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Master Plan for the Rehabilitation and Revitalisation of the Ex-Mega Rice Project Area in Central Kalimantan

NATURAL SUCCESSION IN PEAT SWAMP FORESTS OF CENTRAL KALIMANTAN

Technical Review No. 2

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Euroconsult Mott MacDonald and Deltares | Delft Hydraulics
in association with
DHV, Wageningen UR, Witteveen+Bos, PT MLD and PT INDEC

Master Plan for the Rehabilitation and Rehabilitation of the Ex-Mega Rice Project Area in Central Kalimantan

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Natural Succession in Peat Swamp Forests of Central Kalimantan

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AusAID	The Australian Government's Overseas Aid Programme
BKSDA	Balai Konservasi Sumber Daya Alam
BP-DAS	Balai Pengelolaan Daerah Aliran Sungai
BPP	Balai Penyuluhan Pertanian
CA	Cagar Alam (Strict Nature Reserve)
CDM	Clean Development Mechanism
CIMTROP	Centre for International Co-operation in Management of Tropical Peatland; associated with the University of Palangka Raya
DGIS	Directoraat Generaal Internationale Samenwerking (Netherlands Government Overseas Aid Programme)
dbh	diameter at breast height
EMRP	Ex Mega Rice Project
FMU	Forest Management Unit
HL	Hutan Lindung (Protection Forest)
KfW	Kreditanstalt für Wiederaufbau (The German Government's Overseas Aid Programme)
KPH	Kesatuan Pengelolaan Hutan (Indonesian for FMU)
LULC	Land Use Land Cover
MRP	Mega Rice Project
NLPSF	Natural Laboratory of Peat Swamp Forest
Norad	The Norwegian Government's Overseas Aid Programme
NP	National Park
PA	Protected Area
PLG	Proyek Lahan Gambut (Indonesian acronym for MRP)
PPT	Potential Plus Trees
SM	Suaka Margasatwa (Wildlife Reserve)
TN	Taman Nasional (National Park)
REDD	Reduced Emissions from Deforestation and Degradation
RESTORPEAT	Restoration of tropical peatland to promote sustainable use of renewable natural resources
STRAPEAT	Strategies for implementing sustainable management of peatlands in Borneo
UNPAR	University of Palangka Raya

Foreword

This *Technical Note on Succession* was produced as part of the 3-month extension of the project *Master Plan for the Conservation and Development of the Ex-Mega Rice Project Area in Central Kalimantan* funded by the Government of the Netherlands.

The proposal for this extension highlighted need for a detailed review and study of natural succession in the area to enable decision-making over the allocation of resources for reforestation. There is some overlap in scope between this present technical note and the *Guidelines for peat swamp forest rehabilitation* that was also produced as part of the extension. Both should be seen in tandem, as peat swamp forest rehabilitation needs to be based on natural succession principles.

This is literally a technical note and largely ignores the social dimension associated with peat swamp forest succession. This does not mean that social aspects are unimportant – they are probably the most important aspect in determining the outcome in many parts of the EMRP area – but simply that they are not the focus of this note. It is noted that a future peat swamp forest rehabilitation programme will need to be fully embedded in a social/administrative content in order to achieve any degree of success.

Given the time constraints, the focus is not on conducting an exhaustive review of all information available about natural succession in PSFs, but to produce a background document that assists decision makers in allocating resources for rehabilitation. The objective is therefore to be pragmatic rather than produce a comprehensive study.

Practitioners in PSF rehabilitation and restoration, and persons studying natural regeneration processes in PSFs are encouraged to respond and provide feedback to the authors:

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Palangkaraya, 30 January 2009

1 Introduction to succession in peat swamps

Ecological succession (see Box 1) in peat swamps of Southeast Asia shows that peat formation can begin in either a brackish or freshwater environment (see 2.1), the primary condition for this is that deposition of organic matter is more rapid than its decomposition. Peat accumulation therefore does not occur in areas that are seasonally dry, as decomposition is rapid when matter is exposed under tropical conditions, and it also does not occur in areas where rainfall levels are not high. In Southeast Asia rainfall must generally be above about 2000 mm per annum, without a distinct, long dry season, for peat genesis to occur.

Box 1. Ecological succession

Ecological succession refers to more-or-less predictable and orderly changes in the composition or structure of an ecological community. Succession may be initiated either by formation of new, unoccupied habitat (e.g., a lava flow or a severe landslide) or by some form of disturbance (e.g. fire, logging) of an existing community.

Source: Wikipedia (2009)

As peat accumulates in what is initially an aquatic environment, the system becomes freshwater (if the starting point was brackish) and gradually more akin to a terrestrial system as in the process of pedogenesis, peat accumulates to levels above (ground-) water tables. Peat that is formed in swampy depressions between rivers, for example, may experience seasonal or occasional flooding episodes that bring nutrients into the peat system. Such peatlands are termed topogenic peat swamps. In cross-section such peatland may be irregular and it is rarely raised much above that of the river levees.

Under favourable conditions, peat accumulation may continue to levels whereby a dome-shaped lens of peat is formed. Such peat domes can be up to tens of kilometres in diameter and vary from 4-5 metres thickness to even more than 20 metres. These domed peat swamps – called ombrogenous peat swamps – are raised to well above water tables and annual flooding events from rivers, and are completely dependent upon atmospheric inputs for water and nutrient inputs (see Figure 1). In Indonesia these are mainly found along the east coast of Sumatra, around the coastal lowlands of Kalimantan, and along the southern coast of Papua. Three types of ombrogenous peatland can be recognised in Central Kalimantan (see Box 2).

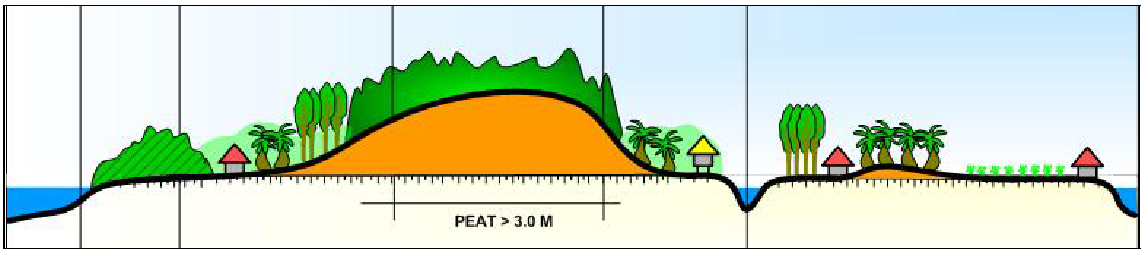


Figure 1 Cross-section of forested ombrogenous peat swamp
(adapted from Euroconsult, 2008).

Box 2. Ombrogenous peatland types in Central Kalimantan

Coastal peatlands

Coastal peatlands occur along the maritime fringe and in deltaic areas where they have developed over marine sediments of clay and silt at, or only slightly above, sea level (1-2 m asl). They are situated inland of accreting mangrove and Nipa palm swamps, which they replace, and where the accumulation of organic deposits eventually excludes inundation by brackish waters. The abundance of toxic sulphides in the waterlogged, brackish mangrove muds restricts bacterial activity enabling the initiation of peat formation under conditions of high rainfall and restricted drainage. The mangrove vegetation is replaced by peat-swamp forest and, as organic material continues to accumulate, these forests become increasingly ombrogenous, forming a domed mound of peat (Anderson, 1983). Peat core data presented by Staub and Esterle (1994) for the Rajang delta in Sarawak indicate that this model of coastal vegetation succession can be circumvented along sand-dominated shorelines, where the build up of mineral sediments behind coastal beach ridges rapidly brings the vegetation above the zone of tidal influence, and the mangrove/Nipa phase is absent. Likewise, in Peninsular Malaysia, particularly on the east coast, the initial development of peat may have occurred in isolated lagoons formed by sand bars and spits over subsoil composed of coarse sediments.

Basin or valley peatlands

Basin or valley peatlands occur inland in sub-coastal locations along river valleys at slightly higher altitudes than coastal peatlands (5-15 m asl), with which they may be contiguous. Peat formation in basin or valley peatlands appears to have been initiated at an earlier period than in the coastal peatlands, as a result of rising ground water levels, linked to changes in sea level. Restriction of drainage led to permanent waterlogging and the establishment of freshwater herbaceous vegetation that, under high rainfall conditions, was followed by a transition to swamp forest and subsequent accumulation of ombrogenous peat. These basin peatlands are often located along rivers in backswamp situations behind alluvial levees. They can achieve a peat thickness of up to 20 m (Anderson, 1983).

High, interior, or watershed peatlands

High (sensu Sieffermann et al., 1988), interior (sensu Page et al., 1999) or watershed peatlands (sensu Morley, 2000) have only been described from Central Kalimantan where they cover low altitude watershed positions (10-30 m asl) between major rivers. These peatlands extend up to 200 km or more inland from the coast and occupy thousands of square kilometres, covering the gently sloping landscape in a manner analogous to temperate zone blanket peat. Peat formation commenced on top of the upper coarse sand layer of the tropical podzol soil formation that extends across the middle of this province (Sieffermann et al., 1988, 1992). The creation of an impervious hard pan within the podzol, at a depth of several metres below the original mineral surface, gradually impeded vertical drainage and led to the waterlogging that was a prerequisite for peat initiation and accumulation. These watershed deposits are only slightly dome-shaped and their maximum recorded thickness is 13 m (Page et al., 1999). On shallower ombrotrophic peats, Brunig (1990) described somewhat analogous kerapah vegetation from inland Sarawak. Kerapah is a type of heath forest (kerangas) that develops under waterlogged conditions.

Source: Page *et al.,* (2006)

As peat develops, so does the associated peat swamp vegetation. Initially, hydrophytes common in freshwater systems may occur along with species more typical for palustrine systems, but these disappear as peat formation progresses and the system becomes more terrestrial. In topogenic peat swamps, species occur that are also found in freshwater swamp forests on mineral soil, and there is a distinct overlap in species associated with riparian swamps, freshwater swamps and topogenic peat swamps.

In Southeast Asia – and certainly in Indonesia – the climax vegetation type is a mixed forest, usually with emergents up to 30-40(-45) metres tall. In ombrogenous peat swamps a variety of forests occur – in Sumatra only 2-3 types have been recognised, but in Kalimantan AND Sarawak at least 6 types are known (see chapter 2). As peat genesis progresses, the vegetation of the centres of the peat domes may become (very) stunted, poor in species, and characterised by an abundance of species adapted to trapping nutrients (e.g. so-called ant-plants or myrmecophytes, and pitcher plants Nepenthaceae). This stunted forest – called *padang* or pole forest is often only 10-15 metres tall and usually has an open canopy. The mixed PSF vegetation of the peat dome margins is often most similar to lowland dipterocarp forest, while that of the nutrient poor centre (padang/pole vegetation) is most like that of poor, podzolised heath (*kerangas*) forest. Intermediate between these two is vegetation where the conifer *Dacrydium* is common (Rieley *et al.*, 1992). In Sarawak, this transitional vegetation is typified by the presence of *Shorea albida* (Anderson, 1983).

Light conditions in peatland vegetation also vary over time. In degraded conditions, light conditions will be harsh and shade requiring species more common in mature PSF will not flourish. In pole forest, light penetration is greater than in mixed/mature PSF, and once again light conditions may be more harsh and contribute to unfavourable conditions for certain species. Little is known about light requirements of PSF tree species, but one may assume that pioneer species have a high tolerance, while species that occur only in mature-mixed PSF are likely to be less tolerant.

Typical for both topogenic and ombrogenous peat swamps in Indonesia is that: i) peat has a high water content (up to 90%); ii) organic matter consists largely of woody material (esp. lignin), unlike peatland in temperate regions where peat largely consists of herbaceous material (esp. *Sphagnum* mosses); iii) humidity levels are high to very high, with water tables rarely more than 40cm below the surface; iv) fires are rare to non-existent; v) the climax vegetation is a peat swamp forest; and vi) current peat domes they are generally of recent origin[1], most having been formed during the last glacial period of 6000-10000 years BP.

[1] There are remnants of past peat deposits dating back much earlier (Miocene and earlier), but these are no longer peat but have been transformed into lignite (Anderson & Muller 1975; van der Kaars, 1991).

2 Primary succession in PSFs

2.1 Succession in PSFs of Sumatra & Borneo

Palynological studies carried out in peat swamp forests of Southeast Asia indicate at least two possible routes for their development: an origin in freshwater swamps, and one whereby peat formation begins in (back) mangrove areas.

As described by Morley (1981) based on peat core samples taken in the Sebangau peat dome in Central Kalimantan, peat formation in this area began abruptly over a topogenous eutrophic or mesotrophic swamp in which grasses (*Poaceae*) and *Lycopodium cernuum* were conspicuous elements. Other species at this early stage include aquatic species such as *Nymphoides indica* and bladderwort *Utricularia flexuosa.* Most peat swamp trees were probably recruited from local plant communities, since pollen of many of the taxa found in the peat swamp was already present during the grass-dominated phase (see 2.2 for more details).

Peat swamps in Kutai, East Kalimantan also have a freshwater origin, but rather than being dominated by grasses during the preceding stage, these swamps were dominated by *Pandanus*, which grades upwards to peat swamp dominated by dipterocarps (Hope *et al.,* 2005). This is similar to the situation found in Riau, where Brady (1997) also recorded an initial pandan-dominated stage in peat swamps of Pulau Padang.

These coastal peatlands are of recent origin, with most of the near coastal peat having been formed during following the last glacial period and are often date back <6000 years BP. Peatlands located further inland are often much older, and studies have shown that these may be 30000-40000 years BP (Box 3).

Box 3. Age of current peat deposits and peat domes

Paleoenvironmental studies of lowland tropical coastal peat deposits in Southeast Asia have demonstrated that these are the youngest peatlands in the region. Peat accumulation commenced in most of these around 4000-5500 cal yrs BP, following stabilisation of rising sea levels (Anderson and Muller, 1975). In comparison, investigations of sub-coastal and inland peatlands, particularly in Borneo, have revealed much earlier initiation dates, ranging from Late Pleistocene (~29,000 cal yrs BP) in the Danau Sentarum basin of West Kalimantan (Anshari et al.*, 2001, 2004) to ~26,000 cal yrs BP in the Sebangau catchment, Central Kalimantan (Page et al., 2004) through to early Holocene (8000-9000 cal yrs BP) for other high and basin/valley peatlands within Borneo (Sieffermann* et al.*, 1988; Staub and Esterle, 1994; Neuzil, 1997). Whilst it had been assumed previously that tropical peat accumulation was primarily a feature of the Holocene, it is now clear that it was also a feature of the last glacial period, with a paleo-record in some tropical peat deposits extending over 30,000 to 40,000 years.*

Adapted from Page *et al* (2006)

Studies by Anderson and Muller (cited by Morley, 1981) indicate that the Marudi peat swamp in Sarawak originated in a (back) mangrove area, having developed over marine clays in the Baram Delta. The Marudi palynological profile shows a gradual change from a mixed mangrove with *Nypa fruticans, Oncosperma tigillarium* and Rhizophoraceae, through a transitional community with *Cyrtostachys lakka, Campnosperma* and *Eleiodoxa,* to a true peat swamp association. A similar history was recorded by Yulianto *et al.* (2005) at Batulicin in South Kalimantan, where sea level rise about 6000-6400 years BP lead to a transition from *Rhizophora*-dominated mangrove to peat swamp forest.

Studies by Anderson (1983) in Sarawak lead to a recognition of six main types of PSF vegetation along a catena in a typical large peat dome, from a relatively species-rich mixed PSF on the margin (his Type 1 dominated by *Gonystylus-Dactylocladus-Neoscortechinia;* Table 1) to an impoverished padang vegetation in the centre of peat domes (his Type 6, dominated by *Combretocarpus-Dactylocladus*). His 6 types were later confirmed by studies carried out by the Conservation of Malaysian Peatswamp Forest Project at Loagan Bunut in 2003-2004 (Table 1).

Although less biodiverse than lowland dipterocarp forests, mixed PSF can attain a canopy height of 35-40 metres and include anywhere from 30-130 tree species at a given location (Giesen, 2004). Simbolon and Mirmanto (2000) list a total of 310 tree and shrub species for PSFs of Central Kalimantan – basically from two sites, Tanjung Puting NP and Sebangau NP. Up to 80 tree species have been recorded in 1-ha plots of LIPI/Bogor Herbarium near Kelampangan (northern Block C, EMRP area; pers. comm. Edi Mirmanto). In large domes that have developed over a long period, a species-poor pole forest with an open canopy may develop in the central part of the dome due to the prolonged waterlogging and extremely nutrient deficient conditions that prevail. Pole forests (sometimes called ‘padang’ forest) have a lower canopy (usually max. of 15 metres) and the trees have considerably smaller boles (max. 35-40 cm). In Sumatra, pole forests on deep peat are dominated by *Calophyllum* and *Syzygium* species and may have only about 12-17 tree species (Giesen & van Balen, 1991a), while in Central Kalimantan these are dominated by *Combretocarpus rotundatus, Syzygium, Tristaniopsis obovata* and *Shorea teysmanniana* (Page & Waldes, 2005; see Table 2).

Table 1 Peat swamp forest types along a catena in Sarawak peat domes

Type	Anderson (1983) * Sarawak	Phasic community	Malaysian Peatswamp Forest Project** Loagan Bunut NP, Sarawak
Type 1	*Gonystylus-Dactylocladus-Neoscortechinia* association (mixed swamp forest). Structure and physiognomy are similar to lowland dipterocarp evergreen forest.	PC1	Mixed swamp forest with commercially important timber trees, in particular, *Gonystylus bancanus* & *Dactylocladus stenostachys* . Other important species include *Shorea platycarpa, Shorea inaequilateralis, Dryobalanops rappa, Hopea pentanervia, Gonystylus forbesii, Durio carinatus, Copaifera palustris, Gluta (Melanorrhoea) beccarii, Madhuca motleyana, Ilex hypoglauca, Elaeocarpus beccarii, Lithocarpus dasystachyus & Combretocarpus rotundatus.*
Type 2	*Shorea albida-Gonystylus-Stemonurus* association. Similar to type 1 but dominated by scattered large *S. albida.*	PC2	Alan or Alan batu forest, occurring as a transitional zone. Besides Alan (*Shorea albida*), two other species that are characteristic of this community are *Gonystylus bancanus* and *Stemonurus umbellatum*.
Type 3	*Shorea albida* consociation. The even upper canopy, which varies between 45-60m in height is dominated by *S. albida.*	PC3	Alan bunga forest. Most extensive community, with pure stands of *Shorea albida*, forming an unbroken emergent canopy, with large and compact grey crowns that are distinctively shaped like cauliflowers. Common are also *Combretocarpus rotundatus, Madhuca motleyana, Dialium laurinum, Dryobalanops rappa & Copaifera palustris.*
Type 4	*Shorea albida-Litsea-Parastemon* association. This is dense, mainly even canopied forest composed of relatively small-sized tree that give the forest a pole-like appearance.	PC4	Padang Alan forest; this is similar to Alan bunga forest but the trees are much smaller in height and diameter. Other species include: *Tristaniopsis beccarii, Madhuca spp., Ctenolophon parvifolius, & Mezzettia leptopoda)*.
Type 5	*Tristania-Palaquium-Parastemon* association. This is transitional between types 4 and 6.	PC5	PC 5 occurs as a narrow transitional zone, with species of *Tristaniopsis, Parastemon* and *Palaquium* as the main associates.
Type 6	*Combretocarpus-Dactylocladus* association. This type more closely resembles savannah woodland than tropical rainforest.	PC6	Padang Keruntum forest, and is formed by an association of *Combretocarpus rotundatus* (Keruntum) & *Dactylocladus stenostachys.*

* Adapted from Anderson (1983), in Rieley *et al.* (1992).
** Conservation and Sustainable Use of PeatSwamp Forests and Associated Wetland Ecosystems UNDP-GEF Project (MAL/99/G31)

2.2 Succession in PSFs in Central Kalimantan/Sebangau NP

Studies on succession in PSF in Central Kalimantan are limited. Morley (1981) carried out a palynological study of six borehole samples taken along an 8-km transect in the northern part of the Sebangau peat dome. Cores varied from 4-7 metres depth, and as stated in 2.1, peat formation in this area began abruptly over a topogenous eutrophic or mesotrophic swamp in which grasses (*Poaceae*) and *Lycopodium cernuum* were conspicuous elements. Other species at this early stage include aquatic species such as *Nymphoides indica* and bladderwort *Utricularia flexuosa.* This swamp is believed to have occurred at or near sea level, as pollen from mangrove species have been carried into this swamp. Following the Graminae stage, a stage of oligotrohic mixed swamp forest with a closed canopy is found abruptly along the entire transect (see Figure 2).

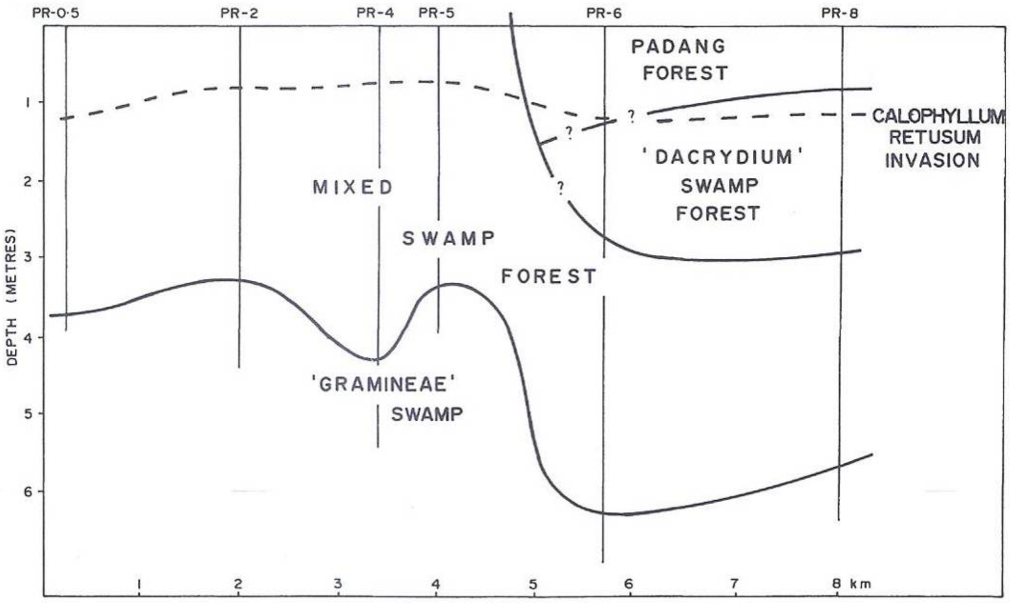


Figure 2 Peat swamp forest succession at Sebangau
(adapted from Morley, 1981).

Species found include *Blumeodendron, Calophyllum, Campnosperma, Combretocarpus rotundatus, Eugenia, Garcinia cuspidate, Gonystylus, Lithocarpus, Neoscortechinia* and *Stemonurus.* Interestingly, all of these species occur in the core samples during the grass-dominated stage, but simply increase in frequency during the mixed PSF phase. This means that these species were probably recruited from local plant communities. On peat of at least three metres depth, *Dacrydium pectinatum* is a consistent component, suggesting that this species – which does not occur in mixed PSF but is found on sandy soils around Sebangau – establishes itself on nutrient poor deeper peat and may represent a transition to pole (padang) forest. *Calophyllum retusum* (and to a lesser extent *C. sclerophyllum)* is common in all stages except the grass-dominated stage, but is particularly common in the pole-stage, along with *Combretocarpus rotundatus.* However, it is not restricted to the pole (padang) vegetation, but appears to have invaded all peat swamps regardless of depth.

Sieffermann (1988) analyzed two samples taken in the Katingan-Rungan area, one at 0.5m and a second at 3.5m depth. This analysis showed that a transition occurred at this location, from a mixed PSF dominated by *Campnosperma,* to a drier transitional forest dominated by the conifer *Dacrydium.*

Succession can also to some degree be inferred from species occurrence along gradients across peat domes, thereby recognising catenae such as by Anderson (1983) in Sarawak. Page and Waldes (2005) describe three main types along a transect in the north-eastern part of the Sebangau peat dome: from mixed PSF at the edge of the dome, via tall interior forest, to low pole forest (see Table 2). A more complicated catena with seven types emerges from an earlier study (Page *et al.,* 1999), which starts with riverine forest and ends with very low canopy forest (Table 3).

Table 2 Main tree species & peat depth

Principal tree species occurring in three peat swamp forest communities on peat of increasing depth across a peatland dome in the Sebangau catchment, Central Kalimantan (adapted from Page & Waldes 2005).

Principal tree species	Mixed swamp forest at the edge of the peat dome	Tall interior forest on the central peatland dome	Low pole forest nearer to the centre of the peat dome
Palaquium ridleyi	x		
Calophyllum hosei	x		
Mesua sp.	x		
Mezzettia parviflora	x		
Neoscortechinia kingii	x	x	
Palaquium cochlearifolium	x	x	
Palaquium leiocarpum		x	
Stemonurus secundiflorus		x	
Mezzettia parviflora		x	
Shorea teysmanniana		x	x
Combretocarpus rotundatus	x		x
Syzygium			x
Tristaniopsis obovata			x

What can we conclude from these studies on succession (in time) and vegetation catenae along peat dome gradients? Firstly, peat swamp forests on Borneo appear to be richer in species and more diverse in successional stages and vegetation types than PSFs in Sumatra. Secondly, there is a lot of variation between sites that are even geographically close, let alone located further apart. This situation is similar to that of lowland dipterocarp forests on mineral soils, where due to a large diversity of species and niches, past histories and chance events play an important role in determining outcomes. Hence there is a lot of ‘static’ in the datasets that can only be eliminated by comparison of large amounts of data. At present these datasets do not exist, while at the same time the object of study (pristine PSF) is rapidly disappearing. Some general conclusions can be drawn, however, and these are summarised below in Figure 3.

Table 3 Vegetation & site characteristics along a gradient at Sebangau

Type	Distance from river (km)	Peat depth (m)	Canopy height (layers)	Hydrology & adaptations	Principle species
i) Riverine forest	Up to 1	Up to 1.5	35m (25-35)	Regularly flooded.	*Shorea balangeran, Campnosperma coriacea, Combretocarpus rotundatus. Thoracostachyum bancanum* characteristic ground cover.
ii) Transition forest (i-iii)	1-1.5	2	35m	Annual flooding.	*Shorea balangeran* is key tree species.
iii) Mixed swamp forest	1.5-4	2-6	35m (15-25) (7-12)	Trees grow on large hummocks formed by root plates, interspersed with hollows that fill with water in the wet season. Many trees have stilt or buttress roots, pneumatophores are common	*Aglaia rubiginosa, Calophyllum hosei, C. lowii, C. sclerophyllum, Combretocarpus rotundatus, Cratoxylum glaucum, Dactylocladus stenostachys, Dipterocarpus coriaceus, Dyera polyphylla, Ganua motleyana, Gonystylus bancanus, Mezzetia leptopoda, Neoscortechinia kingii, Palaquium cochlearifolium, P. leiocarpum, Shorea balangeran, S. teysmanniana, Xylopia fusca*
iv) Transition forest (iii-v)	4-6	?	25-30m	Few trees with stilts or buttresses; pneumatophores are common.	Same as mixed, but densities of *Calophyllum, Combretocarpus* & *P. cochlearifolium* are much higher. *Pandanus & Freycinetia* form almost continuous ground cover.
v) Low pole forest	6-11	7-10	20m (12-15)	Water table permanently high; forest floor very uneven. Trees grow on hummock-like islands, with deep permanent pools in between. Pneu-matophores common, tree roots form mat.	Principle species is *Combretocarpus rotundatus,* with *Calophyllum fragrans, C. hosei, Campnosperma coriacea, Dactylocladus stenostachys.* Many pandans on the ground, and *Nepenthes* are common.
vi) Tall interior forest[2]	12-24.5	9-10	45m (15-25) (8-15)	Water table is below surface throughout the year. Few hummocks & hollows, and few pneumatophores	*Agathis dammara, Calophyllum hosei, C. lowii, Cratoxylum glaucum, Dactylpocladus stenostachys, Dipterocarpus coriaceus, Dyera polyphylla, Eugenia havelandii, Gonystylus bancanus, Gymnostoma sumatrana, Koompassia malaccensis, Mezzetia leptopoda, Palaquium cochlearifolium, P. leiocarpum, Shorea teysmanniana, S. platycarpa, Tristania grandifolia, Vatica mangachopai, Xanthophyllum* spp. & *Xylopia* spp. Pandans uncommon.
vii) Very low canopy forest	Highest point	?	1.5m	Permanent high watertable, with large pools: 200m wide/ 1m deep. Many pneumatrophores.	*Calophyllum* spp., *Combretocarpus rotundatus, Cratoxylum* spp., *Dactylpocladus stenostachys, Litsea* spp., *Ploiarium alternifolium* & *Tristania* spp.

Adapted from Page *et al.* (1999)

[2] This tall interior forest is atypical of most peat dome catenary sequences and is probably only present because the most elevated part of the dome in the northern part of the Sebangau is undergoing degradation – the contemporary climate is possinly no longer sufficiently wet to maintain the (previous) height of the dome.

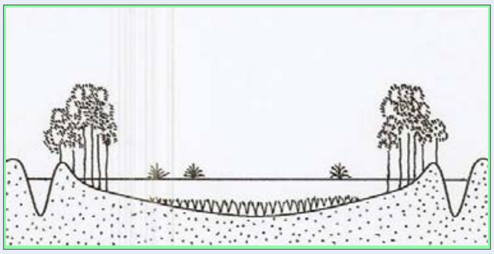
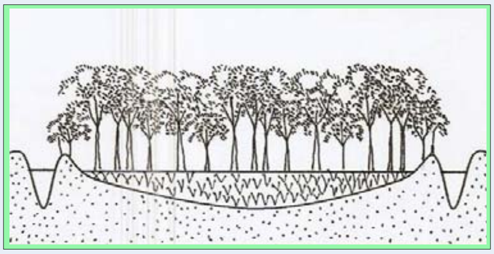
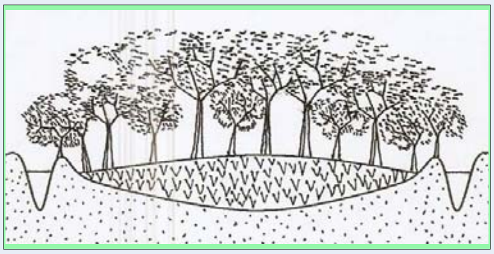
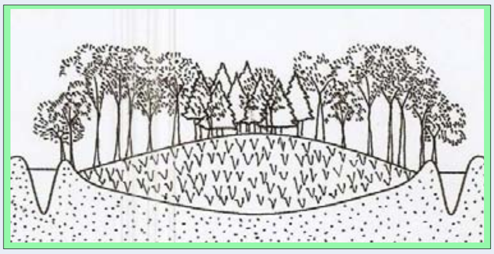
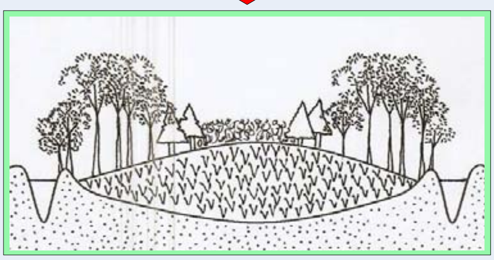
Stage	Cross-section of successional stage	Conditions & species
1		**Freshwater swamp stage.** Conditions are permanently wet, and open water prevails. Typical freshwater species such as *Pandanus helicopus, Hanguana malayana* dominate as organic matter accumulates. Mesotrophic to eutrophic.
2		***Topogenic or valley peat stage***. *Peat accumulates to the point that 'verlandung' occurs and the system becomes terrestrial. Input from floodwaters means that the system has riverine nutrient input. Species are related to riverine species & include Gluta renghas, Campnosperma spp. & Shorea balangeran.*
3		**Ombrogenous or raised peat dome stage – mixed PSF**. Peat accumulation continues to the point that it rises to above average floodwater levels & becomes dome-shaped. Nutrient input is only from rainwater & groundwater levels are near surface. Mixed peat swamp forest with many species, often shared with riverine forest and lowland dipterocarp forest.
4		**Oligotrophic ombrogenous peat dome stage**. Peat development continues; nutrients are very depleted. Species occur that are shared with dry, nutrient poor habitats (e.g. kerangas/heath forest), such as *Calophyllum, Dacrydium, Lithocarpus dasystachyus & Tristaniopsis.*
5		**Highly oligotrophic ombrogenous peat dome stage – Padang (Pole) PSF**. Nutrient depletion is extreme. Vegetation is very stunted, dominated by *Tristaniopsis, Campnosperma, Combretocarpus rotundatus, Ploiarium alternifolium & Calophyllum* species.

Figure 3 Successional stages in Kalimantan PSF

3 Secondary succession in PSFs

Secondary succession occurs where the original vegetation has been disturbed, usually by human intervention. Peat swamp forests follow patterns of secondary succession after logging operations, for example, or following fires. In the EMRP area human disturbance has been a combination of logging and fires, along with a change in the hydrology due to the construction of drainage canals.

What follows below has already been included in the EMRP report *Guidelines for the Rehabilitation of degraded peat swamp forests in Central Kalimantan.* This report does not refer to secondary succession, but to (natural) regeneration following disturbance. However, the same processes are described.

3.1.1 Malaysia

According to Wyatt-Smith (1959) there is a comparative wealth of natural regeneration of all sizes of economic species in the peat swamp forests of Malaysia. He notes, however, that even a slight drop in the mean water table may result in changes to the species composition of the forest, with plants that are more suited to the drier soils succeeding those of the original wetter conditions. Thus *Tetramerista glabra* and *Gonystylus bancanus* often do not regenerate following logging. However, *Koompassia malaccensis, Calophyllum retusum* and *Shorea* spp. do well – so a good timber crop can be expected in regenerated forest.

Natural regeneration and reforestation studies in the peat swamp forests of Sarawak by Lee (1979) found that in the *Alan Batu* forest, the amount of *Shorea albida* dropped from 28% to 2% over a period of 17 years, as *S. albida* seedlings are quickly out competed after logging. Fast-growing species such as *Xylopia coriifolia, Litsea* spp. and *Cratoxylum* spp. increase significantly after logging, while those with medium rates of growth such as *Dactylocladus stenostachys, Ganua* spp. and *Shorea inaequilateralis* showed about 20% increase in distribution. Slower growing species such as *Combretocarpus rotundatus, Melanorrhoea* spp. (now *Gluta)*, *Palaquium* spp. and *Gonystylus bancanus* decreased in distribution by about 30%. Silvicultural treatment aimed at eliminating vegetation competing with a potential tree crop, appear to have a stimulating effect (as measured after 10 years) on growth of fast growing species such as *Cratoxylum* spp., *Dryobalanops rappa, Shorea* spp. and *Dactylocladus bancanus*.

Whitmore (1984) describes secondary vegetation types in peat swamp areas. *Melaleuca cajuputi* is an under storey tree that becomes gregarious after repeated burning, owing to thick, loose, corky bark, and the production of root suckers and coppice shoots. In Malaysia, species commonly associated with *Melaleuca cajuputi* are *Alstonia spathulata, Cratoxylum cochinchinense, Excoecaria agallocha, Fagraea fragrans, Ilex cymosa, Macaranga pruinosa, Ploiarium alternifolium, Randia dasycarpa, Scleria* species and *Stenochlaena palustris*.

Whitmore (1984) found that following logging of *Shorea albida-Gonystylus-Stemonurus* forest in Sarawak, *Shore albida* presence dropped from 28% to 2% as seedlings were killed by competition. In contrast, fast growers such as *Cratoxylum, Litsea* species and *Xylopia coriifolia* had greatly increased; medium growers such as *Dactylocladus stenostachys, Ganua* species and *Shorea inequilateralis* increased by 20%, and slow growers such as *Combretocarpus rotundatus, Gluta* species, *Palaquium* species and *Gonystylus bancanus* decreased by about 30%. In the *Shorea albida-Litsea-Parastemon* forest type, natural regeneration of *Shorea albida*, and other large trees such as *Litsea crassifolia* and *Combretocarpus rotundatus* is mainly vegetative, by suckers or coppice shoots. This forest then has no value for timber, but low extraction costs and high volume makes it valuable for chips or pulp. Extensive pure stands of *Macaranga pruinosa* and *Campnosperma coriacea* in Malaysia of same-sized trees with an even canopy are believed to represent stages in a secondary succession back to mixed swamp forest after clearing (Whitmore, 1984).

Appanah *et al.* (1989) note that in peat swamp forests of Peninsular Malaysia there is an increase in the regeneration of *Shorea* species, *Koompassia malaccensis* and *Calophyllum retusum* after final felling or when the surrounding forest is converted to agriculture. This increase has been attributed to the desiccation of the forest, favouring these species at the expense of species such as *Gonystylus.*

According to Bruenig (1990), commercial tree felling results in a drastic shift in species composition in favour of species which are tolerant to sudden change, such as *Cratoxylum arborescens,* but not species such as *ramin Gonystylus bancanus*. The latter is a naturally slow starting species, and in silvicultural trials, reacted poorly to felling and release operations. In regenerating areas with even canopies there is a risk of a dense, slender pole vegetation resulting which is susceptible to wind damage. Another hazard of commercially felled areas is that of nutrient loss by interrupting the nutrient cycle. Growth can be almost static in secondary growth areas in Borneo (e.g. dominated by *Ploiarium alternifolium*), where monitored secondary forest showed almost zero growth even after 30 years.

Under post-logging conditions in peat swamp forests in Malaysia, Ibrahim (1996) reports that cleaning operations are required to reduce competition for sunlight and nutrients. Where this does not occur, disturbed peat swamp forests are rapidly dominated by fast growing species such as *Macaranga.* In Sarawak, defective and weakened trees are removed by means of girdling and liberation in the first year after logging, and again after 10 years. Some enrichment planting has been carried out, especially of *Gonystylus bancanus* in Sarawak, but no routine silvicultural treatments are performed in logged-over peat swamp forest in Peninsular Malaysia. Seedlings and small trees of commercial trees tend to cluster around the mother tree, and removal of the latter in uncontrolled logging operations results in serious damage <to progeny>, and reduced opportunities for natural regeneration. Enrichment planting is probably the most logical solution if natural regeneration fails to restock degraded peat swamp forest. The main problems associated with enrichment planting of peat swamp forests is obtaining an adequate seed supply of selected species, the remoteness of planting areas, and a lack of process planting techniques in areas which contain much undecomposed organic matter.

3.1.2 Brunei Darussalam

In his study on secondary succession in logged over peat swamp forest dominated by *Shorea albida,* at Sungei Damit, Belait, Kobayashi (2000) found that natural regeneration of *Shorea albida* forests following logging operations is poor. After a four year recovery period he found that less than 10% of the former *Shorea albida* forests were likely to recover as *S. albida* forest, while more than 80% was found to be heavily colonised by *Pandanus andersonii* and *Nephrolepis biserrata* and developing into a shrub-fern vegetation.

3.1.3 Thailand

Only a relatively small area (64,000 ha) of peat swamp forest remains in Thailand (Hankaew, 2003). Whereas a total of 437 angiosperms were recorded in primary peat swamp forest, only 82 species are found in secondary, degraded peat swamp forests. The latter are dominated by *Melaleuca cajuputi* and are characterised by the presence of many Cyperaceae. Peat swamp forest disturbed by repeated fires loses all or most of its peat layer, and underlying clay soils are invariably potential acid sulphate soils. Upon exposure to the air these become strongly acidic, and this favours *Melaleuca,* which is generally tolerant of such conditions. If fires are not only incidental, *Melaleuca*–dominated communities may be replaced by a further degraded Cyperaceae 'grassland'.

Mixed peat swamp forests are generally of two types, one dominated by *Eugenia kunstleri*, the second dominated by *Ganua motleyana.* Upon opening of the canopy, for example, by felling of trees, the vegetation becomes dominated by *Macaranga pruinosa.* Further disturbance and especially fires then leads to the fourth community type already described, dominated by *Melaleuca cajuputi.* Herbaceous species commonly associated with the latter secondary vegetation are *Cyperus* spp., *Lepironia articulata, Lygodium microphyllum, Medinilla crassifolia, Melastoma decemfidum, Nepenthes gracilis, Stenochlaena palustris* and various grasses.

According to Hankaew (2003), recovery of disturbed peat swamp forests via natural succession occurs via the following stages:

- *Melaleuca cajuputi* community type
- *Macaranga pruinosa* community type
- *Eugenia kunstleri – Goniothalamus giganteus – Macaranga pruinosa* community sub-type
- *Eugenia kunstleri – Ganua motleyana* community sub-type
- *Ganua motleyana – Xylopia fusca* community type.

For natural regeneration to occur, it is most important that fires are prevented, and other factors appear to be secondary to this.

Tomita *et al.* (2000) studied in detail the natural regeneration process of *Melaleuca*–dominated peat swamp forest in southern Thailand following a severe fire. The area studied had been drained, cleared, abandoned and burnt, after which the area was rapidly colonised by *Melaleuca cajuputi,* along with *Melastoma malabathricum,* a host of ferns including *Blechnum indicum, Stenochlaena palustris* and *Lygodium microphyllum,* and the sedges *Lepironia articulata* and *Scleria sumatrana.* According to Tomita *et al.* (2000), who studied dispersal and recovery in great detail, these species either arrived as wind-borne seeds (*Melaleuca*) or from surviving subterranean clones (*Lepironia, Blechnum*). In the three year study, *Melaleuca* was observed to grow very rapidly, increasing to a height of 2-3 metres, covering much of the quadrats analysed, and out-competing other species after only 1.5 years.

3.1.4 Papua New Guinea

According to Eden (1973), the current distribution of savannah and grassland in southern Papua is not wholly consistent with environmental conditions, and he concludes that these habitats have been formed as a result of clearing and burning of the original PSF, perhaps influenced by recent climatic fluctuations.

3.2 Degradation seres and regeneration in Indonesia

3.2.1 Indonesia in general

In their assessment of the TPTI selective logging system in Indonesia, Dwiyono and Rachman (1996) conclude that this system does not always allow regeneration, due to:

- poor felling techniques which severely damage young/valuable trees;
- use of young trees (20-30cm dbh class) to construct logging tracks, ramps, etc…;
- some tree species produce seed only once a decade or so;
- suppression of preferred species by other (less valuable) species;
- luxuriant growth of climbers, creepers or rattans; and
- appropriateness of enrichment planting not examined and suitable species unknown.

As a result of felling, there is a decrease in old and large trees, with higher densities of younger and smaller ones as a result. In peripheral peat swamps, *Shorea* species tend to dominate regrowth, while in most open places (e.g. along extraction routes) *Cratoxylum arborescens, C. glaucum* and *Dactylocladus stenostachys* are pioneer species colonizing newly available space. On the whole, such fast growing trees become dominant in the regenerating peat swamp forest. Regeneration is also often quite patchy, and forest stands are often replaced by low growing species such as ferns and shrubs. Other changes noted by Dwiyono and Rachman are structural changes, a reduced structural diversity, and changes in micro-climate.

3.2.2 Sumatra

Kostermans (1958) regarded the lakes at Kayu Agung in South Sumatra as being the result of peat disappearance due to extensive burning. Giesen and van Balen (1991b) describe the lakes along the Siak Kecil River in Riau, which forms part of a large peat dome where the deepest peat in Indonesia has been recorded – 24 metres. The string of lakes along the Siak-Kecil – like pearls on a string – and the ongoing peat degradation and burning strongly suggest that the lakes are in the process of being formed due to peat degradation[3].

[3] Lakes can also occur naturally as part of natural peatland ontogenic processes, particularly during the mature phase of dome development, cf. development of large pools on temperate/boreal peatlands (pers. comm.. S. Page, Jan. 2009).

3.2.3 South Kalimantan

Giesen (1990) considers that virtually all vegetation types in the Sungai Negara wetlands of South Kalimantan are of a secondary nature, derived from primary types by tree felling and burning. Mixed freshwater swamp forests were found to have all been converted to *Melaleuca cajuputi* (*gelam*) [4]dominated swamp forest, sedge and grass swamp or rice paddies, a process that was already observed and noted early in the 20th century. Elsewhere (West Kalimantan, East Kalimantan) freshwater swamp forest is observed to be converted to a vegetation dominated by *Shorea balangeran*. This also appear to have been the case in South Kalimantan, and historic accounts record *gelam* and *S. balangeran* fire seres being replaced by sedge, fern and grass swamps. Giesen (1990) notes that the herb layer of degraded wetlands is often dominated by *Stenochlaena palustris* and *Blechnum indicum.*

Giesen (1990) further describes five types of secondary peat swamp forests (fire seres) derived from mixed peat swamp forest that formerly included *Gonystylus bancanus,* dipterocarps and wild mangoes. These five types are:

- *Eugenia* – dominated fire/logging sere.
- *Shorea balangeran* – dominated fire/logging sere.
- *Combretocarpus rotundatus* – pure stands; also a fire sere, possibly intermediate between the former two.
- *Melaleuca cajuputi* swamp forest – possibly a next degradation stage, following a long history of fires in peat swamp forests on acid sulphate soils.
- Sedge and grass swamp – final stage of degradation. Many species of sedge (*Cyperus, Scleria, Eleocharis, Fimbristylis, Fuirena, Scirpus, Rhynchospora*) and grass (*Ischaemum, Echinochloa, Phragmites, Rottboellia*), and invasive *Mimosa pigra* shrubs.

3.2.4 Central Kalimantan

Kostermans (1958) reports that species such as *Alstonia, Campnosperma* and *Ctenolophon lophopetalum* only develop alongside *Combretocarpus rotundatus* if burning is not too frequent. Both *Shorea balangeran* and *Combretocarpus rotundatus* appear to be stimulated by fire, and show a marked tendency towards gregariousness, each forming nearly pure stands.

According to Rieley and Ahmad-Shah (1996), Bornean dipterocarps are not only tolerant of shade in early stages of growth, but develop faster under these conditions. Opening up of the canopy during logging operations may therefore have adverse effects on these species. Regeneration of burnt areas may be hampered by falling timber, and Rieley and Ahmad-Shah (1996) found that “since the <Kalimantan> fires ended there has been a constant collapse of burned trees to the forest floor causing damage to new growth.”

In their assessment of the effects of the 1997/98 forest fires and deforestation in Central Kalimantan, D’Arcy and Page (2002) found that mixed peat swamp forest lost about 75% of tree density in burnt areas, compared to a maximum loss of 40% in selectively logged areas. Primary forest had the highest mean number of saplings per plot, while burnt areas had the highest mean dbh. Interestingly, they found that *Combretocarpus rotundatus* is one of the main

[4] *Melaleuca cajuputi* is an understorey tree in the primary swampforest (Whitmore, 1984).

species able to survive fires. Forest fires can greatly restrict the regeneration of an area by killing (freshly deposited) seeds[5] and plants that normally resprout post disturbance, and leading to a decline in soil fertility due to the loss of surface organic material. It has been demonstrated (Weiss *et al.,* 2002) that the top 100 cm of peat is crucial in nutrient cycling, as this upper peat layer exhibits bioaccumulation (concentration) of nutrients required for plant growth in comparison to deeper peat.

An IPB study of the recovery of a large area of former peat swamp forest at Kelampangan, Central Kalimantan, has produced some interesting results. A 1 ha plot of 100 by 100 metres was studied over the course of several years after the 1997 fires. Immediately after the fires it was concluded that all species had died, apart from two specimens of *jelutung Dyera polyphylla (lowii)* that had miraculously escaped. In the first four months after the fire, very little regeneration occurred except for resprouting of *Combretocarpus rotundatus,* and it was therefore concluded that (freshly deposited) seeds had also been killed. By May 2003, i.e. 6 years after the fires, Simbolon *et al.* (2003) found that there were 1158 individual trees (with a dbh of 15 cm or more) growing in the plot. 103 tree species were identified, dominated by *Combretocarpus rotundatus, Cratoxylum arborescens, Palaquium gutta, Shorea teysmanniana* and *Syzygium ochneocarpa*. Common species (in terms of number) were: *C. arborescens* (256 indiv.), *S. teysmanniana* (104), *S. ochneocarpa* (50), *Horsfieldia crassifolia* (47) and *Campnosperma squamatum* (46). On the whole, the investigators were surprised by the vigorous regrowth. According to Simbolon (pers. comm., 2003), the seeds did not arrive by wind, as most are too heavy, and they were probably brought by birds and mammals, or by floodwaters. However, the latter happened only once since the IPB team began monitoring the area. One must note, however, that the plot is located only 300 metres from a patch of good peat swamp forest. Simbolon expected dbh to have recovered by 30-40 years, but full floristic recovery would take more than 100 years, and perhaps even several hundred years. In any case, this will depend on the proximity of good forest as a source of seeds.

A WWF-Indonesia team conducted an initial fire impact study in the peat swamp forests of Tanjung Puting National Park, Central Kalimantan in December 1997[6]. They found that the average number of tree species declined from 60 per hectare in unburned areas to fewer than 15 after burning, that the total number of trees that survived the burn is highly correlated with the degree of prior disturbance, and that areas that had burned twice or more generally were devoid of trees. Peat swamps differ from other forests in that fires can travel below the ground surface killing trees by destroying their root systems.

D'Arcy and Graham (2007) found in the Sebangau NP area that primary seed dispersers are important for dispersal and maintenance of tree species diversity in these peat swamp forests. However, their population densities are in decline, and especially in burnt areas are likely to play a limiting role in seed dispersal from adjacent intact areas. The implications are that if this decline continues, peat swamp forest may struggle to regenerate naturally in disturbed areas. Ongoing studies on seed dispersal by frugivorous birds at Sebangau NP indicate that, unlike in the Neotropics, seed dispersal by birds plays a less important role (pers. comm. L. Graham, 2008). However, it must be acknowledged that the forests under study (Sebangau NP) have

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[5] Seed banks that normally occur in the topsoil of many other forest types do not appear to exist in PSFs (L. Graham, unpubl. data). Freshly deposited seeds either germinate rapidly, but do not reside long enough to form a seed bank.

[6] http://www.iffm.or.id/How_are_forests.html

been subjected to disturbance, and numbers of large frugivorous birds such as hornbills are low. Another factor that limits natural regeneration is the virtual absence of s viable seed stock in peat, especially after a fire has swept through an area.

Graham and D'Arcy (2006) found at Sebangau that after the 1997 fires, the dominant tree genera were *Santiria* and *Sterculia,* while *Shorea, Dyera* and *Eugenia* also emerged. Following the second major fires in 2002 diversity dropped, and emerging tree species were low in number, with genera such as *Elaeocarpus, Syzygium* and *Ilex* becoming more dominant. Adult trees of *Combretocarpus rotundatus* (tumih) survived both fires, but saplings were low in number.

Page S.E., Hoscilo, A., Jauhiainen, J., *et al*. (2009) studied vegetation change under different regimes of fire frequency and severity in the northern section of Block C. Results (Table 4) show that sites that have been subjected to only one low intensity fire undergo progressive succession to secondary forest, with initial tree species diversity values comparable to those for the adjacent, relatively undisturbed Sebangau peat swamp forest (e.g. 9–16 species of tree compared to 10−14 species per 400 m^2 plot). With increased intensity and frequency of fire disturbance, the numbers of tree species and of individual trees, saplings and seedlings are greatly reduced, with only two dominant recolonisers, namely *Combretocarpus rotundatus* and *Cratoxylum glaucum*. At the highest levels of degradation secondary succession back to forest is prevented and is replaced by retrogressive succession to lower growing, less structured plant communities dominated by ferns (species of *Stenochlaena, Lygodium, Polypodium* and *Pteris*) and sedges (*Cyperus* and *Scleria* spp.) with very few or no trees. The proposed underlying mechanisms are indicated in Figure 4.

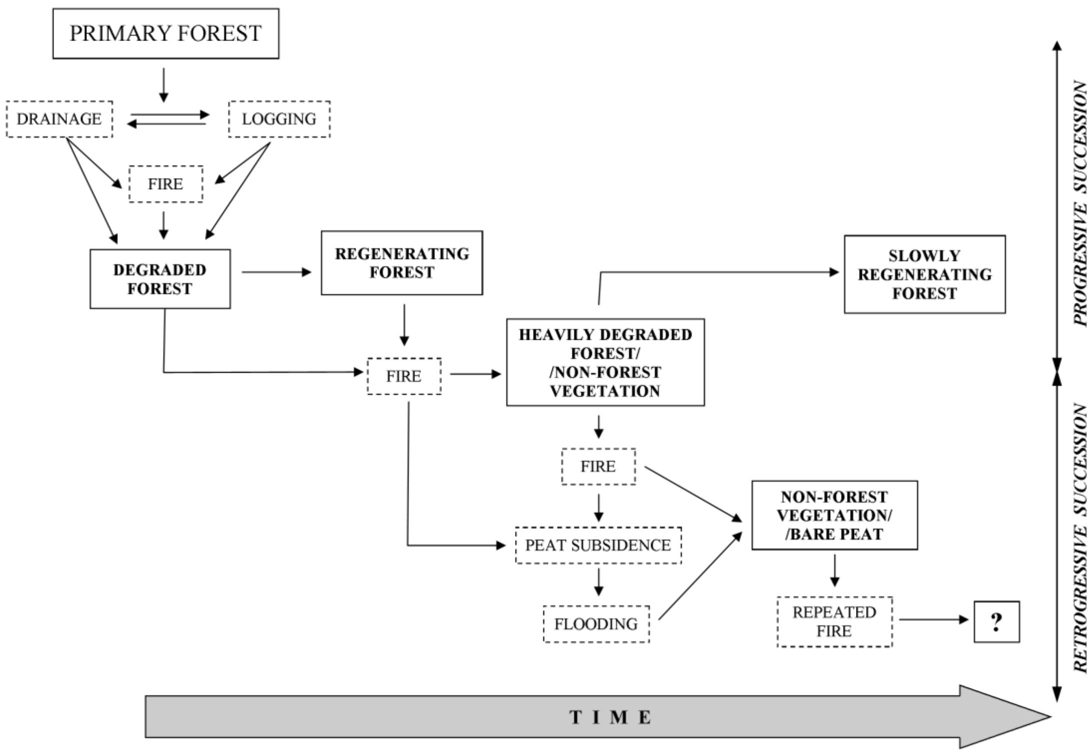

Figure 4 Degradation & regeneration processes in PSFs
source: Page S.E., Hoscilo, A., Jauhiainen, J., *et al.* (2009)

Table 4 Post-fire vegetation succession in study plots of northern Block C

Plot fire history	Number of plots (400 m^2)*	Average no. of trees	Average no. of tree species	Dominant tree species (% dominance amongst trees in plot)	Average no. of saplings	Dominant species of sapling	Average no. of seedlings	Dominant species of seedling	Ferns (% cover)	Bare ground (% cover)
Burnt 1997	4	97.8	16.3	*Combretocarpus rotundatus* (64.5)	165.0	*C. rotundatus*	244.0	Various	0	0
Burnt 1997 & 2002; low intensity fire 2002	5	36.0	9.0	*C. rotundatus* (84.4)	34.2	*C. rotundatus*	6.2	Various	28.0	0
Burnt 1997 & 2002; moderate intensity fire 2002	5	11.6	3.6	*C. rotundatus* (94.8)	13.0	*C. glaucum*	15.4	*C. rotundatus* & *C. glaucum*	76.0	2.8
Burnt 1997 & 2002; high intensity fire 2002	4	2.3	5.8	*C. rotundatus* & *Cratoxylum glaucum* (88.9)	88.3	*C. glaucum*	49.5	*C. glaucum*	90.3	2.5
Burnt 1997 & 2002; high intensity fires in 1997 & 2002	3	0.0	0.0		0.0		0.0		97.7	2.3

Source: Page *et al.* (2009)

*In the plots burnt only in 1997 (row 1 in the Table), each 20 x 20 m plot was divided into four 10 x 10 m subplots within which all trees greater then 5 cm DBH (diameter at breast height, 1.3 m above the ground) were identified and measured. DBH measurements of saplings (1.0−4.9 cm DBH) were made within a 5 x 5 m subplot nested in the corner of each plot and the total number of saplings was extrapolated for the whole plot. Seedlings (DBH less then 1 cm, but greater then 50 cm in height) were counted within a 2.5 x 2.5 m subplot and the total number of seedlings was extrapolated for the whole plot. In all other plots (rows 2−5 in the Table), trees, seedlings and saplings were recorded within the full 20 x 20 m plot.

4 Secondary succession in EMRP area

4.1 Factors affecting succession

Conditions in the EMRP area have changed considerably over the past 15-20 years. This degradation process began with widespread logging/clearfelling, followed by construction of massive drainage systems (with canals that cut across peat domes), and ending with widespread peat subsidence and peat fires. Not all areas are equally affected, however, and the following types of disturbed areas can be recognised:

- **A. Lightly degraded.** Logged, but not drained, and vigorously regenerating (eastern Block E).
- **B. Moderately degraded**. Logged and drained, with some limited burning (western Block E; northern part of Block A; northern tip + scattered patches in Block C).
- **C. Heavily degraded**. Logged, drained and burnt 1-2 times (most of the remaining EMRP).
- **D. Very heavily degraded**. Logged, drained and extensively burnt (along primary and secondary canals in a 1-2 km wide zone + and along roads).

These disturbances affect a lot of natural conditions that determine the path of secondary succession, including peat depth and properties (peat subsides after drainage or is lost when burnt), hydrology (flooding is common as peat levels drop), light conditions (open canopies), nutrient availability and availability of seed stock. These are described below in 4.1.1-4.1.5.

4.1.1 Peat depth & properties

The characteristics of peat in the EMRP have been altered considerably due to a combination of drainage and burning. Drainage leads to irreversible drying out of peat and oxidation, both of which contribute to peat subsidence. Such subsidence can vary from several centimetres to several decimetres per year. Peat that dries out is susceptible to fires, which have become commonplace in the EMRP since the mid-1990s and are a major cause for environmental and human health concern. Peat fires lead to mineralization of organic matter, charcoal formation and the forming of so-called ‘burn scars’ in peatland where peat has been combusted up to depths of one to several metres depending on the number and intensity of fires. Per burning incident a scar of several decimetres to 1-2 metres is formed. Subsidence and burning leads to changes in peatland morphology (and flooding, see 4.1.2), and to changes in water infiltration and retention capacity.

Areas where some (several dm) subsidence has occurred due to drainage are more likely to follow a path of secondary succession that leads to mixed PSF than areas where burning has lead to a loss of 1-2 metres of peat. In order to predict the path of post-fire secondary succession it is important to acquire information on (a) fire frequency (how often the area has burnt); (b) the fire return period (the time period between fires); and (c) the fire severity (a product of fire intensity, fuel consumption, and residence time). The most extreme degradation occurs where there are frequent fires with a short return period and at least one or more fires of high severity. Early data suggests that in degraded areas of peat, the percentage organic carbon can reduce, in some instances being dramatically lower than normal levels (Page *et al*. in press 2009; Graham, pers. comm.).

4.1.2 Hydrology/flooding

The presence of drainage canals significantly affects the hydrology of former PSF in the EMRP area. Waters quickly drain towards the tertiary, secondary and primary canals in the area, lowering the water tables in the peat domes and leading to significant desiccation of peatland, especially in the dry season when levels may be more than several metres below the surface. This drying out will particularly affect zones along the drainage canals and the central parts of peat domes. Burning and subsidence of peat leads to creation of depressions in the peat, and these areas are more likely to be deeply flooded for longer periods during the wet season. As fires and subsidence are greatest along a 1-2 km-wide zone along the canals, these zones are also most prone to flooding. As a result, secondary succession is unlikely to follow a path towards mixed PSF in central parts of domes and (especially) in the 1-2 km wide zones along canals. In fact, such flooded, burnt areas appear to be remarkably persistent. Strings of lakes along the Siak Kecil River (Riau, Sumatra) appear to have arisen because of burning of peat on this large dome of deep to very deep peat. These were already present in 1943 and probably much earlier, and remained largely unchanged by the early 1990s (Giesen & van Balen, 1991b). Smaller but otherwise similar lakes have recently been formed by peat fires along the Air Hitam Laut River in Berbak NP, Jambi (Giesen, 2004).

4.1.3 Light conditions

Light conditions in degraded PSF are often harsh, especially following fires when much of the canopy cover is lost, and shade requiring species more common in mature, mixed PSF will not flourish. In pole forest, light penetration is greater than in mixed/mature PSF, and once again light conditions may be more harsh and contribute to unfavourable conditions for certain species. Little is known about light requirements of PSF tree species, but one may assume that pioneer species have a high tolerance, while species that occur only in mature-mixed PSF are likely to be less tolerant. Giesen and van der Meer (2009) list 47 pioneer species, and it can be assumed that these are generally tolerant of exposure to direct sunlight.

Data collected at the Natural Laboratory, Sabangau Catchment, shows as one moves from the closed forest into the degraded zone, light intensity significantly increases both at ground level and at a height of 1m. Whilst it is visibly apparent that light intensity is greater at 1m height due to the loss of the canopy, this data shows that even extremely dense ground vegetation is not sufficient to ameliorate this effect (Page *et al.* In press, 2009b).

4.1.4 Nutrient availability & mycorrhizae

The normal nutrient cycle whereby aboveground live biomass is slowly recycled in the system no longer functions in these heavily disturbed PSFs. Aboveground live biomass of heavily disturbed PSF is only a fraction of that of undisturbed conditions. Nutrient levels in disturbed peatland of the EMRP are initially (briefly) higher[7] than in undisturbed conditions, as nutrients are released from decaying (oxidising) and burnt peat. However, after several wet seasons these released nutrients will either have been trapped in organic matter or (more likely) been washed out of the system by rainwater. Data collected at the Natural Laboratory, Sabangau Catchment shows that in the degraded areas, phosphorus levels are much lower in the degraded area in the dry season compared to adjacent forested area. However, this trend is not present in the wet season. Nitrogen levels were seen to be lower in some instances, in the degraded area, but the trend was not clear (Page *et al.,* In press, 2009b; Graham, pers. comm.)

In undisturbed PSF conditions, mycorrhizae (see Box 4) play an important role in nutrient availability, but in degraded areas they are unlikely to flourish, especially in burnt areas where fires are likely to have killed most soil fungi and spores. Over time, fungal spores may recolonise disturbed peat soils, provided that the distance to relatively undisturbed peatlands is not too great.

Initial data from the Natural Laboratory suggests that certain species of mycorrhizae can re-colonize a degraded area of peatland after extended disturbance. However, these levels, comparable to forested area levels, are not sufficient for seedlings to attain high growth rates due to the increased stresses from other altered environmental conditions. As such, if mycorrhizae levels are raised above the natural levels (through inoculation of seedlings), then high growth rates for seedlings can be achieved (Graham *et al.,* 2008).

Box 4. Arbuscular mycorrhizae

Arbuscular mycorrhizae are types of mycorrhizae in which the fungus penetrates the cortical cells of the roots of a vascular plant. Arbuscular mycorrhizae (AMs) are characterized by the formation of unique structures such as arbuscules and vesicles by fungi of the phylum Glomeromycota (AM fungi). AM fungi help plants to capture nutrients such as phosphorus and micronutrients from the soil. It is believed that the development of the arbuscular mycorrhizal symbiosis played a crucial role in the initial colonisation of land by plants and in the evolution of the vascular plants. This symbiosis is a highly evolved mutualistic relationship found between fungi and plants, the most prevalent plant symbiosis known, and AM is found in 80% of vascular plant families of today.

Source: Wikipedia (2009)

[7] Unpublished chemical data for burnt and non-burnt peat in northern part Block C shows very depleted chemical composition for burnt peat, especially with Nitrogen being highly depleted (Raphael Wüst, unpublished data).

4.1.5 Dispersal

Secondary succession in disturbed peatland is on the one hand determined by soil and water conditions, and on the other hand by the availability of species. If an area has only been logged most of the original species are likely to remain present, either as small trees, seedlings or seeds and natural regeneration is likely to progress rapidly. However, if fires have occurred most (if not all) remaining trees, seedlings and viable seeds will have been killed, and recolonisation will have to occur from outside. One study suggests however that tropical PSF, even whilst regenerating normally, do not have a seed bank at all. Seeds either germinate within a month or so of reaching the ground, or else become subject to predation and decomposition. As such, it would seem a seed bank is not lost at degraded sites, as there was not one there to lose in the first place (Graham, pers. comm.).

In low lying areas (e.g. where peat has been lost due to burning), floodwaters may bring and deposit seeds. However, these areas are often deeply flooded (and for extended periods), and waterborne seeds are unlikely to take hold, unless these are from (pioneer) species tolerant of flooding. These include species such as *Elaeocarpus petiolatus, Eugenia spicata, Mallotus muticus, Pandanus helicopus, Syzygium cerina* and *Timonius salicifolius.* Windborne seeds such as those of *Alstonia spathulata, A. pneumatophora, Combretocarpus rotundatus, Gluta wallichii* and *Shorea balangeran* are more likely to be carried into peatlands that are not flooded, and are likely candidates for secondary succession in lightly burnt areas.

Seed dispersal by frugivorous birds may play an important role in secondary succession, but not much in known at present. One study using artificial bird perches showed that frugivorous birds can be encouraged to fly into the degraded area through the use of perches, and whilst resting on them, defecate, bringing forest-restricted seeds out into the degraded area. However, very few of these seeds were able to germinate or survive as seedlings, not possessing the appropriate characteristics to tolerate the degraded conditions. Instead, it was the wind-borne or bird-dispersed seeds of species that were already to be found as adult trees in the degraded area that were then able to survive beneath the perches (Graham, unpublished data).

D'Arcy and Graham (2007) found in the Sebangau NP area that primary seed dispersers are important for dispersal and maintenance of tree species diversity in these peat swamp forests. However, their population densities are declining, and especially in burnt areas are likely to play a limiting role in seed dispersal from adjacent intact areas. The implications are that if this decline continues, peat swamp forest may struggle to regenerate naturally in disturbed areas. Ongoing studies on seed dispersal by frugivorous birds at Sebangau NP indicate that, unlike in the Neotropics, seed dispersal by birds plays a less important role (Graham, unpublished data). However, it must be acknowledged that the forests under study (Sebangau NP) have been subjected to disturbance, and numbers of large frugivorous birds such as hornbills are low. Another factor that limits natural regeneration is the virtual absence of a viable seed stock in peat, especially after a fire has swept through an area.

Secondary seed predation can be an issue, both in the forest and the degraded areas (Graham, unpublished data). Rodents were observed to predate highly on seeds scattered on the floor both inside and outside the forest, even up to 500m from the forest. There was little sign of removal or caching, as has been observed in many other tropical ecosystems, suggesting that rodents pose more of a threat to regeneration in the form of secondary seed predation rather than as a help through secondary seed dispersal.

4.2 Secondary succession in EMRP

Lightly degraded areas

Lightly degraded areas that have been logged but not drained (e.g. eastern Block E) are generally vigorously regenerating. Block E has been heavily logged, but as tramlines (kuda-kuda) were used instead of canals for log extraction and drainage canals were not constructed, PSF in the eastern[8] half of this area is regenerating vigorously. Most, if not all, species typical of mixed PSF still occur and secondary succession of these forests will result in vegetation that is not dissimilar from that before the onset of the EMRP. This process will take several decades, as current vegetation is not taller than 15-20 (-25) metres. Illegal logging remains a concern along much of the periphery, especially as loggers make use of small (1-2m wide) channels excavated to extract the timber.

Moderately degraded areas

Moderately degraded areas are those that have been logged and drained, with some limited burning; these include the western half of Block E, the northern tip of Block A, and the northern tip plus scattered patches in Block C. Secondary succession in these areas is likely to be towards PSF adapted to drier conditions (e.g. more likely padang or pole vegetation), although some of the more tolerant mixed PSF may also occur. Certain PSF species can survive fires, e.g. by resprouting from the base of the trunk or from roots, or because of their thick, protecting bark. Species such as *Shorea balangeran* and *Melaleuca cajuputi*, for example, are tolerant of light fires, while species such as *Mallotus* easily resprout from their base.

Heavily degraded areas

Heavily degraded areas are those that have been logged, drained and burnt 1-2 times; these areas are extensive over much of the EMRP area and cover much of Blocks A, B and C. Secondary succession in these areas is likely to be towards a secondary PSF consisting largely of pioneer species with a broad ecological tolerance such as *Campnosperma coriacea, Combretocarpus rotundatus, Cratoxylum glaucum, Eugenia spicata, Ficus deltoidea* and *Ploiarium alternifolium.* Ferns such as *Blechnum indicum* and *Stenochlaena palustris* dominate the herb layer, along with *Scleria* sedges.

Very heavily degraded areas

Very heavily degraded are similar to the heavily degraded area in that they have been logged, drained and burnt, but the fires have been more frequent and pronounced. These areas primarily occur along primary and secondary canals in a 1-2 km wide zone, and along roads. These areas are often deeply flooded during the wet season and these conditions may prevail for a long time each year. As a result, secondary succession may not progress beyond a seasonal lake/pond or even a permanent blackwater lake for a long time. Some colonisation by *Pandanus helicopus* and *Thoracostachyum bancanum* may occur in more deeply flooded areas (that latter provided that the pond is seasonal), while edges may be colonised by species listed above under heavily degraded areas.

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[8] The eastern half is managed by the BOS-Mawas Foundation; the western half is being stripped of remaining timber by a host of illegal loggers.

5 Promotion of succession in degraded PSFs

The main challenges facing secondary succession in degraded PSFs in the EMRP area are those related to peat, hydrology and fire. Factors such as light conditions, nutrients and biological also play a role, but on the scale of things these are only of secondary/minor importance.

5.1 Main challenges facing succession in degraded PSFs

Peat, hydrology and fire are strongly interrelated: drainage leads to peat subsidence and desiccation, and desiccation greatly increases the fire risk. Fire strongly increases the loss of peat and this in turn often leads to prolonged and deep flooding. The main challenge for those managing the EMRP and wanting to rehabilitate degraded PSFs is halting this cycle of drainage, fires and loss of peat.

First and foremost in reducing the risk of fires is rehabilitating[9] the hydrology of drained and degraded peatland and raising groundwater levels to near their former levels. In addition, an active fire management programme is to be applied involving active monitoring, prevention and fire fighting, along with a community engagement programme targeting the fire issue. The fire risk can be further reduced by means of reforestation of cleared areas – although this increases aboveground fuel levels, it increases humidity levels both above and belowground, and after several years the latter effect prevails. Also, if communities are involved in the reforestation programmes (e.g. planting of useful species), this reduces the risk of communities being involved in avoidable fire incidents.

Hydrological rehabilitation has been tried in Central Kalimantan by various agencies (WWF, Wetlands International, BOS Mawas Foundation) under the Netherlands-funded CKPP project. In addition, CIMTROP of the University of Palangkaraya has been involved in a similar programme under the RESTORPEAT project. The main approach in all cases has been blocking the drainage canals or channels using a variety of dams. These dams are usually wooden structures that are filled in with peat soil and lined with sheets of meshed plastic. In some cases bags of mineral soil have been used as well.

Attempts at hydrological rehabilitation have met with only limited success as dams have in some cases been overtopped and destroyed during floods, have had by-passes cut into them, or have been destroyed altogether by people wanting to use the waterway for transport. Even where the dams have survived intact, the results are not extremely promising as rewetting the peatland is limited to a zone along the canals. Also, the head above each dam has often been

[9] Restoration is not possible as the original state cannot be brought back, and the next best alternative is rehabilitation involving bringing back most of the hydrological functions to an area.

too great (often 50 cm or more), reducing the effect of rewetting and increasing the risk of overtopping and dam failure. Ideally, a head should not be more than 10-20 cm. In Sumatra, the paper/pulp production company APRIL has constructed dams out of peat – without timber – using a mechanical approach i.e. with large machines that fill-in the canal with peat and compress this. These structures have held well, and may be promising for future application in the EMRP area.

As resources are limited, programmes aiming at rehabilitation need to be targeted so that the results are maximised.

- Hydrological rehabilitation needs to be undertaken throughout entire peat dome areas and cannot be confined to parts, as the rest of the dome will ultimately be impacted if part of a dome remains drained.
- Similarly, a fire management programme should target entire domes, as fires can spread across a dome from fire prone areas to parts that are less prone.
- Reforestation, however, should focus on moderately and heavily degraded areas. Lightly degraded areas should be allowed to recover by themselves and do not require additional planting/afforestation in order to regenerate. Very heavily degraded areas are unlikely to recover except in the very long term (i.e. many decades), and should only be targeted once steps towards rehabilitation have been undertaken in the moderately to heavily degraded areas.

5.2 Minor challenges facing succession in degraded PSFs

Problems associated with light conditions and light tolerance or requirements of PSF species would not strike an average forester in Kalimantan as unusual, as many timber species of lowland dipterocarp forests require shading during early stages of growth. The usual approach is to start reforestation programmes with species tolerant of exposure to full sunlight and interplant with shade requiring species once the former have become firmly established. However, knowledge of shade requirements of PSF species is not known in detail. Pioneer species are by definition tolerant of exposure to direct sunlight and should be used during early stages of PSF reforestation programmes. Shade requiring species such as ramin *Gonystylus bancanus* and some of the dipterocarps should then be planted later. Among the dipterocarps *Shorea balangeran* is a notable exception (there are others) in that it is highly tolerant of exposure to direct sunlight and seasonal flooding.

The issue of lack of nutrients and symbiotic mycorrhizae in degraded peatland can readily be addressed by providing nutrients to seedlings upon planting and inoculating the substrate with suitable fungi. This can be in the form of slow-releasing nutrient pellets or planting of seedlings in pressed peat blocks to which nutrients are added beforehand. Not enough is known about mycorrhizae in peat swamps of Kalimantan, but a preliminary selection could be made (e.g. Tawaraya *et al., 2003;* Turjaman *et al.,* 2008), certainly on a trial basis.

Degraded peat swamp forests are all impoverished to some degree in terms of biodiversity. Lightly degraded areas will at a minimum have (significantly) lower densities of tree species characteristic of mature PSFs, and the forest fauna will differ from undisturbed forests[10]. Moderately and heavily disturbed PSFs will be significantly impoverished, with only pioneers and hardy species of mature PSFs surviving in moderately disturbed PSF and only pioneers in heavily disturbed PSFs. Only a handful of flood tolerant pioneer species will survive in very heavily disturbed peatland. Enrichment planting with species characteristic of mature PSF in moderately and heavily disturbed peatland should be effective in restoring at least some of the biodiversity values to the reforested areas. If needed, such a measure could also be considered in lightly disturbed PSF, especially if the area under consideration is designated as a biodiversity conservation area. In the latter areas enrichment planting with species that are an important food source for orang-utan or hornbills, (e.g. certain *Ficus* or *Diospyros* species), for instance, could be considered.

5.3 Short-, medium- & long-term measures

Urgent measures required to be undertaken in the short-term (i.e. within the next 1-3 years) are hydrological rehabilitation and fire management. Without these measures the peatland will rapidly degrade and certain problems (e.g. peat loss, flooding of subsided areas) will increase to a point that rehabilitation becomes impossible or very expensive. Both require technical solutions, but these must go hand-in-hand with local political will, social embedding and receive continued attention.

The main measures that are required in the medium-term (i.e. within the next 2-10 years) are all associated with the reforestation programme. It does not make sense to reforest areas that still require hydrological rehabilitation or active fire management, as investments may end up going up in smoke. Hence the medium-term approach to reforestation. However, once hydrological restoration has occurred and fire management is in place, the PSF reforestation programme should commence as soon as possible. In the medium-term certain studies should also be undertaken to increase the knowledge base and ensure that certain unknown aspects are addressed (see chapter 6). The results of these studies can then be incorporated in the medium- to long-term.

Long-term measures (i.e. to be undertaken in the next 5-20 years) include aspects such as enrichment planting of areas to increase biodiversity, livelihood or commercial value of an area. Also, the results of certain studies won’t be known until after 5-10 years, and these may be put into practice in the long-term.

[10] Very little is known about the impacts of PSF degradation on the fauna, as this has not been studied in any detail.

6 Follow-up studies required

6.1 Gaps in knowledge/understanding of succession in PSF

The following gaps exist in current understanding of natural succession in PSFs, particularly those in Central Kalimantan:

- Geographical differences in succession are not fully understood, as data sets are limited and can only be applied to a limited area.
- Detailed studies on natural succession at a single site are very limited. Bogor Herbarium has a number of permanent plots that have been monitored three times over the past 8 years, but continuation of this programme is threatened by a lack of funding. University of Leicester have 20 vegetation monitoring plots established in the northern part of Block C, EMRP, which are representative of a range of secondary vegetation communities, including secondary forest through highly degraded fern-dominated vegetation. These plots could form useful reference locations for studying vegetation succession over time at sites with a known fire history.
- Light requirement, flood tolerance and nutrient requirements of many tree species of mature PSFs is poorly understood.
- Knowledge of arbuscular mycorrhizae occurring under natural conditions in PSF is very limited.
- In Kalimantan, only a handful of studies each with only a very limited number of core samples, have been subjected to palynological study up to now.
- Although the impacts of PSF degradation on fauna is likely to be significant, it is largely unrecorded as it has not been studied in any detail.

6.2 Studies & trials recommended

The following follow-up studies and trials are recommended:

- Establishing permanent plots in lightly degraded PSF areas, moderately degraded PSF areas, heavily degraded PSF areas and very heavily degraded peatland areas and studying these on an annual basis. Recommended are at least 3 plots in each degradation type, and two sets: one with active rehabilitation (i.e. hydrological restoration and fire management), the other without. Ideally these should be representative of different fire regimes (in terms of frequency of fires and their severity).
- Compilation, detailed study and analysis of datasets on natural regeneration and succession in peat swamp forests of Kalimantan.
- Continued funding and study of existing permanent plots, expansion & analysis of data sets.
- Autecological studies on PSF species regarding their light requirements, flood tolerance and nutrient requirements.

- Studies on arbuscular mycorrhizae occurring under natural conditions in PSF.
- Additional palynological studies of peat cores to determine historic development patterns and succession under natural conditions. These could also be useful in identifying previous (if any) disturbance events (e.g. from fire) and post-disturbance vegetation. In the historical past fire has been infrequent in peat swamp forests, but not unknown. It would be relevant to see whether there is evidence of earlier fires in the palaeo record and, if present, whether it is possible to identify the pioneer species involved in post-fire succession back to closed, high forest.
- Studies on impacts of PSF degration on fauna (esp. mammals, birds, amphibians & fish), particularly of presence / role of seed dispersers. It would be highly relevant to investigate how important blocks of remnant forest (eg in northern part Block C) are for recolonisation of surrounding degraded peatland.

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