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Keep wetlands wet: the myth of sustainable development of tropical peatlands - implications for policies and management.

Title: Keep wetlands Wet: The Myth of Sustainable Development of Tropical Peatlands – Implications for Policies and Management

Running Head: Myths of Sustainable Development of Southeast Asian Tropical Peatlands.

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Abstract

Pristine tropical peat swamp forests (PSFs) represent a unique wetland ecosystem of distinctive hydrology which support unique biodiversity and globally significant stores of soil carbon. Yet in Indonesia and Malaysia, home to 56% of the world's tropical peatland, they are subject to considerable developmental pressures, including widespread drainage to support agricultural needs. In this paper we review the ecology behind the functioning and ecosystem services provided by PSFs, with a particular focus on hydrological processes as well as the role of the forest itself in maintaining those services. Drawing on this, we review the suitability of current policy frameworks and consider the efficacy of their implementation. We suggest that while policies in Indonesia and Malaysia, as well as regionally, are often based around the narrative of oil palm and other major monocrops as drivers of prosperity and development, we also show that this narrative is also being supported by on a-priori claims concerning the possibility of sustainability of peat swamp exploitation via drainage-based agriculture through the adherence to best management practices. We discuss how this limits their efficacy, uptake and the political will towards enforcement, and consider how both narratives (prosperity and sustainability) clearly exclude important considerations concerning the ecosystem value of tropical PSFs which are dependent on their un-impacted hydrology. 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.

Keywords

Tropical Peatlands, Hydrology, Climate change, Policy, Management, Indonesia, Malaysia, COP21

Introduction

Tropical lowland peat swamp forests (PSFs) are unique ecosystems. Defined by their hydrology, they are permanently waterlogged and in their natural state, flood up to 50 cm or more during the wet season. As a consequence, the peat substrate is anaerobic, highly acidic (pH2.9-4) and low in nutrients. These conditions inhibit heterotrophic and root respiration and also organic matter decomposition (Yule & Gomez, 2008; Mezbahuddin *et al.*, 2014). Consequently, plant material slowly and only partially decomposes resulting in a net accumulation of organic matter. The peat forms over millennia to create domes up to 20 m deep (Page *et al.*, 2011). As a consequence, these systems are globally significant carbon (C) stores, holding 11-14% (69Gt) of global peat C (Page *et al.*, 2011). As the formation of peat is controlled by the rate and extent of microbial decomposition of plant matter, maintenance of net organic C accumulation is controlled by litter type and production rate, soil biotic community assemblage and critically, the associated habitat conditions, including most importantly, the hydrology of the ecosystem in which these interactions occur.

Southeast Asia contains an estimated 56% of all tropical peatlands (Page *et al.*, 2011), mostly in Indonesia and Malaysia. Southeast Asian peatlands are also some of the deepest, averaging 5.5-7m (Page *et al.*, 2011), compared to South American peats; averaging 0.5-6m (Page *et al.*, 2011). These peats represent long-term C stores, with the majority of Southeast Asian peats, especially those in coastal areas, at 3000-7000 years BP (Dommain *et al.*, 2011). However, inland regional peats can be much older. For example, samples collected from Sebangau, Kalimantan were found to be up to 28,000 years BP (Wüst *et al.*, 2011)

The substantial expansion of agroforestry in the both Malaysia and Indonesia has created significant demand for land. The relatively small human populations in large and contiguous areas of peat swamps coupled with perceptions of these areas as economically unproductive 'wastelands' (Government of Malaysia, 2015), has contributed to a idea that PSFs offer a large, and relatively cheap land bank for large-scale agroforestry (Varkkey, 2016). Within the last two decades, forest cover on peat swamps has reduced from 77 to 36% in Indonesia and Malaysia (Miettinen *et al.*, 2012a) with industrial plantations covering approx. 20% of the region's peatland (Miettinen *et al.*, 2012b). Commercially, mono-cropping of palm oil in Malaysia currently contributes 5-6% of GDP (MPOB, 2011) and its growth as an industry is closely associated with the countries' rapid modernisation, as is evidenced through its popular characterisation as the 'golden crop' (Varkkey, 2016). The overall contribution of palm oil to the Indonesian economy stands at 7% (IST & GCP, 2014). Combined, both countries account for 85% of global production.

The process of peat swamp conversion has been, and remains a subject of considerable controversy in both nations and internationally. Those in support argue for expansion of oil palm on grounds of national economic development. Central to this narrative is the principle that, both countries have the right to utilise their natural resources in order to achieve development goals (Hezri & Hasan, 2006). This has been supported by the production and promotion of 'divergent knowledge' (Goldstein, 2015); that is, the production and widespread use of data that suggests the minimal impacts or even environmental benefits of conversion (e.g. World Growth, 2011). This data is often funded by industry research bodies and primarily published in industrial and non-peer reviewed journals (Goldstein, 2015)). Yet while it is largely written off by the international scientific community, such data is employed to sway debates on PSF management, challenging evidence presented by conservation advocates and fuelling support for continued peatland conversion as part of the development agenda (Goldstein, 2015). Where acknowledgement of impacts is given, the popular discourse emerging is that ecological harm committed in the course of doing so can be significantly mitigated via sustainable development practices (e.g. Government of Indonesia, 2009). As a consequence, the current research and development trajectory around palm oil focuses on the sustainable management or 'wise use' (Joosten & Clarke, 2002) of plantations and other drainage-based agriculture on tropical peatland (Padfield *et al.*, 2014; Hansen *et al.*, 2015). While these studies have strengthened arguments for improved plantation management, they have also supported a concept of sustainable palm oil on both peat and mineral soils primarily via the voluntary adoption of a range of sustainability measures by the industry (e.g. Roundtable for Sustainable Palm Oil (RSPO, 2012); Melling *et al.*; Othman *et al.*, 2011).

While the palm oil sustainability lobby has claimed some success, a growing local and international literature (Padfield *et al.*, 2014) is focused not on optimal management but on the functioning of intact PSFs, loss of function with conversion and role of tropical PSFs in regulating a host of important ecosystem services, including carbon sequestration, flood regulation, biodiversity and water supply. These efforts have highlighted the link between peatland degradation and global carbon emissions. For example, Hooijer *et al.*, (2010) estimated that CO_2 emissions due to peat degradation, fire and fluvial losses following peatland drainage in Southeast Asia contribute the equivalent of 1.3% to 3.1% of current global CO_2 emissions from fossil fuels. Consequently, these studies have raised significant questions concerning the direct and indirect environmental impacts of the palm oil industry on PSFs and the implications that current concepts around sustainability have for the protection of PSFs. In light of this body of literature, this paper will seek to explore one particular critical issue surrounding the development of peatlands which to to-date is often avoided; primarily, that before considering how to sustainably manage peat swamps for drainage-based plantations, we must first consider if we *should.* In this paper we seek to unpack some of the a-priori assumptions surrounding the sustainable exploitation of peat swamps via intensive monoculture and question if it is an achievable goal. In order to do so we address four questions:

1. What are the critical elements of a PSF that contribute to its functioning and provision of ecosystem services?
2. What are the impacts of development of these PSFs in terms of ecosystem loss and subsequent environmental pressures?

3. To what extent do current public and private initiatives serve to ameliorate the negative impacts of peat conversion?
4. And critically, given our understanding of peatland functioning, is sustainable development of peatlands possible, and under what conditions?

PSF Functioning and Ecosystem services

Tropical PSFs provide a range of local, regional and globally significant environmentally and economically significant ecosystem services (Rieley & Page, 2001). Those most fundamentally recognised include significant carbon sequestration and storage, rich biodiversity (including a range of endemic, specialised and endangered species, uniquely adapted to this wetland environment; Posa *et al.*, (2011), and important local hydrological regulation, such as water storage, protection against sea water intrusions (Kumari, 1996) and reducing the impact of flooding during the wet season (Wösten *et al.*, 2008).

Carbon sequestration

Unlike temperate peats, tropical peatlands in their natural state are primarily forested. These forests comprise uniquely adapted species; trees with tolerance to waterlogged and low nutrient conditions (Ng & Ibrahim, 2001; Ong *et al.*, 2015) and also high C sequestration capacity (Dommain *et al.*, 2014). However, while all tropical forests are important for above-ground C sequestration via production of woody biomass, PSFs store a further 5-40 times as much C below ground (Warren *et al.*, 2012). Sequestration of C in tropical peats can be much greater than temperate peats due to higher rates of primary production. As a consequence, sequestration rates can exceed 80 g C m^{-2} yr^{-1} (as opposed to the 8-61 g C m^{-2} yr^{-1} recorded for higher latitude peats) (Roulet, 2000; Page *et al.*, 2004).

Biodiversity

The plant communities of peat swamp forests are distinct from dryland forests such as lowland dipterocarp forests because their inhabitants require many adaptations to survive in the waterlogged, unstable, toxic (due to high levels of phenolic compounds such as tannins and humic acids), acidic, peat environment where the forest floor is seasonally flooded (Table 1). Posa *et al.*, (2011) estimated that 11% of peat swamp plant species are endemic. Physical adaptations such as buttress, stilt and knee roots as well as pneumatophores provide stability and enhance gas exchange while an extremely thick surface root mat facilitates oxygenation and rapid uptake of nutrients from senescent leaves as soon as they fall. The plants also invest in physical (e.g. spines, thorns, toughness) and chemical (e.g. aromatic oils, latex, resins, secondary phenolic compounds) defences against herbivores and microbes (Yule, 2010). Leaching of phenolic compounds from senescent leaves creates the characteristic acidic blackwaters of PSF, which retard microbial decomposition (Freeman *et al.*, 2004). Consequently, clearing of the natural vegetation removes the source of the organic matter which forms the peat and also reverses the physical conditions required for peat accretion. These flooded forests, with their micro-topography of hummocks and pools, seasonal flooding and Dissolved Organic Carbon (DOC)-rich acidic water are vital for an array of uniquely adapted taxa including more than 200 freshwater fish species (Posa *et al.*, 2011) many of which (more than 102 species) are found nowhere else (i.e. stenotopic and unique to the habitat; Giam *et al.*, (2012), such as *Paedocypris progenetica*, the smallest known vertebrate in the world (Kottelat *et al.*, 2006). These habitats are also important habitats for a range of endangered large and charismatic fauna (Posa *et al.*, 2011) (Table 1). For example, the richest remaining habitats for orangutans are high-quality swamp forests and lowland alluvial forests (Russon *et al.*, 2001). PSFs are also important for proboscis monkeys (Phillips, 1998), the flat-headed cat, Sunda clouded leopard, marbled cat (Cheyne *et al.*,

2009) and Sumatran tiger (Wibisono & Pusparini, 2010), as well as being the preferential habitat of the endangered false gharial (Bezuijen *et al.*, 2001).

Table 1: Endangered mammals and birds occurring in regional peat swamp forests (* = close association with water)

Family	Species	Common name	Notes	Authors
Cercopithecidae	*Macaca siberu*	Siberut macaque	Population declines due to hunting and habitat loss	Nijman *et al.*, 2008
Cercopithecidae	*Nasalis larvatus*	Proboscis monkey	* Population declines due to hunting and habitat loss	Nijman *et al.*, 2008; Posa *et al.*, 2011
Cercopithecidae	*Presbytis chrysomelas*	Bornean banded langur	Now considered one of rarest primates in the world. Occurs in < 5% of its historic range	Nijman *et al.*, 2008; Posa *et al.*, 2011
Cercopithecidae	*Presbytis chrysomelas cruciger*	Tri-coloured langur	Now only recorded from a small patch of degraded peat swamp forest in Maludam National Park in Sarawak. May already be extinct	Sebastian, 2002; Nijman *et al.*, 2008
Cercopithecidae	*Presbytis potenziani*	Mentawai langur	Lower densities in PSF than dryland forests due to lack of emergent resting trees and lack of suitable food	Quinten *et al.*, 2010
Cercopithecidae	*Simias concolor*	Pig-tailed langur	Densities in PSF comparable to those in dryland forests	Quinten *et al.*, 2010
Hylobatidae	*Hylobates klossi*	Gibbon	Population declines due to hunting and habitat loss	Nijman *et al.*, 2008; Quinten *et al.*, 2010
Hominidae	*Pongo pygmaeus*	Orang utan	Population declines due to habitat loss, poaching and pet trade	Morrogh-Bernard *et al.*, 2003; Nijman *et al.*, 2008
Felidae	*Neofelis diardi*	Sunda clouded leopard	Population declines due to habitat loss and poaching	Posa *et al.*, 2011
Felidae	*Panthera tigris*	Tiger	Population declines due to habitat loss and poaching - particularly for traditional Asian medicine	Posa *et al.*, 2011
Felidae	*Pardofelis marmorata*	Marbled cat	Population declines due to habitat loss and poaching	Posa *et al.*, 2011
Felidae	*Priornailurus planiceps*	Flat-headed cat	* Fish-eating river specialists. Rarely observed > 3 km from water.	Bezuijen *et al.*, 2001
Ursidae	*Helarctos malayanus*	Malayan sun bear	Population declines due to habitat loss and poaching	Latiff, 2005
Elephantidae	*Elephas maximus*	Asiatic elephant	* Population declines due to habitat loss and poaching	Bezuijen *et al.*, 2001
Tapiridae	*Tapirus indicus*	Tapir	Population declines due to habitat loss and poaching	Latiff, 2005
Mustelidae	*Lutra sumatrana*	Hairy nosed otter	*One of the rarest otter species. Eats fish and crustaceans. Recorded from Toa Daeng PSF in Thailand	Kanchanasaka, 2001
Viverridae	*Cynogale bennettii*	Otter-civet	* Semi-aquatic. Forages in water	Ross *et al.*, 2015

Anatidae	*Asarcornis scutulata*	Whitewinged wood duck	Decline due to destruction of riverine habitats and pollution	Bezuijen *et al.*, 2001

Due to extensive destruction of lowland forests, regional peat swamp forests are increasingly becoming refuges for terrestrial vertebrates, particularly because the high water tables and unstable peat substrate render accessibility for poachers difficult (Gumal, 2004). Furthermore, contrary to the common perception of low productivity, studies by (Cannon *et al.*, 2007), showed that Borneo PSF provide a more reliable food supply than lowland dryland forests because most do not exhibit supra-annual mast fruiting. Instead, fruits are available for extended periods of time (trees fruit for up to 8 months). Sebastian, (2002) noted that 57 species of mammals (not including Muridae and Chiroptera) and 237 birds from Malaysian PSFs were listed by IUCN as globally threatened (no doubt these numbers are now higher).

Local hydrological regulation and flood prevention

Embodying the paradox of "high and wet" (Dau, 1823), intact PSF dome hydrology is self-regulating (Dommain *et al.*, 2010). Due to formation from woody debris, PSF peats have naturally large soil pore sizes (Huat *et al.*, 2011). Yet while these peats can store more water, they also have increased hydraulic conductivity. If constant, this would result in rapid drainage of water under dryer conditions. Yet, the juxtaposition is solved through the dynamic movement of surface soil layers. During flooding conditions, buoyant soils, with a more open pore surface structure, store excess water and in doing so, regulate peak discharge and reduce erosion. When natural water levels drop, soil buoyancy drops and gravity-driven compaction of surface soil reduces pore size and with it, hydraulic conductivity (Price, 2003). This mechanism by intact uppermost peat layers therefore limits the amplitude of water table fluctuations under varying meteorological conditions. Therefore, any artificial compaction (such as that recommended by Melling *et al.* for monoculture) or drainage inhibits the self-regulating capability, effecting not only the area in question, but also the entire hydrological unit of the dome in terms of reduced water storage and regulatory capacity, and also expediting problems associated with land subsidence (See below).

The architectural complexity of the PSF is also critical to this self-regulation, playing a prominent role in regulating the run-off of water. Complex rooting systems of endemic PSF trees, especially those with buttress roots, form barriers to gravity-driven water movement off the dome (Takahashi *et al.*, 2001). The natural hummock-hollow surface patterns created by the vegetation rooting systems also act as a collection of small weirs (Herwitz, 1988). Given the natural tree zonation patterns on domes as described in previous studies (e.g. Page *et al.*, (1999), these hydrology-regulating structures dominate the edges of the dome, coinciding with where the surface topographic gradient is greatest and the retardation of surface run-off most critical, contributing to the storage of excess water during rain events and the controlled slow release during dry periods.

Impacts from development of peat

Land Use Conversion

Despite the globally significant ecological value, up to 84% of the 25MHa of peatlands found in Southeast Asia have been drained (Hooijer *et al.*, 2010). Since the 1970s, deforestation and drainage has been brought about not only by the accelerating demand for land for agriculture, but also the value of associated timber. Of the remaining 36% forest cover on PSFs in Indonesia and Malaysia (Miettinen *et al.*, 2012a), only 10% can be classed as in pristine condition (Miettinen & Liew, 2010). In areas not converted to agriculture and other land uses, deforestation is still widespread via both selective and clear-felled logging, resulting in solar exposure, habitat loss, uncontrolled fires and widespread forest drainage and canal construction to facilitate timber extraction.

Intact forest water table fluctuations generally range from -30 to +30cm, with water levels above the soil surface for many months of the year (Pahang Forestry Department, 2005; Hooijer *et al.*, 2012; Comeau *et al.*, 2013). Only during strong El Niño years is there evidence of intact forest water table depths (WTDs) falling below 40cm (e.g. Usup *et al.*, 2004). However, both Acacia and oil palm require drainage of soils for growth and productive yields (Table 2), resulting in the requirement for extensive drainage throughout a given plantation.

Table 2: Examples of recommended oil palm plantation drainage levels according to the range of studies and government research organizations detailed below. It should be noted that all guidelines recommend immediate drainage when levels reach -25cm WTD.

From surface (cm)	From drains (cm)	Reference
-50 to -75	-	Melling *et al.*
-40 to -60	50-70	RSPO, 2012
-30 to -50*	35-60*	MPOB, 2011
-50 to -80	-	Mutert *et al.*, 1999

* Specific depth range dependant on age class of plantation.

Carbon Emissions

Alteration of the soil environment via drainage and the resulting peat oxidation alters the community composition, abundance, and activity levels of microorganisms, increasing rates of decomposition and GHG emissions via enhanced extracellular enzyme activities (Freeman et al. 1996) and increased microbial biomass (Mäkiranta *et al.*, 2009). Consequently, drained peats revert from C stores to C sinks, with CO_2 emissions from drained peats ranging from 22 to 100t ha^{-1} year^{-1} (Murayama & Bakar, 1996; Hooijer *et al.*, 2012). Indeed, a number of studies and associated models have shown a positive relationship between decreasing long-term WTD and soil respiration as well as C losses (Couwenberg *et al.*, 2010; Hooijer *et al.*, 2010; Carlson *et al.*, 2012). For example, Hooijer *et al.*, (2010) suggested that that soil CO_2 emissions increase by 0.91 Mg ha^{-1} year^{-1} for every centimetre of long-term lowered WTD. However, (Carlson *et al.*, 2015) suggested that while positively correlated, WTD only described 45% of the variation in net C loss from plantation mass balance equations, with additional issues such as fertiliser application, fluvial flux from peat instability and plantation micro-site heterogeneity having potential to contribute. The debate over GHG emissions from converted peat soils has resulted in a narrative which often considers the peat merely as a medium for plantation growth, where the sole consideration for sustainability is to reduce soil respiration. Yet even at this level, considerations of net C balance (especially where comparisons are made with forest GHG emissions) must also consider the continuous contribution of natural PSF vegetation cover which is resistant to microbial decomposition. Significantly, oil palms do not produce such resistant litter, and require fertilizers and lime. Combined, this enhances microbial respiration and thus GHG emissions and replacement of organic matter is also greatly diminished. Indeed Hooijer *et al.*, (2012) showed that even at the highest possible WTD, only 20% deductions in total CO_2 emissions could be achieved. Similarly, even with WTD adherence consistent with sustainability certification group, RSPO, of 40-60cm annual average WTD, a significant net carbon footprint of *c.* 60 tonnes of CO_2 ha^{-1}year^{-1} results (derived from Page *et al.*, (2011b) and Jauhiainen *et al.*, (2012)).

Fluvial Carbon Losses

In tropical PSF catchments, fluvial C fluxes are dominated by organic forms, contributing between approximately 370 Tg of total organic carbon (TOC) to marine pools (Meybeck, 1993). The importance of these ‘blackwaters’ in relation to C loss from PSF conversion and drainage, have only recently come to the fore. Moore *et al.*, (2013) showed a 50% increase in fluvial C export due to artificial drainage as compared to intact sites. When included in total emissions factors, there is a 20% increase in overall flux. However, how much of this aquatic-based C is actually degassed to the atmospheric C pool remains very poorly understood (Sjögersten *et al.*, 2014). Jauhiainen & Silvennoinen (2012) recorded substantial CO_2 (9 -16 tC-CO_2 ha^{-1} year^{-1}) and CH_4 (0.27-3.0 tC-CH_4 ha^{-1} year^{-1}) emissions from water surfaces of drainage canals in Sumatra (Acacia) and Borneo (abandoned peat). Furthermore, ^{14}C aging of DOC from disturbed TPSFs also show that much older (>1000 yrs) fluvial C is being released from disturbed sites, indicating increasing deep instability of drained peatlands (Moore *et al.*, 2013).

Subsidence

Subsidence is the combined processes of organic matter decomposition via oxidation, compaction and shrinkage of peat volume above the water table and compression below the water table. Hooijer *et al.*, (2012) found an average subsidence rate of 142cm for the first 5 years after drainage (with 75cm lost in the first year), with levels stabilising at 5cm per year loss in soils of an annual average WTD of 0.7m. Others have found similar rates of long-term loss from 3.6cm (at 0.5m WTD) and even 8.9cm/yr (DID & LAWOO, 1996; Hensen *et al.*, 2002, respectively), continuing as long as drainage of peat is ongoing. While these sites can initially be gravity drained, soil height will eventually reach sea or adjacent river levels, thus constraining the outflow of water, making surrounding peats undrainable and leading to increased intensity and frequency of flooding as well as potential seawater intrusion (Andriesse, 1988). By modelling subsidence based on a conservative 3.5cm/yr soil height loss, Hooijer *et al.*, (2015) estimated flooding potential for the entire Rajang river delta 850,000ha area, Sarawak at 42% in 25 years and an alarming 82% in 100 years. Given that these extensive peats have formed in the coastal lowlands of Southeast Asia, where tectonic movements over the last 8000 years have reduced the elevation of many coastal zones, peat horizons regionally often extend below sea level. Such flood predictions can therefore be expanded to the larger coastal peats of Malaysia and Indonesia with drainage. These impacts will also be confounded by sea level rise and climate change. Therefore it is important to state that as well as globally catastrophic GHG emissions, subsidence will result in the irreversible loss of extensive coastal land in effected regions, impacting local communities, industries and ironically, the yield and revenue of the plantations responsible. The resulting income losses alongside increased expenditure required for flood defences and community rehousing, means that the economic and social sustainability of such practices must be seriously questioned.

Burning

Lowering the WTD via drainage affects the moisture content of the peat making the organic matter extremely vulnerable to ignition. Fires in peatland not only burn the surface vegetation, but also the peat deposits up to 100 cm below the surface (Boehm *et al.*, 2001). While very shallow fires could be considered as carbon neutral (burning only the modern, rapidly cycled carbon; Trumbore, 2009) deep combustion following repetitive or deeper burning has the potential to affect centuries to millennia old C stores (Turetsky *et al.*, 2015).

Smouldering (or the slow, low-temperature, flameless burning of porous fuels) is the dominant form of burning in peat deposits. These fires can persist under low temperatures and in peat soils with high soil moisture and low oxygen, even crossing wet layers above 250% moisture content (Huang & Rein, 2015). Further, the high wood content and low bulk density of tropical peat enables oxygen to be supplied to the deeper layers exacerbating deep combustion (Usup *et al.*, 2004), causing long-term damage to soil systems (Rein *et al.*, 2008). Hydrology and in particular, the WTD and the moisture content of the soil, govern the ignition, spread and the ultimate extinction of a peat fire (Garlough & Keyes, 2011; Watts, 2013).

Southeast Asian 'haze' episodes associated with peat forest burning are now considered to be an annual phenomenon (Varkkey, 2016). Indeed, in 1997, peat fires released approximately 0.95 Gt of C, equivalent to ~15% of global fossil fuel emissions of the same time period (Page *et al.*, 2002). Apart from a decline in ecosystem function and biodiversity, altered biogeochemical processes and increased GHG emissions, human health issues have become a pressing issue. Peat fires contribute *c.* 80% of the regional haze (Applegate *et al.*, 2002). Air Pollution Index readings in Palangkaraya in Borneo in October 2015 reached >2000, the highest values ever recorded and far above the Emergency level of >500 (BMKG). Exposure to haze events has been shown to cause both immediate and delayed effects, increasing respiratory related mortality from 19-66% (Sahani *et al.*, 2014). Indeed, in the most recent 2015 fires, an estimated 503,874 Indonesians were affected by haze related respiratory infections (BNPB, 2015, as cited in The Jakarta Post, 2015a). Economic losses related to haze are also significant, with estimates for the 2015 fires at $16.1 billion for Indonesia (Center for International Forestry Research, 2015).

Un-drained pristine tropical swamps are generally fire-resistant, owing to the low-flammability of water-saturated soils (Turetsky *et al.*, 2015). Regional airport visibility records since the 1960s indicate no evidence of severe fires prior to large-scale conversion of PSFs to agricultural use (Field *et al.*, 2009).

Social impacts

Even though permanent human population density in PSFs is comparatively low, there are communities who live on their fringes and rely on the ecosystem services and livelihoods provided by the intact forest. In Indonesia alone, this figure reaches more than 10 million people (Mahmud, 2013). Local people have, for generations sustainably harvested paddy, sago, rattan, medicinal plants, roots, leaves, berries, honey, and birds' nests, both for their own subsistence and for exchange (van Noordwijk *et al.*, 2014), with fish being the highest value resource (Andiko, 2015). This resource is dependent on the maintenance of a pristine ecosystem (Ramakrishna, 2005). While the loss of PSF results in fish catch and associated income declines (Anshari & Armiyarsih, 2005), land development also effects water quality for bathing, washing and drinking as well as the increase in flooding events described above.

The extensive impact of peatland development in Malaysia and Indonesia has prompted a response in the form of policies and guidelines to promote environmentally sustainable development of peatlands. Such policies envision a 'win-win' scenario whereby ecosystem services are maintained and a productive, profitable yield from drainage-based agriculture achieved. In the following section, we will examine whether policies and management practices designed to sustainably manage these wetlands:

a) Take full account of the hydrological requirements for ecosystem functions;
b) Are implemented effectively, and
c) Have goals which are even achievable given the conflict between the hydrological requirements of a functioning peat swamp and the needs of drainage-based agriculture.

Peatland policies: The global context

While individual countries may have specific peatland land-use policies, in the tropics, only Malaysia and Indonesia have developed peatland-specific policies related to conservation and sustainable development (Table 3). Globally, some umbrella protection is provided via protected areas (PAs) legislation. The most important of which, is the Convention on Wetlands of International Importance, known as the Ramsar Convention (Ramsar, 2014). Established in 1971 the Ramsar Convention requires member states to identify, quantify and value peatlands. Ramsar also urges its member countries to include at least one peatland site designation per country (Anshari & Armiyarsih, 2005). Despite the increasing number of designated Ramsar wetland sites in the world (2,234 sites at a total of 215 million hectares in 2016), they represent only a fraction of the total amount of global peatlands. Thus, the extent to which PA designation implemented at a global level coincides with peatland areas in the tropics appears low (Anshari & Armiyarsih, 2005). As such, policy initiatives instigated for Indo-Malaysian peats are likely to strongly influence any future political reforms and associated peatland functionality across tropical peatlands zones globally as development (and oil palm expansion, specifically) puts increased pressure on frontiers such as Africa and Central/South America.

Table 3: Peatland policies in ASEAN with a specific focus on hydrology management.

Stakeholder	Country	Policy name & Author	Policy influence	Peatland hydrology policy specifics
Government	Malaysia	*Malaysian National Action Plan for Peatlands (2011)* - Ministry of Natural Resources & Environment	Overarching policy document for peatland management in Malaysia. Not legally binding, merely guidelines.	No detailed information provided on hydrology management. General recommendation provided on aspects such as fire prevention, zero-burn strategies to prevent impairing of hydrology, application of fertilizer within a defined schedule, and the need to establish a baseline of hydrology data.
Government	Indonesia	*Protection and Management of Peatland Ecosystem (2014)* - Republic of Indonesia (71/2014)	Overarching policy document for peatland management in Indonesia. Mandatory and legally binding.	Specific details on management of hydrology include: - Water table should be maintained at 40cm or below Guidance is also provided on the depth of peatlands for development. The policy states that it is prohibited to cultivate or develop peatland area if peat depth is > 3m. Peat >3m is automatically designated as a protected

				ecosystem. Where peat <3m and development has been authorized, 30% of the designated area should be protected. Peatland is classified as damaged if the water table is >1m below the surface of the peat.
Government	Indonesia	*Guideline on Oil Palm Plantation on Peatland (2009)* - Ministry of Agriculture (14/Permentan/PL.110/2/2009)	Overarching policy document for palm oil cultivation on peatland in Indonesia. Mandatory and legally binding.	Specific details on management of hydrology and include: - Water table should be maintained between 60 cm to 80 cm depth - Periphery drains are required to have a width of 4 meters, bottom width of 3 meter and with depth of 2 to 3 meter Guidance is also provided on the depth of peatlands for palm oil cultivation with recommendation that cultivation is not allowed where peat is >3 m deep and that the cultivation area must have a minimum of 70% of peat at < 3 meters.
Palm oil industry association	Malaysia	Various research publications - Malaysia Palm Oil Board (MPOB)	MPOB provide important guidance for planters cultivating on peat; however, policies are not enforceable and legally binding but preferred management guidelines	Specific details on management of hydrology include: - Groundwater level of 50-70 cm depth from the peat surface should be maintained for the best performance of oil palms. For Oil palm of 1-3 years, 30-40 cm water level from peat surface; For oil palms of age 4-7 years (Young mature oil palms), 35-45 cm water level from peat surface; for oil palms of > 8 years (Fully Mature), 40-50 cm water level from peat surface required. - Drought and peat fires should be avoided by maintaining a good water level of 40-50 cm in peatland drainage.
NGO	n/a	*Best Management Practices for Existing Oil Palm Cultivation on Peat* Roundtable for Sustainable Palm Oil (RSPO)	RSPO is an independent and internationally recognised certifying agency for sustainable palm oil. Policies regarding peatland hydrology are not enforced nor linked to certification standard.	Specific details on management of hydrology include: A good water management system for oil palm effectively maintains a water-level of 50-70 cm (below the bank in collection drains) or 40-60 cm (groundwater piezometer reading) Water level in the canals and in the field should be controlled so as to prevent saltwater intrusion into the area Fertilizers application should be avoided during the raining season as the rain aids the leaching of fertilizers into the ground surface.
NGO	Malaysia and Indonesia	*A Quick Scan of Peatlands in Malaysia*	Influential NGO in Malaysia and	Specific details on management of hydrology include: The water table must be 20-30 cm below the

	Wetlands International	Indonesia. Policy is not enforceable nor legally binding but preferred management guidelines.	surface of the peat or higher to avoid drying out and decomposition of the peat, with the subsequent release of carbon dioxide (CO_2)

Peatland Policies in Indonesia and Malaysia

Indonesia

Driven by the large emissions factors cited from burning events, increasing regional pressure due to transboundary haze (Mahmud, 2013), Indonesia's status as the 3rd largest emitter of GHGs globally (van Noordwijk *et al.*, 2014) and more recently, local government and university scientists' verification of international emissions factors for peat soil in plantations (van Noordwijk *et al.*, 2014), Indonesian public policy has increasingly recognised the ecological importance of peatlands, reflected in a range of policies for conservation and best management practices. Among the earliest was Presidential Decree No. 32/1990, and then echoed by Government Regulation No. 26/2008, both of which stated that peat of >3m should automatically be designated as protected areas. Following this, the Regulation of the Ministry of Agriculture No. 14/2009 (*Guideline on Oil Palm Plantation on Peatland*) stipulated that where concessions have a peat thickness of >3m on >30% of their area, the entire concession should remain closed (Wibisino *et al.*, 2011). This regulation includes benchmarks for minimum WTD for palm oil on peatland, maximum widths and depths for drainage channels as well as more general cultivation requirements affecting hydrology (Government of Indonesia, 2009). Most recently, Government Regulation No. 71/2014 (*Protection and Management of Peatland Ecosystem*) mandatorily prohibits the cultivation or development of 30% of an uncultivated peat hydrological unit and then any area peat >3m in addition to this (Government of Indonesia, 2014). While the consideration of management in terms of peat hydrological units has merit, drainage of one part of the hydrological unit (even if on relatively shallow peat zones) will impact the runoff, erosion, drainage, subsidence and GHG emissions of the entirety of the peat area.

Indonesia has also established a national level moratorium on deforestation of primary forests and peatlands. The moratorium was enacted in the context of a national strategy for Reducing Emissions from Deforestation and Forest Degradation (REDD+), to reduce GHG emissions projected for 2020 by 26–41% (Ministry of Forestry Indonesia, 2008). The moratorium was meant to freeze the issuing of new licenses to allow time for the Indonesian government to establish a degraded land database, required for identification of land acceptable for development, including oil palm plantations (World Growth, 2011). After a delayed start, the moratorium commenced in May 2011 with Presidential Instruction No. 10/2011 (Rondonuwu, 2011), and was recently extended (a further 2 years) for the second time in 2015.

Whilst there have been policy developments in Indonesia, problems related to this are twofold; firstly in terms of the consistency and appropriateness of these policies, and secondly concerning the political and economic capacity to enforce them. In relation to the first issue, there is a lack of continuity between policies related to peat, resulting in some serious contradictions. For example, while the Ministry of Agriculture Regulation No. 14/2009 sets water levels targets for peat as 60-80cm, Government Regulation No. 71/2014 specifies levels at 40cm. Contradictions aside, neither goal may be particularly helpful in the long run, given that subsidence and emissions are still substantial at either WTD (Hooijer *et* *al.*, 2012). These contradictions may have arisen due to a more general land management conflict originating from the Constitution of 1945 (Article 33), which mandates the State to manage Indonesia's natural resources, 'for the benefit of the people' (Abdullah, 2002). This was based around a philosophy common throughout Southeast Asia (Hezri & Hasan, 2006; Government of Malaysia, 2015) that viewed natural resource exploitation as a tool to aid development. As a consequence, pristine forests or degraded land were viewed as 'wasteland' or 'idle' land if not exploited to support development (McCarthy & Cramb, 2009).

Secondly, concerning political and economic capacity to effectively implement the policies, there is evidence that patronage-based political arrangements in Indonesia allow the oil palm industry considerable scope for side-stepping formal policy procedures (Carlson *et al.*, 2013). Medrilzam *et al.*, (2014) demonstrated that well-connected 'elite patrons' (often retired government officials) employed as 'functional directors' to perform 'extra-economic functions' are common amongst top-tier plantation firms. These 'directors' often use their influence and connections to bypass important procedures in the land licensing process, for instance the AMDAL (*analisis Dampak linkungan*, or environmental impact assessment) requirement. In principle, the AMDAL process should allow for the identification of peatlands and associated depths (as defines in the policy parameters above) and thus denial of licenses. However, well-connected companies often gain 'special' approvals to proceed with land opening before the AMDAL is carried out (Zakaria *et al.*, 2007), rendering all policies restricting development on peat impotent (Varkkey, 2016). Consequently, up to 25% of concessionaires deviate from this rule and plant on deep peat anyway (Silvius & Kaat, 2010). Decentralization of these processes also contributes to this paralysis; with district governments issuing 26 million ha of oil palm concessions between 2000-2010, despite only 10 million being agreed at the federal level (Ito *et al.*, 2014).

Similarly, until September 2014, Indonesia was the only member state not to ratify the ASEAN agreement on transboundary haze pollution (Government of Malaysia, 2011). Indonesia’s non-ratification was driven by both external (lobby group) and internal (parliamentary-level) pressure. Some of the strongest and most influential lobby groups are the Indonesian Sustainable Palm Oil (ISPO) Commission and Indonesian Palm Oil Association (GAPKI). GAPKI strongly lobbies for ‘the preservation of their heritage and way of life’, referring to the status quo of open burning operations in land clearing and the use of peatlands for plantations. Its lobbying raised concerns over the legal consequences of ratification (Sijabat, 2007), specifically liability clauses related to peatlands and use of fire (Budianto 2008) would threaten the sector’s practices (Varkkey, 2016). Given the close personal relationships between GAPKI members and certain parliamentarians, it was no surprise that many parliamentarians echoed these concerns. However, the irony is that Indonesia already has all these provisions in their existing peatlands legislation.

Again in relation to the REDD+ moratorium detailed above, similar policy weaknesses have been reported (IPCC, 2014). For example it has been argued that the REDD+ moratorium was watered down due to inherent political and private interests (Rondonuwu, 2011; Simamora, 2011) bolstered by patronage networks. For example, the government decided that as part of REDD+, plantation investments (including those on peatlands) already approved by the Indonesian government would not be affected by the moratorium (Kuala Lumpur Kepong Berhad, 2010). Also, it was observed that there was a substantial increase in the permits for large-scale conversions granted just before the moratorium was enacted (Government of Indonesia, 2009). Combined, it is questionable whether REDD+ moratorium can be more effective than previous regulations in restricting the use of peatlands for plantation purposes (Varkkey, 2016).

Following the severe 2015 haze events, declarations outlined in October 2015 (Mongabay.com, 2015) suggest a new and more assertive direction in relation to public policy. Proposed measured include: a halt to all new forest clearance within peatlands (even those in existing concessions), a ban in the use of fire for land clearance and lastly, that all newly established plantation areas which experienced fire in the last haze event should be earmarked for rehabilitation. This was announced in parallel with plans to establish a new Peatland Rehabilitation Agency. All this reflects strong intention; however Indonesia still must overcome all the pre-existing constraints described above.

Malaysia

In Malaysia, the policy framework for peatland management is even less specific and weaker. Hezri & Hasan, (2006) suggest that the lack of commitment to environmental sustainability in Malaysia dates back to Prime Minister Dr Mahathir's late 1980s commitment to 'upholding the right to development of countries in the South, against the "eco-imperialist" position of the wealthy North'. Yet the main driver for policy stagnation appears to be the decentralisation of land policy. Originating from the constitution of 1960, but still in place today, land, forests, water and other natural resources (primary sector) are under State jurisdiction while the then limited tertiary sector (e.g. services, banks, tourism and also now oil) was and still is, Federally controlled. Originally this arrangement meant that the then buoyant tin and rubber sectors provided state governments with substantial revenues. However, the decline of these industries means that in recent years, the Federal revenues significantly exceed that of the state (Memon, 1999). The conservation of lands for ecosystem services and conservation raises no income, and as any environmental disaster (such as flooding) is covered by federal funds, there is little incentive for states to maintain habitat or ecosystem service functionality. Thus, while at a Federal level policies such as Environmentally Sensitive Areas (ESAs) within the Environmental Quality Act 1974 acknowledge the hydrological importance of peatlands and their need for 1km buffer zones, at a state level, policies are often contradictory (e.g. 100m in Selangor State).

Unfortunately, PSFs and their hydrological requirements have not been officially recognised under the Forestry Act (1991) (Gomez, 2009). However, in 2011, the Ministry of Natural Resources and Environment launched the *National Action Plan for Peatland Management* (NAP) providing key management strategies and targets (Busch *et al.*, 2015). However, NAP lacks specific details on how to undertake such strategies, including hydrology management. Furthermore, NAP is not legally binding, so there is no obligation for land owners, cultivators or managers to implement policy. Similarly, the Malaysian Palm Oil Board (MPOB), one of the foremost palm oil industry associations also provides guidance for cultivation on peat, such as recommendations for WTD (see van Noordwijk *et al.*, 2014). However, even if enforced, WTDs suggested promote significant GHG loss anyway.

Currently, it should be noted that policies related to peatland management remain focused on haze and peatland burning (especially in Indonesia), reflecting the diplomatic challenges concerning the transboundary impacts (Marti, 2008). Reduction of carbon emissions is seen as a secondary argument (Ramlah & Lizanah, 2000), which is compounded by the fact that most global estimates do not include emissions from decomposition of carbon in peatlands in carbon emission and climate change models (Ramsar, 2015). Ironically, this has raised concerns that if the governments involved are able to successfully implement haze and burning related reductions, the need to protect peatlands for the reduction of net soil respiration, biodiversity conservation or other ecosystem values may disappear from the agenda (Miettinen *et al.*, 2013).

Overall, the efficacy of policies and guidelines for the sustainable management of peatlands and the conservation of PSFs in Malaysia and Indonesia have been hindered due to the perception that they are in conflict with the national economic development priorities and the interests of the sectors such as palm oil and acacia. For example, Indonesia's official goal for the palm oil sector is to reach a CPO output of 40 million tonnes per year by 2020 (Boer *et al.*, 2012; Hameiri & Jones, 2013). In order for the government's yield goals to be achieved, the country has little option other than to continue establishing plantations on restricted peatland areas (Varkkey, 2016). Indeed, research has shown that strategies of commercial plantations to increase productivity in Indonesia especially, have primarily focused on expansion of new land, rather than replanting or yield increase research (Suharto, 2011). The ongoing need for new land helps to explain the ambiguity surrounding peatland policies in both countries. Yet even attaining yield improvements, without strong policy implementation, there is a risk that improvements of any profit margins will only serve to justify further expansion into marginal lands such as peat.

Additional policies and policy initiatives

Beyond national policies, a number of regional and international actors are playing prominent roles in developing policies, projects and initiating discussions at local and regional levels. Regionally driven initiatives include the *ASEAN Peatland Management Initiative* (APMI) (2002) and the *ASEAN Peatland Management Strategy* (APMS) *and Action Plan for Sustainable Management of Peatlands in ASEAN Member Countries (2006-2020),* both under the purview of the Association of Southeast Asian Nations (ASEAN) Secretariat. The goals of the APMI were *'to promote sustainable management of peatlands through collective efforts and enhanced cooperation among ASEAN Member Countries towards achieving local support and sustaining livelihood options, regional benefits through reduced risk of fire and its associated haze and contributing globally in minimizing impacts of climate change as a result of carbon release from peatlands'* (ASEAN Secretariat, 2003). The APMS more specifically served as a guide for peatland management in the region. Stemming from the APMS, management plans are also being devised for specific sites in the ASEAN region and driven by non-governmental organisations such as Malaysia's Global Environment Centre (GEC).

In this context, NGOs have shown themselves to play a pivotal role in coordinating both government and non-government stakeholders in the development of local and state peatland management plans not only within Malaysia but also on a regional scale. These NGOs are commendable for their efforts despite the challenges they face in terms of governmental constraints related to policy limitations and implementation capacity. On a more global scale, other NGOs such as Wetlands International and the International Mire Conservation Group have been pushing for countries to develop peat-specific policies. However the response from target governments has been slow (Gründling & Grobler, 2005).

Further, there are some corporations that are taking a new position regarding the cultivation of peatlands which has the potential to have wide-reaching impacts on the status of remaining peatlands in Southeast Asia and beyond (Padfield et al. *in press*). One such example is Wilmar International, one of the world's largest traders of palm oil, who committed to 'no deforestation, no peatland and no exploitation' in December 2013 (Wilmar International, 2014). Included in this commitment was no further planting on peat soil regardless of depth, and it extends to all operations within the supply chain, including subsidiaries and third parties from whom Wilmar purchase (Varkkey, 2014). Currently, only a small number of the largest corporations have made similar policy commitments and thus the effect of this new corporate position on the wider management of peatlands is still unclear (Padfield *et al., in press*).

Finally, RSPO is an internationally recognised certifying agency for sustainable palm oil, composed of a range of stakeholders from NGOs to producers and processors, and has developed management guidelines for growers on aspects such as peatland hydrology management (RSPO, 2012). Yet as with government agencies such as MPOB, joining the scheme is not compulsory and even if adhering, having existing concessions on peat does not currently disqualify growers from being certified as sustainable, and thus, further promoting the 'cake-and-eat-it' narrative that peat-based palm oil can be sustainable.

Indeed, the challenge that the persistence of this narrative of sustainability poses to efforts to change policies in relation to peatland is significant. It echoes the more general optimism of ecological modernisation with its assertion that developmental and environmental goals can be pursued simultaneously without hard choices. In this context we should consider the 'hidden intentionalities' (De vries, 2007) underlying such polices. In this case, it is the notion of sustainability itself, which sets the debate in terms of how mitigation can be best achieved, rather than in terms of whether it is possible to mitigate or not. Yet this pursuit of sustainable drainage-based agricultural development is in conflict with current scientific understanding reviewed here, showing that even with best management practices, C losses, loss of ecosystem function, subsidence, flooding, biodiversity reduction and loss of future peat accretion are all undeniable consequences. However, the avoidance of these issues has important implications in relation to what types of data policy makers are likely to employ in the process of decision making, who are identified as the key stakeholders and what are regarded as satisfactory outcomes.

Conclusions and Recommendations: Key policy challenges for peatland hydrology management

This paper has reviewed the current status of scientific research on tropical PSFs and existing peatland policies in Indonesia and Malaysia. More specifically, it has demonstrated the role that the PSF's unique hydrology plays in the maintenance of ecosystem services, and its vulnerability in the face of any human activities which involve drainage. In simple terms, if a swamp is drained, it is no longer a swamp. While the conversion of PSFs has been portrayed as a developmental necessity, this paper also alludes to the economic, social and environmental costs associated with this approach. Such costs include the short- and long-term impact of peat fires and transboundary haze, and associated health and income impacts to millions of people in both nationally and regionally. Increasingly, these costs also include losses predicted in yield and land area due to subsidence and associated flooding to vast coastal areas of the region, and financial implications of future flood control investments (Hooijer *et al.*, 2015). These, when combined with global costs from climate change, may offset the short-term perceived benefits gained from drainage-based agriculture.

This paper has also questioned the notion of the sustainable development of peatlands. Here, we have shown that even where current guidelines and/or policies to control WTDs and limit development to only certain proportions of peat domes are fully implemented, such 'sustainable' practices inevitably result in significant GHG emissions (Hooijer *et al.*, 2012; RSPO, 2012), long-term subsidence of peat soils, significant flooding and loss of land area in

South East Asian coastal peatlands (Hooijer *et al.*, 2015), not to mention significant losses to biodiversity. Given the current state of knowledge, we are still forced to conclude that *any* development on peat involving drainage and clearance of forest is fundamentally unsustainable and should be formally recognized as such.

Protecting the remaining areas of PSF and restoring key degraded systems thus makes economic, social and environmental sense. Significantly, under the United Nations Framework Convention on Climate Change (UNFCCC) 2013 policy (Decision 2/CMP.7) countries can account for GHG emission sources from wetland drainage as well as C storage via rewetting of wetlands. Following on from the recent COP 21 agreements, critical examination of the efficacy of management guidelines and hydrology policy practices for peatlands to reduce emissions will be crucial for achieving these GHG emission goals (Marti, 2008). Such policies would require robust and targeted interventions based on the wealth of recognised scientific understanding (Goldstein, 2015). However, whilst there have been considerable policy developments, notably by the Indonesian Government and a selection of non-state actors, this paper has highlighted the challenges that confront any efforts to implement such a strategy. These include;

i. *Lack of policy specificity and consistency.* While Indonesia has developed specific laws that provide a framework for improved hydrology management, these laws are often inconsistent. On the other hand, in Malaysia (see Table 3) and in the ASEAN region more broadly, there are few specific and legally binding laws. Further, the conflict in policies and priorities between state and federal agencies creates stagnation in effective policy implementation.

ii. *Lack of political will and ineffective enforcement.* Even where laws which show some recognition of ecosystem function and hydrology have been established, there are problems of ineffective law enforcement (Varkkey, 2014). Specifically, less than optimal bureaucratic structures (AseanPeat, 2014) and patronage politics also pose challenges.

iii. *Current policies and guidelines do not take full account of the hydrological requirements for ecosystem function.* Instead, developments of policies and guidelines often promote the narrative of sustainable drainage-based agriculture on peat, providing best management guidelines which promote the notion that a 'win-win' scenario is possible.

To make any progress, recently announced policy initiatives require local political support, raising questions *c*oncerning how key actors can be incentivised to support them. Finally, such policies must recognise the fundamental importance of hydrology and address current preconceptions concerning sustainable PSF conversion. In light of the above, the following sets out a list of policy recommendations to support the long-term integrity of tropical peatlands:

1) Ideally all degraded peatland should have the hydrology restored to natural conditions, irrespective of the depth of the peat, and the vegetation should be rehabilitated. In light of this, the Indonesian President Joko Widodo is to be commended for his recent proposal to restore 2 million ha of degraded peatlands in Indonesia (The Jakarta Post, 2015b).
2) It is vital that the hydrology of intact PSFs should be maintained and buffered from any peripheral drainage activities. Compartmentalizing peat domes should be avoided and conservation areas should ideally cover entire hydrological units.
3) Conversion of peatland to agriculture inevitably leads to a myriad of impacts. Consequently, the recommended economic uses should be solely non-drainage options such as paludiculture and financing via REDD+, especially given the

comparative wealth of C stored. Given the economic unsustainability of current practices, initiative to reintegrate original land-use practices by peatland communities should be supported before losses to ecosystem services and land area by flooding become irreversible.

4) Complete avoidance of peat of any depth for future development alongside the rehabilitation of forest and drainage of all existing developed/degraded peatlands within concessions should be a qualifying element of any sustainable oil palm or acacia certification scheme where any part of the companies' land area is on peat soil.
5) Policies in both countries should be strengthened to have consistency between both state and federal levels and a commitment to better enforcement, monitoring and transparency of activities both within and outside concession boundaries.
6) Local and International funding options should be provided for the development of research and implementation programmes to support non-drainage paludiculture agriculture, ecotourism, set-aside/rehabilitation programmes and other alterative livelihood strategies for smallholder farmers and local communities living in proximity to peatlands.
7) International recognition of the global importance with respect to carbon sequestration and contributions to climate change, transboundary air pollution and loss of endangered species is vital. Recent International collaboration and commitments are commended (Mongabay.com 2016). Yet a fully comprehensive and ongoing commitment is required to remove the drivers of peat development and promote conservation and rehabilitation. Given the financial commitments being made in relation to climate change mitigation, especially in light of the recent COP21 negotiations, a global strategy to rehabilitate areas of significant C loss such as these, would be a strategic use of global financial resources and efforts.

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