendix 3.

Table 5 PSF species suitable for rehabilitation programs under various flooding regimes

No.	Type of flooding	Species	Lifeform
1	Deep, semi-permanent	Hanguana malayana (bakung)	floating very large herb
		Hypolytrum nemorum	large sedge
		Pandanus helicopus (rasau)	shrub to small tree
2	Deep and prolonged	Combretocarpus rotundatus (tumih)	tree
		Lepironia articulata (purun)	sedge
		Mallotus sumatranus (perupuk)	tree
		Morinda philippensis	climber/straggler
		Psychotria montensis	climber/straggler
		Stenochlaena palustris (pakis, kiapak)	climbing fern
3	Moderately deep flooding	Blechnum indicum (pakis)	fern
		Cratoxylum glaucescens (geronggang)	tree
		Ploiarium alternifolium (asam-asam)	tree
		Shorea balangeran (belangiran, kahui)	tree
		Stenochlaena palustris (pakis, kiapak)	climbing fern

Note: adapted from Giesen & van der Meer (2009).

Table 6 PSF species suitable for rehabilitation programs under various levels of degradation

No.	Type of degradation	Species
1	Lightly burnt areas or areas of clear-felling. Newly cleared or early stages of succession.	Alstonia pneumatophora, Alstonia spatulata, Combretocarpus rotundatus, Cratoxylum arborescens, Cratoxylum glaucum, Dyera polyphylla, Horsfieldia crassifolia, Macaranga pruinosa, Melaleuca cajuputi, Shorea balangeran, Syzygium sp. In more flooded areas: Alstonia pneumatophora, Alstonia spatulata, Campnosperma coriaceum, Lophopetalum multinervium, Metroxylon sagu.
2	Lightly burnt areas or areas of clear-felling. Has experienced more advanced stages of succession.	Alstonia pneumatophora, Alstonia spatulata, Combretocarpus rotundatus, Cratoxylum arborescens, Cratoxylum glaucum, Dyera polyphylla, Horsfieldia crassifolia, Macaranga pruinosa, Melaleuca cajuputi, Shorea balangeran, Syzygium sp. For areas where shade trees are present: Campnosperma coriaceum, Gluta (Melanorrhoea) wallichii, Shorea bracteolata, Shorea pauciflora, Shorea smithiana
3	Selectively logged areas, where economically useful species have disappeared. Land cover = degraded forest.	Aglaia rubiginosa, Calophyllum hosei, Diospyros areolata, Durio carinatus, Koompassia malaccensis, Licania splendens, Madhuca motleyana, Neesia malayana, Palaquium cochleariifolium, Palaquium leiocarpum, Tetramerista glabra, Vatica sp.

Note: adapted from Wibisono & Dohong (2017)

3.3.2 Pitfalls in revegetation for ecological restoration

Aerial seeding

MCA-Indonesia is currently (September 2017) funding an aerial seeding programme in South Konara District, Southeast Sulawesi, that is being implemented by the Kalla Foundation. This initiative aims to restore 7,000 ha of degraded land, and 5,500 ha of this that is rather inaccessible will be targeted for aerial seeding with *Gmelina, Acacia mangium, sengon buto [Enterolobium cyclocarpum /* elephant ear tree*]* and red and white *Calliandra*. This foundation has experience with aerial seeding since 2009 and find that they have a 3.8% success rate[26]. In the same article, though, MoEF's DG of protected forests and river bank control, Pak Hilman Nugroho, stated that 22,000 seeds were distributed per 100 ha, with a germination rate of 25% (Jakarta Post, 19 September 2017). Aerial seeding is often carried out in remote, inaccessible areas where there is lots of bare soil, and that is the case in remote hilly and mountainous parts of Southeast Sulawesi targeted by the Kalla Foundation. In degraded peatlands, however, the ground is often 100% covered with a thick and tall layer of ferns and sedges, that will outcompete any seedling planted unless an area is cleared beforehand and even then additional weeding is required several times in the first year after planting. Only under such conditions will a seedling stand a chance of survival, but seeds distributed at random in a very dense sedge-grass wilderness will have a zero chance of survival and should hence not be considered for such areas. An exception may be made for recently burnt areas where there is no ground cover, and even then there is likely to be lots of competition (from sedges and ferns, as these have wind borne seeds) and low survival rates.

[26] This is a reasonably high figure. Hadipoernomo (1979; cited in MacDicken et al. 1997) reports an 8.5% survival rate of *Leucaena leucocephala* in aerail seedings trials in Central Java, but attempts with other species were reported as being far less successful.

Cost of revegetation

The cost of revegetation is often underestimated. On the whole it is often (much) more expensive than rewetting, and therefore should only be undertaken if the circumstances require this (e.g. if an area is devoid of woody vegetation) and provided that rewetting has alreday taken place or is occurring simultaneously. According to government regulation (Peraturan Menteri Lingkungan Hidup dan Kehutanan No. P.39/Menlhk/ Setjen/Kum.1/2016), planting is to occur at densities of at least 1100 seedlings per hectare, and hence the price of seedlings and labour for planting and maintenance is costly. Prices vary depending on a range of factors such as distance to location and accessibility, species being planted, seedlings raised in own nursery or purchased on commercial market, and so on. According to BRG[27], the costs range from USD 500-3000 per ha, while CIFOR[28] estimates the cost to be about USD 2500 per ha.

BGPP example January 2018

As part of the BGPP project in the TAHURA OKH in the bufferzone of Berbak NP, 53 hectares of peatland (being rewetted) were planted[29] in January 2018 with 58,532 seedlings of five peat swamp species, namely jelutung rawa (*Dyera polyphylla,* 40,435 seedlings), 'meranti rawa[30]' (*Shorea balangeran*, 3,150), tembesu rawa (*Fagraea fragrans,* 2,817), gelam (*Melaleuca cajuputi,* 6,170) and sago (*Metroxylon sagu,* 5,960). Monitoring carried out several weeks after planting showed an average survival rate of 91.5%, varying from 88% (gelam) to 93% (jelutung, meranti, tembesu). Gelam showed lower survival rates as seedlings were rather small and tender when transplanted. The average cost was USD 3,475 per ha, which is on the high side compared to BRG and CIFOR figures (above), but this was considered warranted given time constraints and difficult field conditions (wet season, with areas partly flooded). Clear planting lines and a good survival rate can be seen in the photos (8a-c).

[27] http://www.aktual.com/biaya-restorasi-lahan-gambut-hingga-3-000-dollar-per-hektar/

[28] https://www.google.co.id/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwjsoMzu35nXAhWKqI8KHZYCAvwQFggzMAI&url=https%3A%2F%2Fwww.rsis.edu.sg%2Fwp-content%2Fuploads%2F2016%2F10%2FCO16252.pdf&usg=AOvVaw3mcttvDCc2sO_IJsvYoTYT

[29] Planting work was sub-contracted to the local firm in Jambi, CV Gading Raya following MCA-I tendering procedures.

[30] The normal local name for *Shorea balangeran* is belangiran (Indonesian) or kahui/kawi (Kalimantan), and not meranti rawa. However, as *S. balangeran* is a meranti species and occurs on rawa, the confusion is understandable, especially as the species appears to have been introduced to mainland Sumatra in the past decades (it's natural distribution is Kalimantan, Belitung and Bangka).

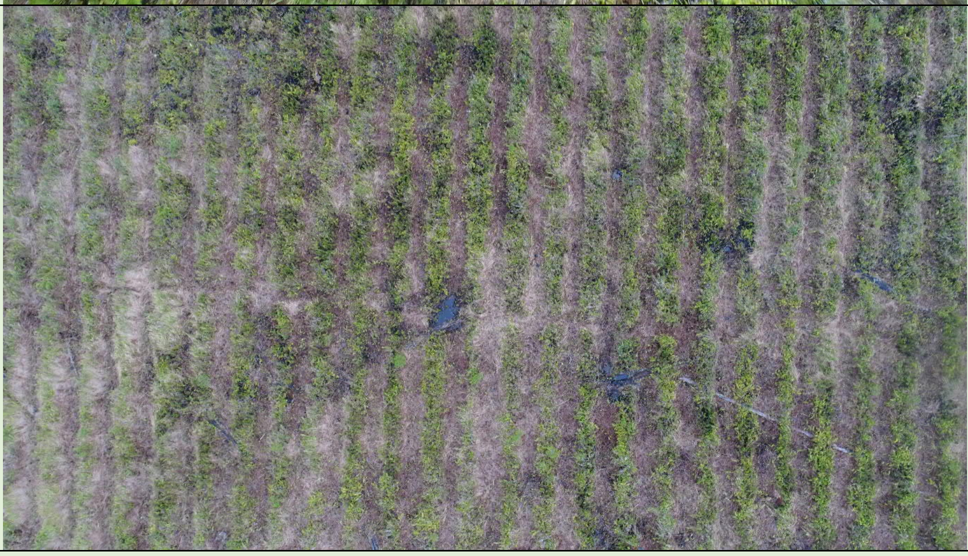
Photos 8a-c. BGPP replanting in the TAHURA OKH, Jambi, January 2018

8.a
All species were colour-coded (on poles); yellow for jelutung (= front specimen)

Photo by Wim Giesen, 28 Jan. 2018

8.b
Burnt logs etc.. can be seen in the replanted area

Drone photo by Nasrul Ichsan, 28 Jan. 2018



8.c
Replanted area seen from above (drone), showing wet areas & burnt (2015 fire) patches.

Drone photo by Nasrul Ichsan, 28 Jan. 2018

3.3.3 Knowledge gaps re ecological restoration

There are many gaps in our understanding of ecological restoration, some of which are of interest in peatland restoration efforts by BRG. Restoration efforts should ideally include species or species combinations that i) contribute to hydrological self-regulation, ii) contribute to the accumulation of large amounts of organic matter, and iii) inhibit growth of soil bacteria and fungi and thereby reduce decomposition rates. These areas are as yet not well understood and studies may focus on the following:

- Hydrological self regulation of PSF. Understanding how various peat swamp forest species or phenological types with various adaptations (e.g. stilt roots, buttresses, surface roots, etc..) and the hump-and-hollow structure of peat swamp forest floor contributes towards water retention. In our understanding of peat swamp forest hydrology it is apparent that most (84%) lateral flow in undisturbed PSF is along the surface rather than in the peat (16%; Baird et al. 2016). Dommain et al. (2010) demonstrate that the hump-and-hollows of undisturbed peat swamp forests likely results in a self-regulating mechanism for water retention and hydrological maintenance. How this could possibly be restored is not understood. Freund et al. (2017) evaluated topographical microhabitat preferences for 21 tree species in a relatively undisturbed tropical PSF in Central Kalimantan, Indonesia, to determine whether these species show preferential association with hummocks or hollows. Only one species emerged as having a preference (Tetractomia tetrandrum, for hollows), while the rest (95%) showed no clear microtopographic preference. According to Freund et al. (2017), “This suggests that many tropical PSF species may be resilient to the natural hydrologic variations that occur in relatively intact peat swamp forests.”

- Productivity of PSF species and contribution to peat development. Ideally, restored peat swamp forest would at some point begin to contribute to a renewed accumulation of organic matter in the soil and building up of peat. The productivity of various PSF species is unknown. About 150+ PSF species are known to be fast-growing pioneer species or species of secondary forests. Do these fast-growing species also contribute more to the accumulation or organic matter in the peat soil? Or do other mechanisms also play a role, such as lignin content?

- Polyphenol concentrations in (common) PSF species. It is known that plant polyphenols inhibit decomposition (see 2.6 and Yule et al. 2016) and thereby facilitates accumulation of peat. Polyphenol concentrations in Indonesian PSF species is largely unknown and unexplored.

- Return of ecosystem functions. When areas are rehabiltated via enrichment planting, large-scale replanting or via paludiculture programmes, it is anticipated that at least some of the key ecosystem functions are likely to return (e.g. biodiversity, water storage, and so on). This process or ecosystem function rehabilitation needs to be studied.

A phenomenon that is also not yet well understood and may present an obstacle to future restoration efforts is the role of smoke and haze from peatland fires on flowering and fruiting of plants. In preparatory work for establishing a nursery for PSF species in Riau in Q2-Q3 of 2016, the first author of this report observed an unusual lack of fruiting and flowering species in remnant patches of PSF. When discussed with *Acacia crassicarpa* plantation operators in the field, they also indicated noticing a surprising lack of flowering and fruiting in *A. crassicarpa* in 2016, while this species normally flowers and sets fruit (pods) throughout much of the year. As 2015 was an El Niño year with much peat smoke and haze, this could well have played a role in this surprising phenomenon. The ramifications are potentially significant, as a lack of fruit and flowers over much larger areas than simply burnt peatland and having an effect on a following year, could affect a wide range of wildlife populations, birds and insects. A study on the ecological effects of peatland smoke and haze therefore seems warranted.

Food species for wildlife. An additional consideration in revegetation efforts is the potential contribution to biodiversity conservation. PSF tree species that are favoured by wildlife and birds include fruit species such as various figs (*Ficus, Artocarpus, Parartocarpus,* of which about 30 species are known from PSFs), illipe nut (certain *Shorea* species), jambu-jambu (*Syzygium,* with 50 PSF species), manggis hutan (*Garcinia,* 19 PFS species) wild mango's (*Mangifera,* 6 PSF species) and wild nutmegs (including *Knema* 14 spp. and *Myristica* 15 spp.). Identifying which of the favoured food species do well in restoration efforts is a potential area that requires further study.

4. Revitalisation

Revitalisation is the third important tenet of peatland restoration after restoration of the hydrology (rewetting) and restoring a vegetation cover in rewetted peatland (revegetation). Revitalisation can be defined as "the action of imbuing something with new life and vitality", and in the case of restored peatland in Indonesia[31] this means ensuring that local communities are imbued with improved livelihoods, due to the provision of new or additional economic opportunities.

It is important (and indeed vital) on peatland restoration programmes that local communities are closely involved and have a stake in implementation. If there is no positive interest from the side of the communities, rewetting (e.g. canal closure) or revegetation (e.g. replanting with PSF tree species) will fail because of lack of maintenance or (worse) actions from the community to reverse or undo what has been restored.

The social and legal aspects associated with peatland restoration activities are defined in Peraturan Kepala BRG No. P.6/KB-BRG-SB/12/2016 Tentang Pedoman Pelaksanaan Kerangka Pengaman Sosial dalam Restorasi Gambut. The guidelines for implementing these regulations are provided in the BRG (2016) publication '*Pedoman Pelaksanaan Kerangka Pengaman Sosial Dalam Restorasi Gambut*' (Guidelines for Implementation of Social Safeguards in Peat Restoration).

4.1 Options for revitalisation

Local communities have drawn livelihoods from peatlands in Sumatra and Kalimantan for eons, but for a long time this consisted only of low impact and extensive extraction of NTFPs, such as collection of rattan, jelutung latex and hunting. In the wake of the logging industry and upsurge of commercial oil palm plantations, local communities have also tried to eke out a living with smallholder oil palm plantations, and by 2015 oil palm smallholdings on peat extend over a greater area than large-scale commercial oil palm plantations (chapter 1). In drained peatland, these smallholdings face the same issues as large-scale commercial plantations, including fires and flooding, and are equally unsustainable in the long-term. Faced with these issues, locals wonder about alternatives, especially as incomes from flooded oil palm holdings decline. In many locations there has been a surge of development of peatland, especially during the past five years, and in these attempts to promote livelihoods very often compromises have been made that lead to unsustainable solutions (Box 13).

At the United Nations Framework Convention on Climate Change (UNFCCC) Convention of Parties (COP) 22 in Marrakech, Morocco, from 8-16 November 2016, BRG confirmed that the revitalization of livelihoods in (areas surrounding) peatlands would be attained through the development of paludiculture farming systems, fisheries and ecotourism. These are indeed the key areas upon which sustainable livelihoods can be developed in restored peatland areas. However, what can be added to this is harvesting of NTFPs in (regenerated or restored) peat swamp forests.

[31] Elsewhere revitalisation can take on other, quite different meanings, for example, in UK studies on restored peatland revitalisation referred to the reinstating vigour into the soil microbial community (Lunt et al. 2010).

Box 13. Compromises leading to choosing unsuitable species

In order to promote long-term sustainability, rewetting and revegetation are required and promoted, but in order to meet the requirement of 'revitalisation' agencies often resort to compromises that lead to less sustainable solutions. Agencies often embark on programmes that promote the planting on rewetted peat of crops such as (Liberica) coffee, cocoa, pinang, coconut, bananas, cempedak, jengkol, maize, duku, durian, oranges, pepper, pinang, pineapple, red ginger rubber and dragonfruit. However, these are all dryland crops that require at least 30-40 cm drainage, so the degree of rewetting is limited to accommodate these crops. At the same time, canals are kept open and canal blocks are equipped with spillways to facilitate the passage of small boats. This results in a range of issues and unsustainability in the long-term.

Of the four livelihood types that can contribute to revitalisation of local economies, paludiculture probably holds the greatest potential. These rural communities are basically farming communities and paludiculture offers a sustainable way of continuing farming on peatland. The other sources of livelihood are more likely to benefit only a few within a community (e.g. ecotourism) or provide an additional or supplementary income at best (e.g. fisheries and agroforestry). These four sectors are described below in 4.2-4.5. In addition, restored peatlands may be registered for REDD+ and proponents may benefit from accrued carbon credits – this is beyond the scope of the current report but described briefly in Box 14.

Box 14. REDD+ in Indonesia

Restored peatlands may be registered for REDD+ and proponents may benefit from accrued carbon credits. Under such carbon schemes, benefit sharing with local communities is likely to occur, and depending on disbursement and development of the carbon market in general, this could form an important part of revitalisation of local communities. Such funds are likely to be distributed via regional or village level development funds, and could conceivably contribute to local development (e.g. via infrastructure development). However, it is beyond the scope of this report to go into details regarding REDD+ projects, and further reference should be made to:
http://theredddesk.org/countries/indonesia
http://www.unredd.net/regions-and-countries/asia-pacific/indonesia.html
https://www.cifor.org/redd-case-book/case-reports/indonesia/

4.2 Paludiculture and revitalisation

4.2.1 Paludiculture & local livelihoods

Paludiculture – as a concept in Indonesia – is described in detail in 3.2, while appendix 1 includes a short-list of 81 promising species. In order to promote paludiculture so that it benefits local communities and livelihoods, however, an additional number of barriers need to be overcome, and these include the following:

- Local acceptance of paludiculture approach.
- Local acceptance of these new commodities.
- Value chain and market development for paludiculture products.
- Technical knowledge on cultivation of many paludiculture species is very limited.
- Tenurial aspects, institutuional constraints and the development of paludiculture.

These are described in more detail below. On the whole, a flexible approach to paludiculture development is needed and not a 'one size fits all', and ideas for paludiculture need to be discussed extensively with the local community before any plans are laid out, as they need to be fully supported in order to be successful.

Local acceptance of paludiculture approach. The idea of rewetting peatland that has been drained strikes many in the local community as an odd thing to do, as agriculture and horticulture to date is all based on dryland species (except for rice). Most see that too much water is an issue, not too little, so a lot of awareness raising (*sosialisasi*) is required so that community members understand the paludiculture concept and the reasoning behind rewetting. The best approach is seeing and believing, and having a few successful examples where one can take local community members to see how it is done and what is achieved would greatly increase acceptance.

Local acceptance of new commodities. The short-list of potential paludiculture species (Appendix 1) can be a starting point for discussions with local community members about their options, but these species may not be locally known and there may not be any recent local experience. As with the paludiculture concept, the best approach is seeing and believing, and being able to demonstrate a few successful examples would greatly increase acceptance. Sago, for example, used to be far more widespread throughout Sumatra but nowadays it is mainly cultivated in Aceh (e.g. Singkil) and Riau (e.g. Kepulauan Meranti). In order to promote sago in Jambi, one could take a few interested community members to an active smallholder sago plantation in Riau and ask them to talk about this and give a simple presentation to other community members afterwards. Another approach would be to develop demonstration plots (*demplots*) near the location one wants to target with paludiculture; one drawback is that many species take at least several years before producing anything.

Value chain and market development for paludiculture products. Before a paludiculture programme is unleashed a market assessment is required to assess potential, and one may need to also invest in market development in order to guarantee a market for the paludiculture produce. Bottlenecks may exist such as a lack of transport infrastructure or a lack of local processing facilities, while other market handicaps may include lack of local knowledge about the product(s). For assisting and revitalising the local economy it is better if 'value added' can be attained locally, rather than exporting raw products. For example, rather than selling tengkawang (illipe) nuts or sago trunks to middlemen it would be better if the illipe nuts were processed to illipe butter or oil, or the sago trunks were processed to sago flour locally. This level of processing does not involve very advanced technology, and the gains that could be made in terms of economic benefit to local communities may be very significant. Distance and access to markets can also be an issue, and this depends also on the level of infrastructure development.

Technical knowledge on cultivation of many paludiculture species is very limited. The section on knowledge gaps (3.2.5) mentions that more information is needed about performance of promising paludiculture species on peat. However, in addition, a lot of technical knowledge is required on a wide range of topics, including:

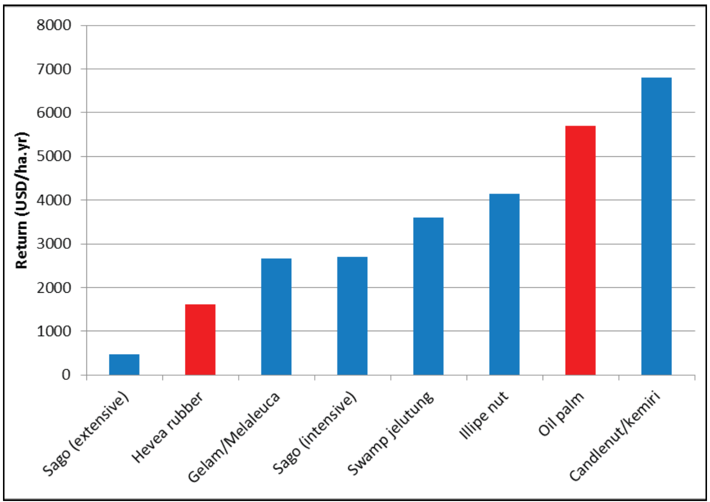
- Seed sourcing and treatment (how to store, how to assist germination). Jelutung (*Dyera polyphylla*) seeds, for example, if simply stuck into the soil the germination rate is low, while if placed vertically with the germination point facing up then this goes up to >90%. Many species have peculiar requirements re seeds and for most very little is known.
- Nutrient requirements.
- Intercropping possibilities, shade tolerance or requirement, inhibition by presence of certain species, and so on.
- Harvesting methods, tapping intensity tolerated, and so on.
- Product processing: storage of fruits, nuts, and so on.

Tenurial aspects, institutional constraints and the development of paludiculture. Rural communities may face tenurial constraints when wanting to develop paludiculture, as they may not have titles of deeds for the land they want to cultivate, and indeed they may have only usufruct rights. These legal/tenurial challenges need to be identified and addressed when development and supporting paludiculture programmes, otherwise the local community members may not be able to benefit. Recent regulations such as Permen. No. P.82/MENLHK/SETJEN/KUM.1/10/2016 on Social Forestry serve to provide clarity on usufruct and sharing rights (*bagi hasil*) between community members and the forestry agency involved. On the BGPP project in Jambi, a zoning plan developed for the TAHURA Orang Kayo Hitam involves the development of a 'Zona Koleksi' (ZK) and a 'Zona Permanfaatan' (ZP). A range of activities can continue in the ZP such as ongoing agriculture, although the aim is for this to be adapted to rewetted peat over time, and paludiculture. The ZK is to be replanted with useful peat swamp forest species and NTFPs are to be harvested by local communities, who will be given rights to do so in written agreements with the UPTD Tahura.

Institutional constraints may also occur in attempts to promote various forms of paludiculture, but these have yet to be properly identified, for example, in the ongoing value chain studies whereby stakeholders in the value chains are assessed and possible bottlenecks and constraints for paludiculture development identified.

Economic returns from paludiculture. Paludiculture has the potential to provide significant economic returns, depending on the commodity and the development of the market. As most commodities are tree crops (see 3.2 and Giesen 2013), however, it usually takes from 5-10 years before returns emerge as it takes this long for trees te begin producing fruits, latex and so on. A solution is to intercrop with annual crops until these are shaded out, and by that time the trees will usually have started producing. Intercrops that could be considered are herbaceous species such as gambir (*Uncaria gambir* or gambier), kangkung (*Ipomoea aquatica* or water spinach), pakis (*Nepholepis biserrata, Stenochlaena palustris* or edible ferns), paré (*Momordica charantia* or bitter gourd) and purun tikus (*Eleocharis dulcis* or water chestnut). Financial returns of various commodities on peat are provided in Figure 5. These financial returns are tentative, as few studies of commodities grown on peat exist, except on sago (*Metroxylon sagu;* Sonderegger and Lanting, 2011) and swamp jelutung (*Dyera polyphylla;* Sofiyuddin et al. 2012). Figures for other commodities such as tengkawang (illipe nuts), paperbark (gelam or *Melaleuca cajuputi* and candlenut (*Aleurites moluccana*) have been adjusted by Giesen (2015) for expected lower production on peat.

Figure 5 Financial returns from commodities on peat



Adapted from Giesen (2015): Sago: Flach and Schuiling 1989, Sonderegger and Lanting 2011; Hevea rubber: Sonderegger and Lanting 2011; Gelam/Melaleuca: Duc and Hufschmidt 1993; Swamp jelutung: Sofiyuddin et al. (2012); Illipe nut: Smythies 1961, Blicher-Mathiesen 1994; Oil palm: Sheil et al. 2009, Sofiyuddin et al.2012b; Candlenut/Kemiri: Manap et al.2009, Kibazohi and Sangwan 2011.

4.2.2 Paludiculture & plantation industries

***Dyera polyphylla* (swamp jelutung)** As mentioned in 3.2.3 and in Photo 6, jelutung rawa was cultivated near Sungai Aur village, Tanjung Jabung Timur district, in Jambi, by the company PT Dyera Hutan Lestari, from 1991-2004 and by 2004 a total of about 2,000 ha had been planted and latex tapping already occurring (Muuss 1996, Giesen 24). However, as the hydrology had not been rehabilitated, the plantation was destroyed by fires in 1997 and again in 2004 and subsequently abandoned. The company did demonstrate, however, that cultivation of the species on a commercial industrial scale is indeed possible. Since then, ICRAF, FORDA and the local forestry department have continued trial plantings with jelutung rawa and the species can be regarded as being well on the way to domestication (Tata et al. 2016), although all hurdles have far from been cleared (see 3.2.5).

Alternative pulp species. The pulp and paper company Asia Pulp and Paper (part of the Sinarmas group) has conducted trials in Siak, Riau, on alternative species for *Acacia crassicarpa* on rewetted peat. A 16 ha trial area[32] was planted in 2016 with four species: terentang *Campnosperma coriaceum,* geronggang *Cratoxylum arborescens,* gelam *Melaleuca cajuputi* and belangeran *Shorea balangeran,* of which gelam seems the most promising in terms of growth rate and pulping properties (APP 2017). In addition to these four species APP aims to trial tumih/perapat *Combretocarpus rotundatus,* sesendok *Endospermum diadenum,* perupuk *Lophopetalum multinervium,* bengkal *Nauclea subdita and* kess/bus putih *Lophostemon* species. In addition, with assistance from UGM, they are sourcing a second gelam species from Kalimantan (*Melaleuca leucadendra*) and *Casuarina equisetifolia* from Pulau Belitung (APP 2017).

Tengkawang (*Shorea* spp.) Tengkawang or illipe nut produces high value fats/butter that can be used as a cocoa substitute or in cosmetics. In 2017, the company PT Tolan Tiga Indonesia (PT TTI) established trials with tengkawang species on 10 ha of rewetted peatland at Sungai Barumun in Riau. In all, five *Shorea* species were trialled, namely *Shorea stenoptera, S. pinanga, S. seminis, S. leprosula* and *S. selanica,* of which the first three species produce tengkawang (illipe) nuts. These first trials faced lots of challenges, such as difficulties in sourcing propagation material, and their mortality rates were high (67% average). Nevertheless, PT TTI is optimistic that they can greatly improve plantings and can reach survival rates of 60% or more; they will continue their trials in the coming years (de Clermont-Tonnerre 2017).

4.2.3 Traditional paludiculture: sago cultivation

Sago has been cultivated traditionally in parts of Sumatra for decades, if not hundreds of years, especially in Riau and Aceh, and in all extends over a total area of probably several tens of thousands of hectares. In some parts of Sumatra it has disappeared, such as in Jambi where it also was common until several decades ago. In Riau, it is commonly grown in peatland on the islands of Bengkalis, Padang and Tebing Tinggi, where cultivation goes back more than 100 years. Sago cultivation on Pulau Padang was studied by Sonderegger and Lanting (2011). On this island it forms the main commodity grown, together with rubber, as both extend over about the same area. Sago is grown extensively with low investments, nevertheless generating a revenue of Rp. 4.5 million/ha.year (2010 figures). As mentioned in Giesen (2013), peatland is generally undrained, although small channels (*parit*) of 20-30 cm depth are excavated to allow easier access and extraction of the sago trunks.

On adjacent Pulau Tebing Tinggi, the main peatland commodity ia also sago, which is grown as a cash crop and for subsistence by communities living in the area. The inauguration of BRG was held in Sungai Tohor (on the northeastern side of the island), as this village has been depicted as an "International Peatland Laboratory" (Widaretna & Janssen 2017). Sago has been grown by the community of Sungai Tohor at least for decades; it has been their staple food since the 1970s and

[32] The trials and specie selection were set up and designed by EMM in 2016.

sago plays a central role in the community's daily life. Processing of sago is conducted at home industry level, and delivers end user products such as sago starch, noodles, snack such as sagu telur and sagu lemak, while sago starch is commonly exported abroad.The community has had conflicts with external investors who would like to see sago replaced with oil palm or *Acacia* (Widaretna & Janssen 2017). The planting area of sago trees near Sungai Tohor is always wet peat, and although the community has constructed canals, this is for transportation purposes only and traditional canal blocks are made from wood to managing the water level (Widaretna & Janssen 2017).

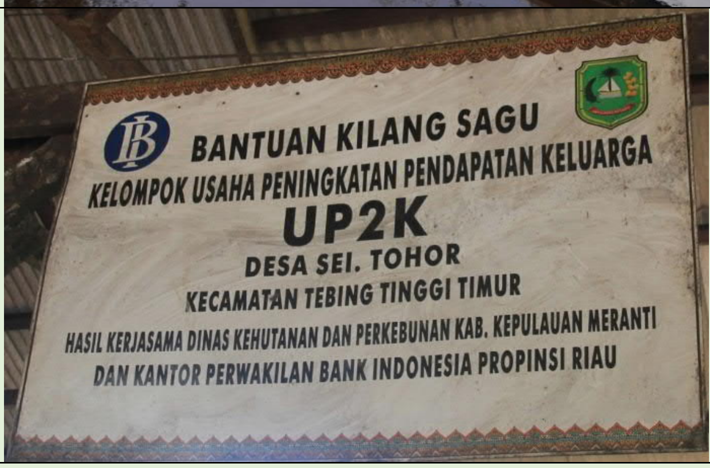
Photos 9a-c – Sago cultivation at Sei Tohor, Riau

9.a Sago plantation near canal and road.

Photo by Kim Janssen, Dec. 2017

9.b Segments of sago trunks (or tuals) transported in canals

Photo by Kim Janssen, Dec. 2017



9.c Information panel at sago processing factory in Sungei Tohor

Photo by Kim Janssen, Dec. 2017

4.3 Peat adapted agroforestry and local livelihoods

Sustainable forms of peat-adapted forestry that could benefit local livelihoods involve the harvesting of NTFPs from restored or regenerated (semi-)natural peat swamp forests. In conservation areas this is not allowed and also undesirable, but (in theory) where such forests occur in *daerah budidaya* the sustainable harvesting of NTFPs could benefit local communities. Such NTFP species will already be present naturally (see chapter 2 and Appendix 1), but their abundance could be promoted by enrichment planting, such as occurs in mixed forests traditionally managed by communities (e.g. the traditional *tembawang* forest management system in West Kalimantan; Michon & de Foresta 1995, Marjokorpi & Ruokolainen 2003).

There are two main obstacles to peat adapted forestry for local livelihoods, namely: i) most remaining PSFs are likely to be *daerah konservasi* rather than *daerah budidaya,* and the potential may be (very) limited and ii) a swathe of government regulations exist that were formulated to protect natural stocks, but provide a strong disincentive to developing NTFP markets further, even if the stocks are enriched (by planting) and properly managed. These regulations and their impacts are described in 3.2.5.

4.4 Ecotourism and local livelihoods

There is a lot of local interest in developing ecotourism in and around peatland areas, for example, in Jambi province (pers. comm. Pak Irmansyah, Dinas Kehutanan, 2016). However, degraded peatlands are not particularly interesting or attractive for most visitors and the greatest potential for tourism is probably in

- agrotourism in restored and replanted areas, and
- ecotourism in remaining areas of natural peat swamp forest, such as in Berbak NP in Jambi, parts of Sembilang NP in South Sumatra, Giam-Siak Kecil-Bukit Batu in Riau, and Sebangau NP in Central Kalimantan.

These natural PSF areas are often poorly accessible, though, and do not have the infrastructure for tourism (transport, accommodation), and both past and present numbers of tourists are low. Some locations, however, such as near Palangkaraya, Central Kalimantan, are easily accessible and do have some basic infrastructure. However, the potential needs to be assessed, along with the kinds of investments required for this to take off. Also, it should be part of a regional development plan and not ‘stand alone’, otherwise it will not be sustainable. In addition, it should be at a level that will not adversely affect biodiversity and other ecosystem service values. What is also needed is an assessment of which peat ecosystem functions may be affected by ecotourism development, and how this can best be channelled to avoid negative impacts and promote positive development.

4.5 Fisheries and local livelihoods

Indonesia has one of the highest diversities of freshwater fish, ranked second in the world following Brazil (Kurniawan et al. 2016). Its various freshwater habitats such as rivers, lakes, swamps, peatlands and brackish waters are home to more than 1,000 species (Kurniawan et al. 2016). Indonesian peatlands are important habitats to wide variety of species, including species that are specially adapted to live in these acidic and low-oxygenated environments. Specialist peat fish include the world’s smallest vertebrate, *Paedocypris progenetica*, a recently discovered species that actually lives in the peat, and the type specimen of which was found “15 km from Muara Sabak on the road to

Jambi" [33]. However, these peatland habitats and their fish species are threatened by conversion into monocultures such as oil palm. Giam et al. (2012) extrapolated that if TPSF deforestation continues, 77% of fish species are likely to become extinct in the Greater Sundas, with Central Kalimantan being most severely impacted.

Extensive fish surveys in the Sabangau peat-swamp forest and river (Central Kalimantan) found a total of 54 different species from 16 different families (Thornton 2017). Future fish surveys using a greater variety of methods are expected to add to this species list. Sule et al. (2016) recently compiled lists of fish species recorded in Malaysian peat-swamps. In Peninsular Malaysia, the authors list 114 species from North Selangor TPSF, 49 from Paya Beriah TPSF, 13 from multiple sites in Johor, 58 from multiple sites in Pahang and 9 from Pahang and Terengganu. In Malaysian Borneo, 31 species from 12 families and 40 species belonging to 13 families were recorded from Sabah and Sarawak, respectively (Sule et al. 2016).

In 2012 about 6.4 million people were engaged in fishing and fish farming in Indonesia (FAO 2014b). Fish are a significant source of protein throughout the country with about 54% of animal protein coming from fish and seafood (FAO 2014b) and the fishing industry contributed to 3% of the Indonesia's Gross Domestic Product (GDP) in 2012 (FAO 2014b). Fisheries in peatland areas offer significant potential for additional income and supplementary nutrition for local communities. Fish is one of the main sources of livelihood and dietary protein for many communities across Kalimantan, with fishing often supporting the poorest members of society (Graham 2013, Schreer 2016, Thornton, 2017). In Central Kalimantan peatlands, for example, fisheries were found to provide a supplementary income to the order of 6% of total annual income in local community households (van Beukering et al. 2008). In Sabangau (Central Kalimantan), the average annual consumption of fish per person was found to be 49 kg (Thornton 2017): 2.6 times the global average of 19.2 kg/year (FAO 2014a). This is comparable to previously reported annual fish consumption figures by Saman and Limin (1999), which reached 40.08 kg per person in 1998 for Central Kalimantan. These figures illustrate a continued and high dependence on fish as a main source of protein. Furthermore, Thornton (2017) reports that 29% of household income in the Sabangau area is potentially spent on buying fish for consumption, again indicating a high dependence on fish for livelihoods in the area.

As fishing can be done without significant initial financial investment, it can often attract the poorest members of the community, but in Sabangau it fails to lift them out of poverty (Thornton 2017). Fishing income still provides an important support to these members of the community: Suyanto et al. (2009) found that income from fishing in the ex-MRP reduced the overall inequality of income within each village, with this source of income being relatively high for the poorer segments of society, with about 97% of respondents engaged in fishing. Thornton (2017) found that 75% of community members in her survey site in the Ex Mega Rice Project depended on fishing for their livelihoods. Fishing is therefore both supportive and acts as an important fall-back occupation (Thornton 2017).

Whilst most of the emphasis in fisheries development targets species fit for human consumption, the live trade in ornamental fish from peat associated blackwaters can also provide benefit (van Beukering et al. 2008), and it is common knowledge that many ornamental fish species are found in peat swamps (Ng & Tan 1997). A recent study in the Tripa peat swamps in Aceh, for example, listed a total of 73 species, including 46 fit for human consumption, 17 with a potential for aquaculture and 10 with a potential as ornamental fish (Muchlisin et al. 2015).

[33] *Paedocypris* is a new genus of paedomorphic cyprinid fish from highly acidic blackwater peat swamps in Southeast Asia. It includes two new species, one of which (*Paedocypris progenetica*) appears to be the smallest fish and vertebrate known, with the smallest mature female measuring a mere 7.9 mm (Kottelat et al. 2006).

There are indications that peatland fish populations in Central Kalimantan are facing increasing pressures. Around the Sabangau forest, a previous survey of local communities found that 80% of those fishing reported a decline in their harvests over the previous 10-year period (Lyons 2003). A total 99% of respondents reported a decline in fish size within individual species caught, with large fish being caught less frequently (Lyons 2003). Schreer (2016) writes that discussions with elders revealed that local fish stocks in Katingan had drastically declined over the last three decades and were expected to continue to decline in the future. Thornton (2017) found that the majority of survey participants reported a decrease in fish catches and fish sizes over recent years. Decreases in fish catches were attributed to there being more people fishing, the use of harmful fishing methods such as electric fishing and poison, and environmental degradation from fires, logging, canal building and canal blocking. Schreer (2016) found that the declining fish stocks in the Katingan was reportedly due to a combination of water pollution, forest degradation and habitat loss, as well as overexploitation and unsustainable fishing practices. Investigation of fish biodiversity in Central Kalimantan is therefore of high relevance and necessity as this can help to inform the classification of High Conservation Value Forest (HCVF; forests which have additional critical environmental and social values that require special consideration) (Giam et al. 2012). This is particularly important for areas where communities depend on fishing as a main source of livelihood; in these locations, assessing and understanding changes in the local fish stocks are both vital.

Tantulo & Gevers (2008) conducted an extensive survey of the potential for fisheries in the Ex-Mega Rice Project area in Central Kalimantan, and concluded that there were significant opportunities in three main areas:

- expansion of freshwater aquaculture production
- rehabilitation of traditional *beje* fisheries (Box 14), and
- marketing of ornamental fish.

However, Tantulo & Gevers (2008) stress that the development of these fisheries depends strongly on the condition and carrying capacity of the ecosystem, and that data on fisheries resources, exploitation and environment (such as water quality) are needed to support decision making to better manage the fisheries resources and to avoid further resource depletion. Drainage, clearing and other interventions in peatland areas have depleted stocks (Box 15) and current opportunities first need to be assessed.

Throughout the Sabangau and ex-MRP area, bejes have been used for many years (Gumiri et al. 2005, Jagau et al. 2008). These fish ponds are normally 300m² in dimension, and 1.5-2m deep (Jagau et al. 2008). A household with 4 or 5 fish ponds can reportedly harvest between 500-1,200 kg of fish per season; generating an income of GBP 78-222 per year (Jagau et al. 2008). However, the number of fish ponds especially in the ex-MRP has been declining as deteriorating water quality, construction of canals and damage to fish habitats has led to villagers experiencing a 95% decrease in fish pond ‘production’ of fish, compared to that during the pre-MRP era (Jagau et al. 2008, Setiadi 2014).

Most of the potential for fisheries in rewetted peatland areas is probably in the streams flowing from the restored peatland, rather than in canals in which canal blocks have been constructed. In the latter, infilling will either be carried out during rewetting programmes, or will occur naturally over the course of a number of years, unless these canals are regularly maintained (which is unlikely, and undesirable from a rewetting point of view). Maintaining a vegetation cover along such streams is required, otherwise water temperature will be too high, which will result in low ambient oxygen levels and be detrimental for fish and other aquatic organisms.

Fishing is also a source of fire in Central Kalimantan. Fire is used to clear the riverside to facilitate access to the river and to make it easier to set fishing traps and nets (Thornton 2017). Further research is needed to establish if this is as significant a source of fire in other areas, though this may be expected, given the high reliance of many rural forest-edge communities on fishing in Central Kalimantan (Thornton 2017).

Box 15. Peatland fisheries in Central Kalimantan impacted by development (Tantulo & Gevers 2008)

Over the years, human intervention such as canal construction for agriculture development, logging and mining and pond construction in mangrove areas have destroyed and degraded ecosystems in the Ex Mega Rice Project area that are critical to the survival and growth of fish species. Changes in water quality, turbidity and sedimentation have led to deterioration of fish habitats leading to the disappearance of certain species, changes in species composition and a decreased aquaculture and fisheries production, in particular of the traditional beje fisheries. Development of structures such as dams and gates in the drainage canals limit the seasonal movement and migration of fish species from peat swamp areas to rivers and back.

A traditional type of fisheries in these peatland areas is the beje fisheries. A beje is a ditch connecting the swamp areas to the main river, constructed to retain fish during the rainy season when the water level rises. The Dayak communities have used this traditional fisheries system or capture method for years and it still provides a very important source of income to the local communities.

Fisheries are not without impact – apart from potentially affecting fish resources (e.g. if over-fishing occurs), fisherfolk may also be a source of fires that affect the peat, especially in areas directly along rivers.

Peatland conservation initiatives that integrate the ecological and social values associated with fish and fishing into their project planning are likely to result in improved outcomes for both peatland areas, forests and people (Thornton 2017).

4.6 Agriculture, rice cultivation & food security

To avoid the occurrence of forest- and peatland fires it is necessary to coordinate between the government and the community in taking preventative actions. To prevent the occurrence of forest and peatland fires the Indonesian government has issued the regulation on “Zero Burning Peatland Management” by PP No. 57/2016 on Protection and Management of Peat Ecosystems. However, as a consequence there is a new challenge in the incidence of food insecurity that occurs in communities in peatland areas. This occurs where communities are unaware of methods of peat land preparation as an alternative to burning, for example near Palembang in South Sumatra, where the tradition of ‘padi sonor’ involves burning of peat prior to planting of rice (Chokkalingam et al. 2007). Therefore, it is necessary to make efforts to overcome this food insecurity and optimizing the benefits of peatlands as food production land by demonstrating zero burning peatland management techniques as an alternative. To that end, the Peatland Restoration Agency through the Deputy of Construction, Operation and Maintenance has conducted a study on the application of decomposer microbes in land preparatiion for agriculture. This method can be applied in peatlands for rice or crops production without having to apply burning as a tool. From the research results that has been done by applying this method, the peat soil can be a good planting medium without having a negative impact on the environment.

An example of this successful agricultural activity by zero burning is a 1-ha trial in Sebangau Jaya Village, Sebangau Kuala Sub-district, Pulang Pisau District, Central Kalimantan Province. The yields obtained from this agricultural activity is 4.5 tons grain per hectare, a result that could be optimized further if the maintenance activities are done in accordance with the standard operation procedure.

Nevertheless, the production of 4.5 tons/ha is greater than the production obtained from rice cultivatio using the burning method for land preparation, which yields 2.8 tons grain per hectare.

In addition to the above example, another example related to agriculture on peatlands is a 5,000 ha rice estate developed by PT Sinar Pangan Indonesia (PT SPI) in Pantik Village, Pandih Batu Sub-district, Pulang Pisau District, Central Kalimantan Province. PT SPI began carrying out its activities after realizing that most of the land in Kalimantan, including [shallow] peatlands, can be utilized for the development of rice estate to support food security. To develop the rice estate on peatlands in Kalimantan, there are several obstacles that need to be solved, such as the limited availability of labour and the high cost of land clearing. PT SPI develops rice estates through partnerships with the communities, and business models developed by PT SPI include:

- Reinventing Nucleus Plasm Farming Concept/Perkebunan Inti Rakyat.
- The company PT SPI is responsible for all technical aspects.
- Applying fully mechanized agribusiness
- The rice productivity target is 25 tonnes/ha.yr while the sales target is 3.750.000 tonnes/year
- Process first batch 15.000 ha divided into 3 @5.000 that costing IDR 25 million/ha
- Starting with generic rice but proceeding to premium level brown rice, which is healthier.
- The farmer will act as a partner of PT. SPI, receiving a monthly salary and also earning part of proceeds from the harvest from their land
- Lab tests show that result PT. SPI can achieve 25 tonnes/ha.yr compared with traditional farmer that result 12-16 tonnes /ha.yr.
- The farming land will be intensified and revitalized through technology used in seed, tending, pesticide use and harvest.

A trial carried out in Sebangau Kuala, Central Kalimantan, involved land restoration, using the biological decomposer (for weed processing) and application of organic fertilizer (Hidayat 2017). Application of the biological decomposer costs only a quarter of what dolomite fertilizer costs per hectare, and people are now harvesting 2-2.5 tons of rice per hectare. The idea is to develop rice cultivation on peat on shallow to moderately deep peat (<2m depth) on the edge of peat domes (Hidayat 2017). In between the conserved peat dome and the rice fields would be a transition zone (peat depth 2-3 m) on which permanent tree crops are to be cultivated.

It must be pointed out, though, that rice generally does not perform well on deep peat and that mechanization may have implications for peat mangement and emissions. Also, there are various drawbacks associated with cultivation of rice on the edges of peat domes. These can be summarized as follows:

- Flooding remains an issue in shallow peat, as these are often areas where peat levels have dropped due to subsidence, or they are located close(st) to rivers. In that case high yielding rice varieties are less appropriate than flood tolerant varieties such as ‘floating rice’. These used to be widespread in South Kalimantan, and it is still common on the banks of Tonle Sap lake in Cambodia.
- Managing water in the margins of peat domes without impacting the rest of the peat dome will remain a major challenge. In theory this is possible, but will entail keeping water levels high and well managed, and especially the latter is a major problem as funds for maintenance are usually scarce.
- The application of fertilizer and biological decomposer material will also further speed up peat decomposition, and this will in turn increase carbon emissions and speed up peat subsidence, leading to water management issues, and increased problems with flooding.

In summary, rice cultivation on peat is probably best carried out when the area consists of shallow peat or when it is not part of a larger peat dome. There are areas with (pockets of) shallow/moderately deep peat and these could be targeted for rice growing activities. Alternatively, farmers may have to accept using slower growing and lower yielding floating rice, without massive fertilizier application.

4.7 Livestock farming and fodder cultivation

Livestock can be reared in peatlands as long as there is adequate fodder availability. The fodder can be fulfilled from plants that grow naturally on peatlands, and some species occurring in the peatlands of Kalimantan that can be utilized as fodder are: 1) Sasendok or Uyah-uyahan (*Plantago major*), 2) Delingu (*Dianella ensifolia*), 3) Bird's nest fern (*Asplenum nidus*), 4) Asem-aseman (*Baccaurea bracteata*), 5) Ajihan; 6) Geronggang (*Cratoxylum arborescens*), 7) Kelakai (*Stenochlaena palustris*); 8) Lombokan (*Clerodendrum phyllomega*); 9) Karamunting (*Melastoma malabathricum*) that grow throughout the year and are available in sufficient quantities (Bestari, 2008). Plant matter from these species can be used as fodder.

Research by Bestari (2008) indicates that the calcium (Ca) content for fodder grown naturally in peatlands (i.e. the aforementioned species) ranged from 0.56 to 2.85%, and of these species Sasendok contains the highest Ca mineral content. Importantly, the Ca content of fodder from peatlands is not different from elephant grass *Pennisetum purpureum* (0.7%), field grass (0.45%) (Rayburn, 2006) or alfalfa *Medicago sativa* (also known as lucerne; 1.47%) (Dahlin, 2006). Phosphorus content for fodder from peatlands ranged from 0.06 to 0.21%; however, these concentrations were lower than for non-peatland fodder such as elephant grass *Pennisetum purpureum* (0.7%), field grass (0.38%) and alfalfa (0.24%). From these results it can be concluded that natural peatland vegetation can provide fodder for livestock, but that supplements will be required, for example of Phosphorus, but also of Zn (zinc).

4.8 Poultry

The keeping of chickens in swamps and peatlands is usually not very viable, as they have to be kept in raised cages and fed throughout a large part of the year as they will not survive waterlogged conditions that often prevail. Keeping them in pens often leads to diseases and high mortality rates, and having to provide feed raises costs considerably. A better option is keeping ducks, as these are naturally suited to wet conditions and can generally find much of the forage required, although they are likely to need some supplementary feed if a farmer wants to produce eggs or meat in sufficient amounts for sale. In Hulu Sungai district of South Kalimantan province, the rearing of ducks has long been a traditional enterprise in and around towns such as Kandangan, Alabio and Amuntai, and they endure regional fame (e.g. Sunarlin & Sirait 1984, Sari 2015).

Duck feed must have a sufficiently high protein level in order for eggs to be of a good quality (Sari 2015), and achieving that may prove a challenge. In South Kalimantan, farmers traditionally provide feed composed of grain, rice bran, dried fish and (the exotic) golden apple snail (keong mas *Pomacea maculata*) (Sari 2015).

4.9 Honeybee cultivation & Gelam (*Melaleuca cajuputi*)

Bee-keeping and honey production are viable options in rewetted and revegetated peatland – not in degraded peat dominated by sedges and ferns, as in the latter areas there will not be any honey production. The market in Indonesia for honey and other bee products such as wax and propolis is very good and the prices are high. There are also additional benefits such as pollination, which can in some cases greatly benefit production (e.g. tomatoes; Putra & Kinasih 2014).

Not all stands of revegetated areas will be equally productive, but species such as gelam *Melaleuca cajuputi* appear to be particularly good for honey production. In the U Minh forests of the Mekong Delta in Viet Nam, for example, *Melaleuca cajuputi* has been replanted on deep peat (3-5m depth) in restoration programmes that resulted in the restoration of >5,000 ha of gelam. These focused on multiple use of the replanted forest, with gelam producing poles, timber and oil (distilled from the leaves, as *minyak kayu putih*), beekeeping for honey production, sedges (*purun*) for weaving and some fisheries during the wet season (Maltby et al. 1996; Box 16).

In Peninsular Malaysia, the culture of stingless (Meliponine) bee colonies is promoted in rubber plantations aimed at increasing income levels and socioeconomic status of the rubber smallholders (Razak et al. 2016). As with domesticated Eurasian honey bees (*Apis mellifera*) these stingless bees produce honey, pollen cerumen (bee bread) and propolis. While there are more than 50 species of stingless bee in the Indo-Malayan group of species, only four species of stingless bees (*Heterotrigona itama, Geniotrigona thoracica, Lepidotrigona terminate* and *Tetragonula laeviceps*) are domesticated and reared for their honey, propolis and bee bread. Production of honey averages at about 0.5 kg/month per hive, and about 40-50 hives were placed per ha of rubber plantation; prices are generally (much) higher than for normal honey from *Apis* species as concentrations of medicinally active compounds are significantly higher. Rubber trees (*Hevea brasiliensis*) flowers are a good source of pollen and nectar (extrafloral nectaries, and the exudate also plays a role; jelutung plantations might therefore also be successfully 'intercropped' with stingless bees (pers. comm. Aiz 2017).

Melaleuca cajuputi (gelam) plantations can provide significant returns on the basis of a combination of commodities including poles and wood, charcoal, cajuput/cineol oil destilled from the leaves, and honey production from bees kept in the plantations. In some systems there is also the possibility of reed production alongside gelam, while during periods of flooding there may also be some fish production. Economic assessments in Vietnam show that an IRR of more than 40% ay be attained (Duc & Hufschmidt 1993). On BGPP (Janssen & Widaretna 2017), an economic assessment of a system based on NTFPs only (i.e. without wood/pole harvesting) may have an IRR of >25%. There is also lots of market potential, as the internal Indonesian demandt for cajuput oil (1,500 tons per year) is 3x what is being produced at present (450-500 tons/year) and the balance is imported from China (from *Eucalyptus* plantations). Similarly, the domestic demand for honey is 7,500 tons/year, while production is only 2,000-4,000 tones per year, with the balance being imported.

Box 16. Gelam (*Melaleuca cajuputi*) and oney in Mekong Delta peat swamps, Vietnam

Gelam (Melaleuca cajuputi) flowers produce good quality honey and are favoured by honeybees. Honey – mainly from the migratory Asian Giant Bee, Apis dorsata – is harvested from wild beehives in the peat swamp forests of U Minh in the Mekong Delta of Vietnam. In Indonesia, the harvesting of honey is currently often small-scale and for subsistence purposes only, although there is obvious scope for honey production as Indonesia is a net importer of this product. The market is potentially great, as honey is perceived to be of medicinal value (obat). Gelam flowers profusely all-year round and produces copious amounts of nectar, making it an ideal host species for bees. Bee-keeping is proposed by the project to be carried out on a modest scale, in conjunction with the gelam plantation. Maltby et al. (1996) report that 5-6 litres of honey can be harvested per hectare of gelam per year. In the Song Trem State Forest, with about 2500 ha of replanted gelam, the best forests for honey production are 4-6 year old stands which are still quite open, with 'rafters' being placed to attract bees; Mulder (1993) found a rafter occupancy of 50-60% in the dry season and 60-90% in the rainy season. Honey is collected during two major seasons, each nest being cropped 3-4 times per season. The first harvest is usually done three weeks after the observed first arrival of the colony, followed by the next harvest after a two week interval. The yield per harvest is about 4 kg of honey (Mulder 1993).

Studies by Manurung et al. (2015) show that there is significant potential for cajuput oil production from gelam on degraded peatlands in Central Kalimantan, including shallow up to deep peat. Widiana et al. (2015) showed that of the two species found in Central Kalimantan (*Melaleuca leucadendra* and *Melaleuca cajuputi*), *M. cajuputi* has the highest content of essential oils and holds the greatest potential. Studies by Widiana et al. (2014a, 2014b) show that there is potential for using the waste of processed gelam leaves as fodder for cattle, and that in addition also the solid residues after processing can be used as fodder.

4.10 Knowledge gaps re Revitalisation

- Technical knowledge of paludiculture species. This includes information about seed sourcing and treatment, nutrient requirements, intercropping possibilities, harvesting methods and intensities, product processing and so on.
- Ecotourism potential. An assessment of (eco-)tourism potential of remaining peat swamp forests, such as at Berbak NP in Jambi, parts of Sembilang NP in South Sumatra and Giam-Siak Kecil-Bukit Batu in Riau, plus an assessment of how this can be developed.
- Peatland fisheries. There is a need to study existing fish stocks and water quality in degraded peatland and restored peatland waters, to assess the potential for fisheries development, including aquaculture. A market assessment should be made of both of fish fit for human consumption purposes and ornamental fish.
- Impact of zero-burning methods used to date on peat emissions and subsidence. Do the microbe decomposers added to the cut vegetation have an impact on the peat? What are the impacts of water management?
- Value chain assessments & markets. Some studies have been carried out or are underway (e.g. gelam, kemiri, jelutung, sago, tengkawang, gemor), but for many potential commodities on rewetted peat little is known about the market prospects and requirements for development. Potential commodities include *Aquilaria beccariana* (gaharu), *Eleocharis dulcis* (purun tikus), *Momordica charantia* (paré), *Syzygium aqueum* (jambu air), *Terminalia catappa* (ketapang) and *Uncaria gambir* (gambir), but a range of others may also be investigated.
- Institutional constraints to development of paludiculture need to be properly identified, e.g. via value chain studies whereby stakeholders are assessed and possible bottlenecks and constraints for paludiculture development identified.

5. Summary of research needs

Rewetting

1. **Testing effectiveness of canal blocks**
Most canal blocks consist either of box dams constructed by NGOs (or their partners) as part of projects, or are compacted peat dams constructed by companies on their concessions. Urgently needed is a comprehensive and unbiased assessment of dams constructed in the past 10-12 years have fared, so that 'lessons learned' are based on more solid footing. This should include an assessment of dam type (box, compacted peat), dam condition, maintenance received (if any), costs, and the degree to which water tables have been raised (hydrological effectiveness) and subsidence has been slowed.

2. **pF curves for various peat types & conditions**
Field and laboratory studies be carried out on pF / water retention in a range of peat types, so that the relationship is better understood, as this has implications, for example, for the currently recommended maximum drainage depth of -40 cm. Also included could be the effect of peat compaction, such as carried out in Malaysian oil palm plantations.

3. **Fate of DOC & POC that leaves peatland**
The loss of carbon as POC and DOC from (degraded) peatlands is not well understood; just over half is rapidly outgassed from blackwater rivers draining from peatlands by the time they reach the coast, but the fate of the remainder is unknown and other mechanisms may also play a role (e.g. rapid assimilation or trapping).

Revegetation

4. **Hydrological self regulation of PSF**
Understanding how various peat swamp forest species or phenological types with various adaptations (e.g. stilt roots, buttresses, surface roots, etc..) and the hump-and-hollow structure of peat swamp forest floor contributes towards water retention. In our understanding of peat swamp forest hydrology it is apparent that most (84%) lateral flow in undisturbed PSF is along the surface rather than in the peat (16%). Humps-and-hollows of undisturbed peat swamp forests likely results in a self-regulating mechanism for water retention and hydrological maintenance. How this could possibly be restored is not understood.

5. **Productivity of PSF species and contribution to peat development**
Ideally, restored peat swamp forest would at some point begin to contribute to a renewed accumulation of organic matter in the soil and building up of peat. The productivity of various PSF species is unknown. About 150+ PSF species are known to be fast-growing pioneer species or species of secondary forests. Do these fast-growing species also contribute more to the accumulation or organic matter in the peat soil? Or do other mechanisms also play a role, such as lignin content?

6. **Polyphenol concentrations in (common) PSF species**
It is known that plant polyphenols inhibit decomposition and thereby facilitates accumulation of peat. Polyphenol concentrations in Indonesian PSF species is largely unknown and unexplored.

7. **Food species for wildlife**
An additional consideration in revegetation efforts is the potential contribution to biodiversity conservation. Identifying which of the favoured food species do well in restoration efforts is a potential area that requires further study.

8. **Performance of potential NTFP species on rewetted peat**
Many plant species of the original peat swamp flora have been identified as having potential for paludiculture programmes, as they occur naturally on peat (i.e. peat without drainage) and have a known economic value. However, usually very little is known about how these species perform on rewetted peat and this lack of knowledge of many promising species on rewetted peatland leads to an understandable reluctance of farmers to invest in these commodities.

9. **Impact of NTFP cultivation on peat hydrology**
Peat adapted NTFPs will have different impacts on the hydrology of rewetted peat, depending on various factors such as planting density, potential for intercropping, growth rates, methods for harvesting, evapotranspiration rates, and so on. Some NTFP crops are likely to have a more positive impact on the hydrology of rewetted peat than other NTFP crops. Similarly, intercropping/mixed agroforestry approaches are likely to be more beneficial for peat hydrology than monocultures, as humidity is likely to be higher if the vegetation has various layers/strata. In any case, such impacts can only be guessed at at present and require further study, in order to optimize NTFP cultivation so that positive impacts on peat are maximized.

10. **Low impact access to rewetted peatland**
Once peat hydrology is restored (by canal blocking) and the rewetted peat is replanted with promising, peat-adapted NTFP species, the major challenge to the success of maintaining such a system is providing low impact access so that NTFPs can be harvested. Basically there are three main approaches for facilitating of access in fully rewetted areas, namely alternatives for crossing canal blocks, trail or rail systems and adjusting the timing of harvest. However, none are optimal at present, and practical studies are required to develop a low cost, low impact approach for accessing rewetted peat.

11. **Return of ecosystem functions**
Return of ecosystem functions. When areas are rehabiltated via enrichment planting, large-scale replanting or via paludiculture programmes, it is anticipated that at least some of the key ecosystem functions are likely to return (e.g. biodiversity, water storage, and so on). This process or ecosystem function rehabilitation needs to be studied.

<u>**Revitalisation**</u>

12. **Technical knowledge of paludiculture species**
For many paludiculture species little is known about practicalities such as seed sourcing and treatment, nutrient requirements, intercropping possibilities, harvesting methods and intensities, product processing and so on.

13. Ecotourism potential

An assessment of (eco-)tourism potential of remaining peat swamp forests, such as at Berbak NP in Jambi, parts of Sembilang NP in South Sumatra and Giam-Siak Kecil-Bukit Batu in Riau, plus an assessment of how this can be developed.

14. Peatland fisheries.

There is a need to study existing fish stocks and water quality in degraded peatland and restored peatland waters, to assess the potential for fisheries development, including aquaculture. A market assessment should be made of both of fish fit for human consumption purposes and ornamental fish (of which many occur in peatland waters).

15. Impact of zero-burning methods

What is the impact of microbe decomposers added to cut vegetation on peat emissions and subsidence, and what are the impacts of water management? To date zero burning programs have focused on the impact on productivity (e.g. rice production in tonnes/ha.yr), but the impact on the peatland needs to be studied in parallel.

16. Value chain & market studies

Value chain assessments. Some studies have been carried out or are underway (e.g. gelam, kemiri, jelutung, sago, tengkawang, gemor), but for many potential commodities on rewetted peat little is known about the market prospects and requirements for development. Potential commodities include *Aquilaria beccariana* (gaharu), *Eleocharis dulcis* (purun tikus), *Momordica charantia* (paré), *Syzygium aqueum* (jambu air), *Terminalia catappa* (ketapang) *and Uncaria gambir* (gambir), but a range of others may also be investigated.

17. Institutional constraints

Institutional constraints to development of paludiculture need to be properly identified, e.g. via value chain studies whereby stakeholders are assessed and possible bottlenecks and constraints for paludiculture development identified.

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Appendix 1 Peat swamp forest species with (potential) major economic use

#	Family	Species	Common name	PROSEA No.	Main type of use
1	Anacardiaceae	*Mangifera caesia* Jack	binjai (I)	2	Fruit
2	Anacardiaceae	*Mangifera foetida* Lour.	limus,membacang (I), horse mango (E)	2	Fruit
3	Anacardiaceae	*Mangifera griffithii* Hook. f.	asam rawa (I)	2	Fruit
4	Anacardiaceae	*Mangifera quadrifida* Jack	asam kumbang (I)	2	Fruit
5	Apocynaceae	*Dyera costulata* (Miq.) Hook.f.	jelutung (I)	18	Latex
6	Apocynaceae	*Dyera polyphylla* (Miq.) Steenis *(D. lowii)*	jelutung rawa (I)	18	Latex
7	Araceae	*Cyrtosperma merkusii* (Hassk.) Schott *(C. lasioides)*	taro rawa (I), swamp taro (E)	9	Starch (non-seed)
8	Araucariaceae	*Agathis borneensis* Warb. *(A. dammara)*	damar sigi, damar pilau (I)	18	Resin
9	Arecaceae	*Calamus caesius* Blume	rotan sega (I)	6	Rattan
10	Arecaceae	*Caryota mitis* Lour.	sarai (I), fishtail palm (E)	9	Starch (non-seed)
11	Arecaceae	*Caryota urens* L.	sarai (I), fishtail palm (E)	9	Starch (non-seed)
12	Arecaceae	*Korthalsia flagellaris* Miq.	rotan dahan(-an) (I)	6	Rattan
13	Arecaceae	*Korthalsia laciniosa* (Griff.) Mart. *(K. grandis)*	rotan dahan(-an) (I)	6	Rattan
14	Arecaceae	*Metroxylon sagu* Rottb.	sagu (I) rumbia (Sum), sago (E)	9	Starch (non-seed)
15	Blechnaceae	*Stenochlaena palustris* (Burm. f.) Bedd.	pakis (I)	15	Vegetable
16	Burseraceae	*Canarium asperum* Benth.	kembang rekisi (I)	18	Resin
17	Burseraceae	*Canarium hirsutum* Willd.	kanari jaki, ki bonteng (I), white dhup (E)	18	Resin
18	Burseraceae	*Canarium littorale* Blume	kayu ariong (I)		Nuts
19	Caesalpiniaceae	*Sindora velutina* Baker	sepetir beludu (I)	18	Resin
20	Chloranthaceae	*Chloranthus erectus* (Buch.-Ham.) Verdcourt	keras tulang (I)	16	Tea
21	Clusiaceae	*Garcinia mangostana* L.	manggis (I), mangosteen (E)	2	Fruit
22	Combretaceae	*Terminalia catappa* Linné	ketapang (I)	3	Tannin, edible seed
23	Convolvulaceae	*Ipomoea aquatica* Forsk. *(I. reptans)*	kangkong (I)	8, 12(2)	Vegetable
24	Cucurbitaceae	*Momordia charantia* L.	bitter melon (E)	8, 12(1)	Vegetable
25	Cyperaceae	*Actinoscirpus grossus* (L.f.) Goetgh. & D.A. Simpson	mensiang, walingi (I), greater club rush (E)	17	Weaving
26	Cyperaceae	*Cyperus rotundus* L. *(rotundatus)*	teki ladang (I), red nut sedge (E)	9, 12(1)	Starch (non-seed)
27	Cyperaceae	*Eleocharis dulcis* (Burm.f.) Henschel.	purun tikus (I), water chestnut (E)	9	Starch (non-seed)
28	Cyperaceae	*Lepironia articulata* (Retz.) Domin.	purun (I), grey sedge (E)	17	Weaving
29	Cyperaceae	*Scirpodendron ghaeri* (Gartn.) Merr.	rumbai (I)	17	Weaving
30	Dipterocarpaceae	*Dipterocarpus gracilis* Blume	keruing kesat (I)	18	Resin
31	Dipterocarpaceae	*Shorea compressa* Burck	tengkawang		Oil bearing illipe nuts
32	Dipterocarpaceae	*Shorea macrophylla* (de Vriese) P.S.Ashton	tengkawang hantelok		Oil bearing illipe nuts
33	Dipterocarpaceae	*Shorea pinanga* Scheff.	tengkawang rambai		Oil bearing illipe nuts
34	Dipterocarpaceae	*Shorea seminis* (De Vriese) Sloot.	tengkawang terendak (I)	14	Oil bearing illipe nuts
35	Dipterocarpaceae	*Shorea stenoptera* Burck	tengkawang tungkal		Oil bearing illipe nuts
36	Dipterocarpaceae	*Shorea teysmanniana* Dyer ex Brandis	tengkawang		Oil bearing illipe nuts
37	Dipterocarpaceae	*Vatica mangachapoi* Blanco	tengkawang		Oil bearing illipe nuts
38	Dipterocarpaceae	*Vatica rassak* (Korth.) Blume	resak (I)		Dammar/resin
39	Ericaceae	*Gaultheria leucocarpa* Blume	gandapura (I)	19	Essential oil
40	Ericaceae	*Vaccinium bracteatum* Thunb.	rangkas (I), sea bilberry (E)	2	Fruit
41	Euphorbiaceae	*Aleurites moluccana* (L.) Willd.	kemiri (I), candlenut (E)	13	Edible nut
42	Euphorbiaceae	*Elateriospermum tapos* Blume	tapas, tapus (I)		Nuts
43	Euphorbiaceae	*Macaranga tanarius* (L.) Müll.Arg.	hanuwa, mapu (I), hairy mahang (E)	3, 12(3)	Dye
44	Flacourtiaceae	*Flacourtia rukam* Zoll. & Mor.	rukam (I), India plum (E)	2	Fruit
45	Juncaceae	*Juncus effusus* Linné	sumpu (I), soft rush, common rush (E)	17	Weaving
46	Lauraceae	*Nothaphoebe coriacea* (Kosterm.) Kosterm. *(Alseoda*	gemor (I)		Incense bark
47	Lauraceae	*Nothaphoebe umbelliflora* (Blume) Blume	gemor (I)		Incense bark
48	Marantaceae	*Donax canniformis* (G.Forst.) K.Schum.	bemban (I), common donax (E)	17	Weaving
49	Meliaceae	*Sandoricum koetjape* (Burm.f.) Merr.	sentul (I), santol (E)	2	Fruit
50	Menispermaceae	*Fibraurea tinctoria* Lour. *(F. chloroleuca)*	akar kuning (I), peron (Jav)	3	Dye

#	Family	Species	Common name	PROSEA No.	Main type of use
51	Moraceae	*Artocarpus elasticus* Reinw. Ex Blume	terap nasi, benda (I) terap (E)	17	Fibre
52	Myrtaceae	*Melaleuca cajuputi* Powell	gelam (I), paperbark (E)	19	Essential oil
53	Myrtaceae	*Rhodomyrtus tomentosa* (Aiton) Hassk.	kemunting (I)	2	Fruit
54	Myrtaceae	*Syzygium aqueum* (Burm.f.) Alston	water apple (E), jambu air (I)	2	Fruit
55	Myrtaceae	*Syzygium polyanthum* (Wight) Walp. *(Eugenia polyant*	salam, daun salam (I), Indonesian laurel	13	Spice
56	Nepenthaceae	*Nepenthes ampullaria* Jack	lid pitcher plant (E)	17	Fibre
57	Nepenthaceae	*Nepenthes rafflesiana* Jack	plant (E)	17	Fibre
58	Nepholepidaceae	*Nephrolepis biserrata* (Sw.) Schott	pakis (I)		Vegetable
59	Olacaceae	*Anacolosa frutescens* (Blume) Blume	kopi gunung, belian landak (I)	2	Fruit
60	Pandanaceae	*Pandanus atrocarpus* Griff. (*Benstonea atrocarpa)*	mengkuang (I), menguang pandan (E)	17	Fibre
61	Pandanaceae	*Pandanus furcatus* Roxb.	cangkuang, pandan kowan (I)	17	Fibre
62	Phyllanthaceae	*Aporosa frutescens* Blume	sebasah (I)	3	Dye
63	Phyllanthaceae	*Baccaurea motleyana* (Müll.Arg.) Müll.Arg.	tampoi (I)	2	Fruit
64	Phyllanthaceae	*Baccaurea racemosa* (Reinw. ex Blume) Müll.Arg.	tampoi (I)	2	Fruit
65	Proteaceae	*Finschia chloroxantha* Diels	Finschia nuts (E)	2	Nuts
66	Rubiaceae	*Uncaria gambir* (Hunter) Roxb.	gambir (I),	3	Dye
67	Sapindaceae	*Dimocarpus longan* Lour.	leng-keng (I), longan (E)	2	Fruit
68	Sapindaceae	*Nephelium cuspidatum* Blume	kedet, rambutan kabung (I)	2	Fruit
69	Sapindaceae	*Nephelium lappaceum* L.	rambutan (I), (E)	2	Fruit
70	Sapindaceae	*Nephelium maingayi* Hiern	ridan, penjaih (I)	2	Fruit
71	Sapindaceae	*Pometia pinnata* Forst. & Forst.	kasai (daun besar) (I), kayu sapi (Jav)		Nuts
72	Sapotaceae	*Madhuca motleyana* (de Vriese) J.F.Macbr. *(Ganua m*	nyatoh ketiau (I)	18	Latex
73	Sapotaceae	*Palaquium gutta* (Hook.f.) Burck	nyatoh taban merah (I)	18	Latex
74	Sapotaceae	*Palaquium leiocarpum* Boerlage	jongkang (I)	18	Latex
75	Sapotaceae	*Palaquium obovatum* (Griffith) Engler	nyatoh putih (I)	18	Latex
76	Sapotaceae	*Payena leerii* (Teijsm. & Binn.) Kurz	balam beringin (I), balam suntei (Sum)	18	Latex
77	Thymelaeaceae	*Aquilaria beccariana* van Tiegh.	gaharu (I), eaglewood, agarwood (E)		Incense
78	Thymelaeaceae	*Aquilaria filaria* (Oken.) Merr.	gaharu (I), eaglewood, agarwood (E)		Incense
79	Thymelaeaceae	*Gonystylus bancanus* (Miq.) Kurz.	ramin (I)		Incense
80	Thymelaeaceae	*Wikstroemia tenuiramis* Miq.	gaharu cengkeh (I)		Incense
81	Urticaceae	*Poikilospermum suaveolens* (Blume) Merr.	mentawan (I)	16	Tea

Appendix 2 PSF species with arbuscular mycorrhizae

No.	Species	Family	Reference
1	Acronychia porteri	Rutaceae	Suciatmih 2003
2	Aquilaria filaria	Thymelaeaceae	Turjaman et al. 2006
3	Calophyllum biflora	Guttiferae/Clusiaceae	Suciatmih 2003
4	Calophyllum hosei	Guttiferae/Clusiaceae	Turjaman et al. 2008
5	Calophyllum sclerophyllum	Guttiferae/Clusiaceae	Tawaraya et al. 2003
6	Calophyllum soullatri	Guttiferae/Clusiaceae	Tawaraya et al. 2003
7	Calophyllum teysmannii	Guttiferae/Clusiaceae	Suciatmih 2003
8	Campnosperma auriculata	Anacardiaceae	Tawaraya et al. 2003
9	Campnosperma coriaceum	Anacardiaceae	Suciatmih 2003
10	Castanopsis foxworthyii	Fagaceae	Suciatmih 2003
11	Chionanthus sp.	Oleaceae	Suciatmih 2003
12	Cratoxylum arborescens	Hypericaceae	Tawaraya et al. 2003
13	Cratoxylum glaucum	Hypericaceaee	Suciatmih 2003
14	Diospyros dajakensis	Ebenaceae	Suciatmih 2003
15	Diospyros hermaphroditica	Ebenaceae	Suciatmih 2003
16	Dyera polyphylla (D. lowii)	Apocynaceae	Turjaman et al. 2006, Graham et al. 2013
17	Elaeocarpus longipetiolatus	Elaeocarpaceae	Suciatmih 2003
18	Elaeocarpus mastersii	Elaeocarpaceae	Suciatmih 2003
19	Garcinia eugeniifolia	Guttiferae/Clusiaceae	Suciatmih 2003
20	Garcinia laterifolia	Guttiferae/Clusiaceae	Suciatmih 2003
21	Garcinia parvifolia	Guttiferae/Clusiaceae	Suciatmih 2003
22	Garcinia rostrata	Guttiferae/Clusiaceae	Suciatmih 2003
23	Garcinia tetandra	Guttiferae/Clusiaceae	Suciatmih 2003
24	Gonystylus bancanus	Thymelaeaceae	Tawaraya et al. 2003
25	Gonystylus macrophyllus	Thymelaeaceae	Suciatmih 2003
26	Gymnacranthera eugeniifolia	Myristicaceae	Suciatmih 2003
27	Horsfieldia crassifolia	Myristicaceae	Suciatmih 2003
28	Ilex sp.	Aquifoliaceae	Suciatmih 2003
29	Knema cinerea	Myristicaceae	Suciatmih 2003
30	Knema intermedia	Myristicaceae	Suciatmih 2003
31	Koompassia malaccensis	Leguminosae	Suciatmih 2003
32	Lithocarpus elegans	Fagaceae	Suciatmih 2003
33	Lithocarpus rassa	Fagaceae	Suciatmih 2003
34	Lithocarpus resinosa	Fagaceae	Suciatmih 2003
35	Litsea rufo-fusca	Lauraceae	Suciatmih 2003
36	Melastoma malabathricum	Melastomataceae	Tawaraya et al. 2003
37	Michelia montana	Magnoliaceae	Suciatmih 2003
38	Neoscortechinia philippensis	Euphorbiaceae	Suciatmih 2003
39	Palaquium gutta	Sapotaceae	Tawaraya et al. 2003
40	Ploiarium alternifolium	Bonnetiaceae	Turjaman et al. 2008
41	Santiria griffithii	Burseraceae	Suciatmih 2003
42	Scyphyphora hydrophylacea	Rubiaceae	Suciatmih 2003

No.	Species	Family	Reference
43	Shorea balangeran	Dipterocarpaceae	Graham et al. 2013
44	Shorea guiso	Dipterocarpaceae	Suciatmih 2003
45	Shorea teysmanniana	Dipterocarpaceae	Tawaraya et al. 2003
46	Shorea uliginosa	Dipterocarpaceae	Tawaraya et al. 2003
47	Stemonurus scorpioides	Icacinaceae	Suciatmih 2003
48	Syzygium castaneum	Myrtaceae	Suciatmih 2003
49	Syzygium densinervium	Myrtaceae	Suciatmih 2003
50	Tetramerista glabra	Tetrameristaceae	Tawaraya et al. 2003
51	Timonius flavescens	Rubiaceae	Suciatmih 2003
52	Tristania bakhuizenii	Myrtaceae	Suciatmih 2003
53	Xanthophyllum palembanicum	Polygalaceae	Suciatmih 2003

Appendix 3 Paludiculture species & flood tolerance

Species	Rarely flooded peatland	Moderately flooded peatland	Frequently/deeply flooded peatland
Actinoscirpus grossus		■	■
Agathis borneensis	■		
Aleurites moluccana	■		
Anacolosa frutescens	■		
Apososa frutescens	■		
Aquilaria species	■		
Artocarpus elasticus	■		
Baccaurea species	■		
Canarium species	■		
Caryota mitis	■	■	
Caryota urens	■		
Calamus caesius	■		
Chloranthus erectus	■		
Cyperus rotundatus		■	■
Cyrtosperma merkusii		■	
Dimocarpus longan	■		
Dipterocarpus gracilis	■		
Donax canniformis	■	■	■
Dyera costulata	■		
Dyera polyphylla	■	■	■
Elateriospermum tapos	■		
Eleocharus dulcis		■	■
Fibraurea tinctoria	■		
Finschia chloroxantha	■	■	
Flacourtia rukam	■	■	■
Gaultheria leucocarpa	■		
Garcinia mangostana	■		
Gonystylus bancanus	■	■	
Ipomoea aquatica		■	■
Juncus effusus	■	■	■
Korthalsia species	■	■	
Lepironia acutangula		■	■
Macaranga tanarius	■	■	
Madhuca motleyana	■		
Mangifera species	■		
Melaleuca cajuputi	■	■	■
Metroxylon sagu		■	■
Momordica charantia	■	■	
Nepenthes species	■		
Nephelium species	■		
Nothaphoebe species	■	■	
Palaquium species	■	■	

Pandanus species			
Payena leeri			
Poikilospermum suaveolens			
Pometia pinnata			
Rhodomyrtus tomentosa			
Sandoricum koetjape			
Scirpodendron ghaeri			
Shorea species			
Sindora velutina			
Stenochlaena palustris			
Syzygium species			
Terminalia catappa			
Uncaria gambir			
Vaccinium bracteatum			
Vatica species			
Wikstroemia tenuiramis			

Appendix 4 Means of propagation of PSF rehabilitation species

No.	Species	Family	Common name	Propagation method
1	Aglaia rubiginosa	Meliaceae	Kajalaki	W, S
2	Alstonia pneumatophora	Apocynaceae	Pulai	S
3	Alstonia spatulata	Apocynaceae	Pulai	S
4	Calophyllum hosei	Clusiaceae	Bintangur	W, S
5	Campnosperma coriaceum	Anacardiaceae	Terentang	S
6	Combretocarpus rotundatus	Anisophylleaceae	Tumih	W, S, C
7	Cratoxylum arborescens	Hypericaceae	Geronggang	W, S
8	Cratoxylum glaucum	Hypericaceae	Geronggang	W, S
9	Diospyros areolata	Ebenaceae	Malam-malam	S
10	Durio carinatus	Malvaceae	Durian hutan	S
11	Dyera polyphylla	Apocynaceae	Jelutung	S
12	Garcinia sp. #	Clusiaceae	Manggis hutan	S, W
13	Gluta (Melanorrhoea) wallichii	Anacardiaceae	Rengas burung	S
14	Gonystylus bancanus	Thymeleaceae	Ramin	S
15	Horsfieldia crassifolia	Myristicaceae	Mendarahan	S
16	Koompassia malaccensis	Fabaceae	Kempas	W, S
17	Licania splendens	Chrysobalanaceae	Bintan	W, S
18	Litsea sp. #	Lauraceae	Medang	S
19	Lophopetalum multinervium	Celastraceae	Perupuk	W, S
20	Macaranga pruinosa	Euphorbiaceae	Mahang	S
21	Madhuca motleyana	Sapotaceae	Katiau	W, S
22	Melaleuca cajuputi	Myrtaceae	Gelam	W, C, S*
23	Metroxylon sagu	Arecaceae	Sagu	Sh
24	Neesia malayana	Malvaceae	?	S
25	Palaquium cochleariifolium	Sapotaceae	Nyatoh	S
26	Palaquium leiocarpum	Sapotaceae	Nyatoh	S
27	Shorea balangeran	Dipterocarpaceae	Kahui, Belangiran	W, S*
28	Shorea bracteolata	Dipterocarpaceae	Meranti rawa	S, C
29	Shorea pauciflora	Dipterocarpaceae	Meranti rawa	S, C
30	Shorea smithiana	Dipterocarpaceae	Meranti rawa	S, C
31	Syzygium sp. #	Myrtaceae	Jambu-jambu	S
32	Tetramerista glabra	Tetrameristaceae	Punak	S
33	Tristaniopsis obovata	Myrtaceae	Belawan	W, S
34	Vatica sp. #	Dipterocarpaceae	Rasak rawa	S

Notes: List is adapated from Wibisono & Dohong (2017)

Additions by author = *

Garcina species in PSF = 20; *Litsea* species in PSF = 16; *Syzygium* species in PSF = 50+; *Vatica* species in PSF = 9.

Propagation method: C = cuttings; S = seed; Sh = shoot; W = wilding