

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

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

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20 **Abstract**

21 Pristine tropical peat swamp forests (PSFs) represent a unique wetland ecosystem of
22 distinctive hydrology which support unique biodiversity and globally significant stores of soil
23 carbon. Yet in Indonesia and Malaysia, home to 56% of the world's tropical peatland, they
24 are subject to considerable developmental pressures, including widespread drainage to
25 support agricultural needs. In this paper we review the ecology behind the functioning and
26 ecosystem services provided by PSFs, with a particular focus on hydrological processes as
27 well as the role of the forest itself in maintaining those services. Drawing on this, we review

28 the suitability of current policy frameworks and consider the efficacy of their
29 implementation. We suggest that while policies in Indonesia and Malaysia, as well as
30 regionally, are often based around the narrative of oil palm and other major monocrops as
31 drivers of prosperity and development, we also show that this narrative is also being
32 supported by on a-priori claims concerning the possibility of sustainability of peat swamp
33 exploitation via drainage-based agriculture through the adherence to best management
34 practices. We discuss how this limits their efficacy, uptake and the political will towards
35 enforcement, and consider how both narratives (prosperity and sustainability) clearly exclude
36 important considerations concerning the ecosystem value of tropical PSFs which are
37 dependent on their un-impacted hydrology. Current research clearly shows that the actual
38 debate should be focused not on how to develop drainage-based plantations sustainably, but
39 on whether the sustainable conversion to drainage-based systems is possible at all.

40 **Keywords**

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

43 **Introduction**

44 Tropical lowland peat swamp forests (PSFs) are unique ecosystems. Defined by their
45 hydrology, they are permanently waterlogged and in their natural state, flood up to 50 cm or
46 more during the wet season. As a consequence, the peat substrate is anaerobic, highly acidic
47 (pH2.9-4) and low in nutrients. These conditions inhibit heterotrophic and root respiration
48 and also organic matter decomposition (Yule & Gomez, 2008; Mezbahuddin *et al.*, 2014).
49 Consequently, plant material slowly and only partially decomposes resulting in a net
50 accumulation of organic matter. The peat forms over millennia to create domes up to 20 m
51 deep (Page *et al.*, 2011). As a consequence, these systems are globally significant carbon (C)

52 stores, holding 11-14% (69Gt) of global peat C (Page *et al.*, 2011). As the formation of peat
53 is controlled by the rate and extent of microbial decomposition of plant matter, maintenance
54 of net organic C accumulation is controlled by litter type and production rate, soil biotic
55 community assemblage and critically, the associated habitat conditions, including most
56 importantly, the hydrology of the ecosystem in which these interactions occur.

57 Southeast Asia contains an estimated 56% of all tropical peatlands (Page *et al.*, 2011), mostly
58 in Indonesia and Malaysia. Southeast Asian peatlands are also some of the deepest, averaging
59 5.5-7m (Page *et al.*, 2011), compared to South American peats; averaging 0.5-6m (Page *et*
60 *al.*, 2011). These peats represent long-term C stores, with the majority of Southeast Asian
61 peats, especially those in coastal areas, at 3000-7000 years BP (Dommain *et al.*, 2011).
62 However, inland regional peats can be much older. For example, samples collected from
63 Sebangau, Kalimantan were found to be up to 28,000 years BP (Wüst *et al.*, 2011)

64

65 The substantial expansion of agroforestry in the both Malaysia and Indonesia has created
66 significant demand for land. The relatively small human populations in large and contiguous
67 areas of peat swamps coupled with perceptions of these areas as economically unproductive
68 ‘wastelands’ (Government of Malaysia, 2015), has contributed to a idea that PSFs offer a
69 large, and relatively cheap land bank for large-scale agroforestry (Varkkey, 2016). Within the
70 last two decades, forest cover on peat swamps has reduced from 77 to 36% in Indonesia and
71 Malaysia (Miettinen *et al.*, 2012a) with industrial plantations covering approx. 20% of the
72 region’s peatland (Miettinen *et al.*, 2012b). Commercially, mono-cropping of palm oil in
73 Malaysia currently contributes 5-6% of GDP (MPOB, 2011) and its growth as an industry is
74 closely associated with the countries’ rapid modernisation, as is evidenced through its
75 popular characterisation as the ‘golden crop’ (Varkkey, 2016). The overall contribution of

76 palm oil to the Indonesian economy stands at 7% (IST & GCP, 2014). Combined, both
77 countries account for 85% of global production.

78

79 The process of peat swamp conversion has been, and remains a subject of considerable
80 controversy in both nations and internationally. Those in support argue for expansion of oil
81 palm on grounds of national economic development. Central to this narrative is the principle
82 that, both countries have the right to utilise their natural resources in order to achieve
83 development goals (Hezri & Hasan, 2006). This has been supported by the production and
84 promotion of ‘divergent knowledge’ (Goldstein, 2015); that is, the production and
85 widespread use of data that suggests the minimal impacts or even environmental benefits of
86 conversion (e.g. World Growth, 2011). This data is often funded by industry research bodies
87 and primarily published in industrial and non-peer reviewed journals (Goldstein, 2015)). Yet
88 while it is largely written off by the international scientific community, such data is employed
89 to sway debates on PSF management, challenging evidence presented by conservation
90 advocates and fuelling support for continued peatland conversion as part of the development
91 agenda (Goldstein, 2015). Where acknowledgement of impacts is given, the popular
92 discourse emerging is that ecological harm committed in the course of doing so can be
93 significantly mitigated via sustainable development practices (e.g. Government of Indonesia,
94 2009). As a consequence, the current research and development trajectory around palm oil
95 focuses on the sustainable management or ‘wise use’ (Joosten & Clarke, 2002) of plantations
96 and other drainage-based agriculture on tropical peatland (Padfield *et al.*, 2014; Hansen *et al.*,
97 2015). While these studies have strengthened arguments for improved plantation
98 management, they have also supported a concept of sustainable palm oil on both peat and
99 mineral soils primarily via the voluntary adoption of a range of sustainability measures by the

100 industry (e.g. Roundtable for Sustainable Palm Oil (RSPO, 2012); Melling *et al.*; Othman *et*
101 *al.*, 2011).

102 While the palm oil sustainability lobby has claimed some success, a growing local and
103 international literature (Padfield *et al.*, 2014) is focused not on optimal management but on
104 the functioning of intact PSFs, loss of function with conversion and role of tropical PSFs in
105 regulating a host of important ecosystem services, including carbon sequestration, flood
106 regulation, biodiversity and water supply. These efforts have highlighted the link between
107 peatland degradation and global carbon emissions. For example, Hooijer *et al.*, (2010)
108 estimated that CO₂ emissions due to peat degradation, fire and fluvial losses
109 following peatland drainage in Southeast Asia contribute the equivalent of 1.3% to 3.1%
110 of current global CO₂ emissions from fossil fuels. Consequently, these studies have raised
111 significant questions concerning the direct and indirect environmental impacts of the palm oil
112 industry on PSFs and the implications that current concepts around sustainability have for the
113 protection of PSFs. In light of this body of literature, this paper will seek to explore one
114 particular critical issue surrounding the development of peatlands which to to-date is often
115 avoided; primarily, that before considering how to sustainably manage peat swamps for
116 drainage-based plantations, we must first consider if we *should*. In this paper we seek to
117 unpack some of the a-priori assumptions surrounding the sustainable exploitation of peat
118 swamps via intensive monoculture and question if it is an achievable goal. In order to do so
119 we address four questions:

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

124 3. To what extent do current public and private initiatives serve to ameliorate the
125 negative impacts of peat conversion?

126 4. And critically, given our understanding of peatland functioning, is sustainable
127 development of peatlands possible, and under what conditions?

128

129 **PSF Functioning and Ecosystem services**

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

137 *Carbon sequestration*

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

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

172 2009) and Sumatran tiger (Wibisono & Pusparini, 2010), as well as being the preferential
 173 habitat of the endangered false gharial (Bezuijen *et al.*, 2001).

174

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

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

177

178

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

188 *Local hydrological regulation and flood prevention*

189 Embodying the paradox of "high and wet" (Dau, 1823), intact PSF dome hydrology is self-
190 regulating (Dommain *et al.*, 2010). Due to formation from woody debris, PSF peats have
191 naturally large soil pore sizes (Huat *et al.*, 2011). Yet while these peats can store more water,
192 they also have increased hydraulic conductivity. If constant, this would result in rapid
193 drainage of water under dryer conditions. Yet, the juxtaposition is solved through the
194 dynamic movement of surface soil layers. During flooding conditions, buoyant soils, with a
195 more open pore surface structure, store excess water and in doing so, regulate peak discharge
196 and reduce erosion. When natural water levels drop, soil buoyancy drops and gravity-driven
197 compaction of surface soil reduces pore size and with it, hydraulic conductivity (Price, 2003).
198 This mechanism by intact uppermost peat layers therefore limits the amplitude of water table
199 fluctuations under varying meteorological conditions. Therefore, any artificial compaction

200 (such as that recommended by Melling *et al.* for monoculture) or drainage inhibits the self-
201 regulating capability, effecting not only the area in question, but also the entire hydrological
202 unit of the dome in terms of reduced water storage and regulatory capacity, and also
203 expediting problems associated with land subsidence (See below).

204

205 The architectural complexity of the PSF is also critical to this self-regulation, playing a
206 prominent role in regulating the run-off of water. Complex rooting systems of endemic PSF
207 trees, especially those with buttress roots, form barriers to gravity-driven water movement off
208 the dome (Takahashi *et al.*, 2001). The natural hummock-hollow surface patterns created by
209 the vegetation rooting systems also act as a collection of small weirs (Herwitz, 1988). Given
210 the natural tree zonation patterns on domes as described in previous studies (e.g. Page *et al.*,
211 (1999), these hydrology-regulating structures dominate the edges of the dome, coinciding
212 with where the surface topographic gradient is greatest and the retardation of surface run-off
213 most critical, contributing to the storage of excess water during rain events and the controlled
214 slow release during dry periods.

215 **Impacts from development of peat**

216 *Land Use Conversion*

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

224 exposure, habitat loss, uncontrolled fires and widespread forest drainage and canal
 225 construction to facilitate timber extraction.

226

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

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

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

236 * Specific depth range dependant on age class of plantation.

237

238 *Carbon Emissions*

239 Alteration of the soil environment via drainage and the resulting peat oxidation alters the
 240 community composition, abundance, and activity levels of microorganisms, increasing rates
 241 of decomposition and GHG emissions via enhanced extracellular enzyme activities (Freeman
 242 et al. 1996) and increased microbial biomass (Mäkiranta *et al.*, 2009). Consequently, drained
 243 peats revert from C stores to C sinks, with CO₂ emissions from drained peats ranging from
 244 22 to 100t ha⁻¹ year⁻¹ (Murayama & Bakar, 1996; Hooijer *et al.*, 2012). Indeed, a number of
 245 studies and associated models have shown a positive relationship between decreasing long-
 246 term WTD and soil respiration as well as C losses (Couwenberg *et al.*, 2010; Hooijer *et al.*,

247 2010; Carlson *et al.*, 2012). For example, Hooijer *et al.*, (2010) suggested that that soil CO₂
248 emissions increase by 0.91 Mg ha⁻¹ year⁻¹ for every centimetre of long-term lowered WTD.
249 However, (Carlson *et al.*, 2015) suggested that while positively correlated, WTD only
250 described 45% of the variation in net C loss from plantation mass balance equations, with
251 additional issues such as fertiliser application, fluvial flux from peat instability and plantation
252 micro-site heterogeneity having potential to contribute. The debate over GHG emissions from
253 converted peat soils has resulted in a narrative which often considers the peat merely as a
254 medium for plantation growth, where the sole consideration for sustainability is to reduce soil
255 respiration. Yet even at this level, considerations of net C balance (especially where
256 comparisons are made with forest GHG emissions) must also consider the continuous
257 contribution of natural PSF vegetation cover which is resistant to microbial decomposition.
258 Significantly, oil palms do not produce such resistant litter, and require fertilizers and lime.
259 Combined, this enhances microbial respiration and thus GHG emissions and replacement of
260 organic matter is also greatly diminished. Indeed Hooijer *et al.*, (2012) showed that even at
261 the highest possible WTD, only 20% deductions in total CO₂ emissions could be achieved.
262 Similarly, even with WTD adherence consistent with sustainability certification group,
263 RSPO, of 40-60cm annual average WTD, a significant net carbon footprint of *c.* 60 tonnes of
264 CO₂ ha⁻¹year⁻¹ results (derived from Page *et al.*, (2011b) and Jauhiainen *et al.*, (2012)).

265

266 *Fluvial Carbon Losses*

267 In tropical PSF catchments, fluvial C fluxes are dominated by organic forms, contributing
268 between approximately 370 Tg of total organic carbon (TOC) to marine pools (Meybeck,
269 1993). The importance of these ‘blackwaters’ in relation to C loss from PSF conversion and
270 drainage, have only recently come to the fore. Moore *et al.*, (2013) showed a 50% increase in
271 fluvial C export due to artificial drainage as compared to intact sites. When included in total

272 emissions factors, there is a 20% increase in overall flux. However, how much of this
273 aquatic-based C is actually degassed to the atmospheric C pool remains very poorly
274 understood (Sjögersten *et al.*, 2014). Jauhiainen & Silvennoinen (2012) recorded substantial
275 CO₂ (9 -16 tC-CO₂ ha⁻¹ year⁻¹) and CH₄ (0.27-3.0 tC-CH₄ ha⁻¹ year⁻¹) emissions from water
276 surfaces of drainage canals in Sumatra (Acacia) and Borneo (abandoned peat).
277 Furthermore, ¹⁴C aging of DOC from disturbed TPSFs also show that much older (>1000 yrs)
278 fluvial C is being released from disturbed sites, indicating increasing deep instability of
279 drained peatlands (Moore *et al.*, 2013).

280

281 *Subsidence*

282 Subsidence is the combined processes of organic matter decomposition via oxidation,
283 compaction and shrinkage of peat volume above the water table and compression below the
284 water table. Hooijer *et al.*, (2012) found an average subsidence rate of 142cm for the first 5
285 years after drainage (with 75cm lost in the first year), with levels stabilising at 5cm per year
286 loss in soils of an annual average WTD of 0.7m. Others have found similar rates of long-term
287 loss from 3.6cm (at 0.5m WTD) and even 8.9cm/yr (DID & LAWOO, 1996; Hensen *et al.*,
288 2002, respectively), continuing as long as drainage of peat is ongoing. While these sites can
289 initially be gravity drained, soil height will eventually reach sea or adjacent river levels, thus
290 constraining the outflow of water, making surrounding peats undrainable and leading to
291 increased intensity and frequency of flooding as well as potential seawater intrusion
292 (Andriess, 1988). By modelling subsidence based on a conservative 3.5cm/yr soil height
293 loss, Hooijer *et al.*, (2015) estimated flooding potential for the entire Rajang river delta
294 850,000ha area, Sarawak at 42% in 25 years and an alarming 82% in 100 years. Given that
295 these extensive peats have formed in the coastal lowlands of Southeast Asia, where tectonic
296 movements over the last 8000 years have reduced the elevation of many coastal zones, peat

297 horizons regionally often extend below sea level. Such flood predictions can therefore be
298 expanded to the larger coastal peats of Malaysia and Indonesia with drainage. These impacts
299 will also be confounded by sea level rise and climate change. Therefore it is important to
300 state that as well as globally catastrophic GHG emissions, subsidence will result in the
301 irreversible loss of extensive coastal land in effected regions, impacting local communities,
302 industries and ironically, the yield and revenue of the plantations responsible. The resulting
303 income losses alongside increased expenditure required for flood defences and community
304 rehousing, means that the economic and social sustainability of such practices must be
305 seriously questioned.

306

307 *Burning*

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

314

315 Smouldering (or the slow, low-temperature, flameless burning of porous fuels) is the
316 dominant form of burning in peat deposits. These fires can persist under low temperatures
317 and in peat soils with high soil moisture and low oxygen, even crossing wet layers above
318 250% moisture content (Huang & Rein, 2015). Further, the high wood content and low bulk
319 density of tropical peat enables oxygen to be supplied to the deeper layers exacerbating deep
320 combustion (Usup *et al.*, 2004), causing long-term damage to soil systems (Rein *et al.*, 2008).
321 Hydrology and in particular, the WTD and the moisture content of the soil, govern the

322 ignition, spread and the ultimate extinction of a peat fire (Garlough & Keyes, 2011; Watts,
323 2013).

324

325 Southeast Asian ‘haze’ episodes associated with peat forest burning are now considered to be
326 an annual phenomenon (Varkkey, 2016). Indeed, in 1997, peat fires released approximately
327 0.95 Gt of C, equivalent to ~15% of global fossil fuel emissions of the same time period
328 (Page *et al.*, 2002). Apart from a decline in ecosystem function and biodiversity, altered
329 biogeochemical processes and increased GHG emissions, human health issues have become a
330 pressing issue. Peat fires contribute *c.* 80% of the regional haze (Applegate *et al.*, 2002). Air
331 Pollution Index readings in Palangkaraya in Borneo in October 2015 reached >2000, the
332 highest values ever recorded and far above the Emergency level of >500 (BMKG). Exposure
333 to haze events has been shown to cause both immediate and delayed effects, increasing
334 respiratory related mortality from 19-66% (Sahani *et al.*, 2014). Indeed, in the most recent
335 2015 fires, an estimated 503,874 Indonesians were affected by haze related respiratory
336 infections (BNPB, 2015, as cited in The Jakarta Post, 2015a). Economic losses related to haze
337 are also significant, with estimates for the 2015 fires at \$16.1 billion for Indonesia (Center for
338 International Forestry Research, 2015).

339

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

344

345 *Social impacts*

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

356

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

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

367

368 **Peatland policies: The global context**

369 While individual countries may have specific peatland land-use policies, in the tropics, only
370 Malaysia and Indonesia have developed peatland-specific policies related to conservation and

371 sustainable development (Table 3). Globally, some umbrella protection is provided via
 372 protected areas (PAs) legislation. The most important of which, is the Convention on
 373 Wetlands of International Importance, known as the Ramsar Convention (Ramsar, 2014).
 374 Established in 1971 the Ramsar Convention requires member states to identify, quantify and
 375 value peatlands. Ramsar also urges its member countries to include at least one peatland site
 376 designation per country (Anshari & Armiyarsih, 2005). Despite the increasing number of
 377 designated Ramsar wetland sites in the world (2,234 sites at a total of 215 million hectares in
 378 2016), they represent only a fraction of the total amount of global peatlands. Thus, the extent
 379 to which PA designation implemented at a global level coincides with peatland areas in the
 380 tropics appears low (Anshari & Armiyarsih, 2005). As such, policy initiatives instigated for
 381 Indo-Malaysian peats are likely to strongly influence any future political reforms and
 382 associated peatland functionality across tropical peatlands zones globally as development
 383 (and oil palm expansion, specifically) puts increased pressure on frontiers such as Africa and
 384 Central/South America.

385 Table 3: Peatland policies in ASEAN with a specific focus on hydrology management.
 386

Stakeholder	Country	Policy name & Author	Policy influence	Peatland hydrology policy specifics
Government	Malaysia	<i>Malaysian National Action Plan for Peatlands (2011)</i> - 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	<i>Protection and Management of Peatland Ecosystem (2014)</i> - 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	<i>Guideline on Oil Palm Plantation on Peatland (2009)</i> - 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	<i>Best Management Practices for Existing Oil Palm Cultivation on Peat</i> 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	<i>A Quick Scan of Peatlands in Malaysia</i>	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)
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387

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389

390 **Peatland Policies in Indonesia and Malaysia**

391 *Indonesia*

392 Driven by the large emissions factors cited from burning events, increasing regional pressure
393 due to transboundary haze (Mahmud, 2013), Indonesia's status as the 3rd largest emitter of
394 GHGs globally (van Noordwijk *et al.*, 2014) and more recently, local government and
395 university scientists' verification of international emissions factors for peat soil in plantations
396 (van Noordwijk *et al.*, 2014), Indonesian public policy has increasingly recognised the
397 ecological importance of peatlands, reflected in a range of policies for conservation and best
398 management practices. Among the earliest was Presidential Decree No. 32/1990, and then
399 echoed by Government Regulation No. 26/2008, both of which stated that peat of >3m
400 should automatically be designated as protected areas. Following this, the Regulation of the
401 Ministry of Agriculture No. 14/2009 (*Guideline on Oil Palm Plantation on Peatland*)
402 stipulated that where concessions have a peat thickness of >3m on >30% of their area, the
403 entire concession should remain closed (Wibisino *et al.*, 2011). This regulation includes
404 benchmarks for minimum WTD for palm oil on peatland, maximum widths and depths for
405 drainage channels as well as more general cultivation requirements affecting hydrology
406 (Government of Indonesia, 2009). Most recently, Government Regulation No. 71/2014
407 (*Protection and Management of Peatland Ecosystem*) mandatorily prohibits the cultivation or

408 development of 30% of an uncultivated peat hydrological unit and then any area peat >3m in
409 addition to this (Government of Indonesia, 2014). While the consideration of management in
410 terms of peat hydrological units has merit, drainage of one part of the hydrological unit (even
411 if on relatively shallow peat zones) will impact the runoff, erosion, drainage, subsidence and
412 GHG emissions of the entirety of the peat area.

413 Indonesia has also established a national level moratorium on deforestation of primary forests
414 and peatlands. The moratorium was enacted in the context of a national strategy for Reducing
415 Emissions from Deforestation and Forest Degradation (REDD+), to reduce GHG emissions
416 projected for 2020 by 26–41% (Ministry of Forestry Indonesia, 2008). The moratorium was
417 meant to freeze the issuing of new licenses to allow time for the Indonesian government to
418 establish a degraded land database, required for identification of land acceptable for
419 development, including oil palm plantations (World Growth, 2011). After a delayed start, the
420 moratorium commenced in May 2011 with Presidential Instruction No. 10/2011
421 (Rondonuwu, 2011), and was recently extended (a further 2 years) for the second time in
422 2015.

423

424 Whilst there have been policy developments in Indonesia, problems related to this are
425 twofold; firstly in terms of the consistency and appropriateness of these policies, and
426 secondly concerning the political and economic capacity to enforce them. In relation to the
427 first issue, there is a lack of continuity between policies related to peat, resulting in some
428 serious contradictions. For example, while the Ministry of Agriculture Regulation No.
429 14/2009 sets water levels targets for peat as 60-80cm, Government Regulation No. 71/2014
430 specifies levels at 40cm. Contradictions aside, neither goal may be particularly helpful in the
431 long run, given that subsidence and emissions are still substantial at either WTD (Hooijer *et*

432 *al.*, 2012). These contradictions may have arisen due to a more general land management
433 conflict originating from the Constitution of 1945 (Article 33), which mandates the State to
434 manage Indonesia's natural resources, 'for the benefit of the people' (Abdullah, 2002). This
435 was based around a philosophy common throughout Southeast Asia (Hezri & Hasan, 2006;
436 Government of Malaysia, 2015) that viewed natural resource exploitation as a tool to aid
437 development. As a consequence, pristine forests or degraded land were viewed as 'wasteland'
438 or 'idle' land if not exploited to support development (McCarthy & Cramb, 2009).

439

440 Secondly, concerning political and economic capacity to effectively implement the policies,
441 there is evidence that patronage-based political arrangements in Indonesia allow the oil palm
442 industry considerable scope for side-stepping formal policy procedures (Carlson *et al.*, 2013).
443 Medrilzam *et al.*, (2014) demonstrated that well-connected 'elite patrons' (often retired
444 government officials) employed as 'functional directors' to perform 'extra-economic
445 functions' are common amongst top-tier plantation firms. These 'directors' often use their
446 influence and connections to bypass important procedures in the land licensing process, for
447 instance the AMDAL (*analisis Dampak lingkungan*, or environmental impact assessment)
448 requirement. In principle, the AMDAL process should allow for the identification of
449 peatlands and associated depths (as defines in the policy parameters above) and thus denial of
450 licenses. However, well-connected companies often gain 'special' approvals to proceed with
451 land opening before the AMDAL is carried out (Zakaria *et al.*, 2007), rendering all policies
452 restricting development on peat impotent (Varkkey, 2016). Consequently, up to 25% of
453 concessionaires deviate from this rule and plant on deep peat anyway (Silvius & Kaat, 2010).
454 Decentralization of these processes also contributes to this paralysis; with district
455 governments issuing 26 million ha of oil palm concessions between 2000-2010, despite only
456 10 million being agreed at the federal level (Ito *et al.*, 2014).

457

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

471

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

481 effective than previous regulations in restricting the use of peatlands for plantation purposes
482 (Varkkey, 2016).

483

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

492 *Malaysia*

493 In Malaysia, the policy framework for peatland management is even less specific and weaker.
494 Hezri & Hasan, (2006) suggest that the lack of commitment to environmental sustainability in
495 Malaysia dates back to Prime Minister Dr Mahathir's late 1980s commitment to 'upholding
496 the right to development of countries in the South, against the "eco-imperialist" position of
497 the wealthy North'. Yet the main driver for policy stagnation appears to be the
498 decentralisation of land policy. Originating from the constitution of 1960, but still in place
499 today, land, forests, water and other natural resources (primary sector) are under State
500 jurisdiction while the then limited tertiary sector (e.g. services, banks, tourism and also now
501 oil) was and still is, Federally controlled. Originally this arrangement meant that the then
502 buoyant tin and rubber sectors provided state governments with substantial revenues.
503 However, the decline of these industries means that in recent years, the Federal revenues
504 significantly exceed that of the state (Memon, 1999). The conservation of lands for

505 ecosystem services and conservation raises no income, and as any environmental disaster
506 (such as flooding) is covered by federal funds, there is little incentive for states to maintain
507 habitat or ecosystem service functionality. Thus, while at a Federal level policies such as
508 Environmentally Sensitive Areas (ESAs) within the Environmental Quality Act 1974
509 acknowledge the hydrological importance of peatlands and their need for 1km buffer zones,
510 at a state level, policies are often contradictory (e.g. 100m in Selangor State).

511

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

522

523 Currently, it should be noted that policies related to peatland management remain focused on
524 haze and peatland burning (especially in Indonesia), reflecting the diplomatic challenges
525 concerning the transboundary impacts (Marti, 2008). Reduction of carbon emissions is seen
526 as a secondary argument (Ramlah & Lizanah, 2000), which is compounded by the fact that
527 most global estimates do not include emissions from decomposition of carbon in peatlands in
528 carbon emission and climate change models (Ramsar, 2015). Ironically, this has raised
529 concerns that if the governments involved are able to successfully implement haze and

530 burning related reductions, the need to protect peatlands for the reduction of net soil
531 respiration, biodiversity conservation or other ecosystem values may disappear from the
532 agenda (Miettinen *et al.*, 2013).

533

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

548

549 *Additional policies and policy initiatives*

550 Beyond national policies, a number of regional and international actors are playing prominent
551 roles in developing policies, projects and initiating discussions at local and regional levels.
552 Regionally driven initiatives include the *ASEAN Peatland Management Initiative* (APMI)
553 (2002) and the *ASEAN Peatland Management Strategy* (APMS) and *Action Plan for*
554 *Sustainable Management of Peatlands in ASEAN Member Countries (2006-2020)*, both under

555 the purview of the Association of Southeast Asian Nations (ASEAN) Secretariat. The goals
556 of the APMI were *'to promote sustainable management of peatlands through collective*
557 *efforts and enhanced cooperation among ASEAN Member Countries towards achieving local*
558 *support and sustaining livelihood options, regional benefits through reduced risk of fire and*
559 *its associated haze and contributing globally in minimizing impacts of climate change as a*
560 *result of carbon release from peatlands'* (ASEAN Secretariat, 2003). The APMS more
561 specifically served as a guide for peatland management in the region. Stemming from the
562 APMS, management plans are also being devised for specific sites in the ASEAN region and
563 driven by non-governmental organisations such as Malaysia's Global Environment Centre
564 (GEC).

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

573

574 Further, there are some corporations that are taking a new position regarding the cultivation
575 of peatlands which has the potential to have wide-reaching impacts on the status of remaining
576 peatlands in Southeast Asia and beyond (Padfield et al. *in press*). One such example is
577 Wilmar International, one of the world's largest traders of palm oil, who committed to 'no
578 deforestation, no peatland and no exploitation' in December 2013 (Wilmar International,
579 2014). Included in this commitment was no further planting on peat soil regardless of depth,

580 and it extends to all operations within the supply chain, including subsidiaries and third
581 parties from whom Wilmar purchase (Varkkey, 2014). Currently, only a small number of the
582 largest corporations have made similar policy commitments and thus the effect of this new
583 corporate position on the wider management of peatlands is still unclear (Padfield *et al.*, *in*
584 *press*).

585

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

593

594 Indeed, the challenge that the persistence of this narrative of sustainability poses to efforts to
595 change policies in relation to peatland is significant. It echoes the more general optimism of
596 ecological modernisation with its assertion that developmental and environmental goals can
597 be pursued simultaneously without hard choices. In this context we should consider the
598 ‘hidden intentionalities’ (De vries, 2007) underlying such policies. In this case, it is the notion
599 of sustainability itself, which sets the debate in terms of how mitigation can be best achieved,
600 rather than in terms of whether it is possible to mitigate or not. Yet this pursuit of sustainable
601 drainage-based agricultural development is in conflict with current scientific understanding
602 reviewed here, showing that even with best management practices, C losses, loss of
603 ecosystem function, subsidence, flooding, biodiversity reduction and loss of future peat
604 accretion are all undeniable consequences. However, the avoidance of these issues has

605 important implications in relation to what types of data policy makers are likely to employ in
606 the process of decision making, who are identified as the key stakeholders and what are
607 regarded as satisfactory outcomes.

608

609 **Conclusions and Recommendations: Key policy challenges for peatland hydrology**
610 **management**

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

624

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

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

634

635 Protecting the remaining areas of PSF and restoring key degraded systems thus makes
636 economic, social and environmental sense. Significantly, under the United Nations
637 Framework Convention on Climate Change (UNFCCC) 2013 policy (Decision 2/CMP.7)
638 countries can account for GHG emission sources from wetland drainage as well as C storage
639 via rewetting of wetlands. Following on from the recent COP 21 agreements, critical
640 examination of the efficacy of management guidelines and hydrology policy practices for
641 peatlands to reduce emissions will be crucial for achieving these GHG emission goals (Marti,
642 2008). Such policies would require robust and targeted interventions based on the wealth of
643 recognised scientific understanding (Goldstein, 2015). However, whilst there have been
644 considerable policy developments, notably by the Indonesian Government and a selection of
645 non-state actors, this paper has highlighted the challenges that confront any efforts to
646 implement such a strategy. These include;

647

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

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

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

664

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

671 1) Ideally all degraded peatland should have the hydrology restored to natural
672 conditions, irrespective of the depth of the peat, and the vegetation should be
673 rehabilitated. In light of this, the Indonesian President Joko Widodo is to be
674 commended for his recent proposal to restore 2 million ha of degraded peatlands in
675 Indonesia (The Jakarta Post, 2015b).

676 2) It is vital that the hydrology of intact PSFs should be maintained and buffered from
677 any peripheral drainage activities. Compartmentalizing peat domes should be avoided
678 and conservation areas should ideally cover entire hydrological units.

679 3) Conversion of peatland to agriculture inevitably leads to a myriad of impacts.
680 Consequently, the recommended economic uses should be solely non-drainage
681 options such as paludiculture and financing via REDD+, especially given the

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

686 4) Complete avoidance of peat of any depth for future development alongside the
687 rehabilitation of forest and drainage of all existing developed/degraded peatlands
688 within concessions should be a qualifying element of any sustainable oil palm or
689 acacia certification scheme where any part of the companies' land area is on peat soil.

690 5) Policies in both countries should be strengthened to have consistency between both
691 state and federal levels and a commitment to better enforcement, monitoring and
692 transparency of activities both within and outside concession boundaries.

693 6) Local and International funding options should be provided for the development of
694 research and implementation programmes to support non-drainage paludiculture
695 agriculture, ecotourism, set-aside/rehabilitation programmes and other alternative
696 livelihood strategies for smallholder farmers and local communities living in
697 proximity to peatlands.

698 7) International recognition of the global importance with respect to carbon sequestration
699 and contributions to climate change, transboundary air pollution and loss of
700 endangered species is vital. Recent International collaboration and commitments are
701 commended (Mongabay.com 2016). Yet a fully comprehensive and ongoing
702 commitment is required to remove the drivers of peat development and promote
703 conservation and rehabilitation. Given the financial commitments being made in
704 relation to climate change mitigation, especially in light of the recent COP21
705 negotiations, a global strategy to rehabilitate areas of significant C loss such as these,
706 would be a strategic use of global financial resources and efforts.

707

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