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Is flooding considered a threat in the degraded tropical peatlands?

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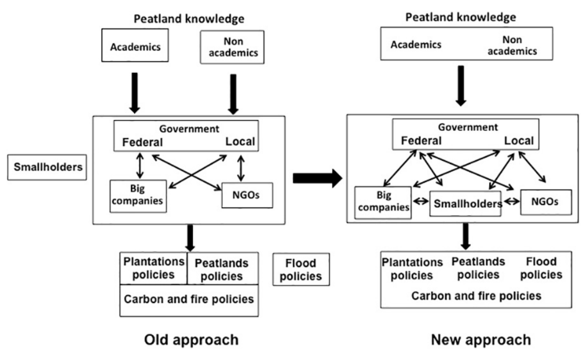
HIGHLIGHTS

- Floods on degraded peatlands should be considered a hazard to the oil-palm industry.
- Peatland policies in SE Asia are largely disconnected from flood considerations.
- Peatland policies should link causes and effects across environmental impacts.

GRAPHICAL ABSTRACT



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ABSTRACT

Tropical peatland degradation due to oil palm plantation development has reduced peat's ability to naturally regulate floods. In turn, more severe and frequent flooding on peatlands could seriously impair plantation productivity. Understanding the roles of peatland ecosystems in regulating floods has become essential given the continued pressure on land resources, especially in Southeast Asia. However, the limited knowledge on this topic has resulted in the oversimplifications of the relationships between floods, commercial plantations and peatland sustainability, creating major disagreement among policymakers at different levels in governments, companies, NGOs and society.

Hence, this study identifies whether flood policies are integrated within peatland management through a qualitative policy analysis of publicly available papers, government reports, and other official documents that discuss flooding, and/or more in general, hydrology in peatlands. Document analysis was then triangulated with data obtained from several semi-structured discussions.

The analysis indicates that the industry on peatlands and the peatland's environmental sustainability could be threatened by increased flooding. We show that, in spite of this, flood policies in SE Asian countries like Malaysia and Indonesia have not been well-integrated into peatland management. We also discuss how the countries could move forward to overcome this problem.

1. Introduction

Peatlands hold ~10% of the global freshwater (Joosten and Clarke, 2002), and have important hydrological functions. They attenuate

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flooding in nearby areas, store water during high-precipitation events (Acreman and Holden, 2013; Gao et al., 2016), contribute to river base flows (Bourgault et al., 2014; Hooijer, 2005), maintain groundwater levels in superficial aquifers (Hooijer, 2005), provides 3.83% of all potable water stored in reservoirs (Xu et al., 2018), and buffers against saltwater intrusion (Hooijer et al., 2012a, 2012b; Silvius et al., 2000). Peatland degradation in the tropics, especially due to plantation development, has impaired the peat's ability to naturally regulate floods (Hooijer et al., 2015a; Sumarga et al., 2016).

Tropical peatlands cover an area 441,025 km^2 (~11% of global peatland area) of which 247,778 km^2 (56%) is in Southeast Asia, with Indonesia and Malaysia having the largest areas (Page et al., 2011). The pressure of economic development has caused large swathes of these peatland forests to be opened-up for plantation industries. In 1990, 76% of SE Asia's peatlands were still covered by forest, with only 11% converted into industrial plantations and smallholder use. However, by 2015, just 29% of the forest remained, and 50% had been converted to plantations (mainly oil palm, OP) and smallholder agriculture (Miettinen et al., 2016).

Even though these industries are important contributors to the countries' GDP (Table 1) and also engines of rural and industrial development, their effects have been negative through biodiversity losses driven by deforestation (Giam et al., 2012; Koh et al., 2011; Posa et al., 2011), carbon loss via oxidation, dissolution and fire (Carlson et al., 2017; Couwenberg et al., 2010; Hirano et al., 2012; Warren et al., 2017). Furthermore, transboundary haze produced by peat fires has impacts on human health, regional economies and ecosystems (Chisholm et al., 2015; Jaafar and Loh, 2014; Marlier et al., 2013; Stockwell et al., 2016).

Partly in response to the rapid development and its related negative impacts, scientists over the last few decades have focused on the importance of peatland from several aspects: ecosystems as carbon sinks (Hergoualc'H and Verchot, 2011; Lawson et al., 2015; Page et al., 2011) and how degradation of these ecosystems (especially via fires) increase carbon emissions (Page et al., 2002; Parker et al., 2016), contributing to climate change and haze (Varkkey, 2016). From a policy point of view, peatland-management policies in SE Asian countries are rather limited as they give significant importance to economic development, and mostly focus on fires and climate change mitigation strategies.

In natural conditions, tropical peatlands are permanently waterlogged. Their conversion to agricultural use requires drainage to increase soil aeration essential for crop production (Comte et al., 2012). However, draining drastically changes peatland hydrology, leading inevitably to peat loss through subsidence and oxidation, and thus reducing the peatland's water-storage capacity (Rieley, 2007; Ritzema, 2007).

Different studies corroborate that subsidence rates in drained tropical peatlands in Malaysia and Indonesia are at about 5 cm per year (Andriesse, 1988; Couwenberg and Hooijer, 2013; DID, 2001; Hooijer et al., 2012a, 2012b; Wösten et al., 1997). Consolidation and compaction are the major contributors to subsidence only in the first years after drainage; after that, the main reason is biological oxidation (Andriesse, 1988; Wösten et al., 1997; Hooijer et al., 2012a, 2012b). Peat loss through oxidation in drained peatland occurs due to lower water table that introduces oxygen into soil. This creates an aerobic environment, which stimulate increased microbial activity that decomposes peat (Hooijer et al., 2012a, 2012b). There is no evidence of a significant slowdown in subsidence rates on the long-term after the first few years, until peat is depleted or mineral content layers are reached (Hooijer et al., 2012a, 2012b; Stephens et al., 1984).

Table 1
Importance of the oil palm industry in Malaysia and Indonesia.

Criteria	Malaysia	Indonesia
Mha planted with oil palm	5.2	12.3
% on peat	13%	25%
% world production	41	46
% GDP	5–6	7
% working population employed in sector	12.2	34.3
% smallholders	39	45
Future expansion plans	5.6Mha, mostly in coastal Sarawak peatlands	15 Mha

Source: World Bank, 2014. World Bank Development Indicators.

Along with the loss of carbon, a major consequence of land subsidence is that drained peatlands can often lower to levels where they become vulnerable to flooding. These events can start well before the peat surface is near river or sea levels, when surface gradients from the peatland towards natural rivers are reduced to the level where additional rainwater can no longer be removed by gravity drainage (Hooijer et al., 2012a, 2012b; Hooijer et al., 2015b). While it is technically feasible to pump excess water out of the plantations once gravity drainage is not possible, it is highly costly (Lim et al., 2012; Roggeri, 1995).

With subsidence, another factor that can increase flooding risk is changes in evapotranspiration rates. This is especially true in young OP that show the lowest values compared to undisturbed forest, due to less water demand by the plant. This leads to higher peat water content, and consequently higher chance of flooding during heavy-rainfall events (Comte et al., 2012; Manoli et al., 2018) (Fig. 1).

Recent model simulation for the Kampar Peninsula in Riau, Indonesia (Hooijer et al., 2015a) showed that already in 2014, 31% of the total peatland area of Acacia plantations affected by poor drainage had either flooding or drainability problems. In the next 25 years, this number could increase by 32–71%, depending on different drainability scenarios. Similarly, in Kalimantan in the Mega Rice Project, near-permanent drainage problems are expected to start for small areas in 25 years, whereas in 100 years' time some 46% of the peat area will be subject to near-permanent flooding (Sumarga et al., 2016). In the Rajang Delta in Sarawak, data showed that ~30% of the peatland area had already high-flood risk in 2009. A 'conservative impact' scenario, assuming no further oil palm expansion beyond 2014 in the area, showed that the flooded areas will increase to 41.9% by 2034, 56% by 2059 and 82% by 2109 (Hooijer et al., 2015b).

Unregulated flooding may not only affect negatively plantations but also villages close to the plantation areas, especially during the wet season (Wells et al., 2016). As water flows directly into the drainage ditches and then out of the peatland, the quantity of water is larger in drained peatlands compared to intact ones (Adnan and Atkinson, 2011; Katimon et al., 2013) (Fig. 1). Surveys of 364 villages conducted in Indonesian Borneo in 2009 and 2012, showed that over the past 30 years, the probability of floods was higher in villages near watersheds with more extensive OP plantations and mines, compared to forested ones (Wells et al., 2016). This is the contrary during the dry season, when the streamflow is lower and drainage canals are closed by the companies resulting in water scarcity and quality problems in some villages (Merten et al., 2016).

Residents living in villages near from plantation areas are usually involved in smallholder activities on peat and are the main workforce for the commercial plantations.

Based on these findings, it is evident that exacerbated flooding on the plantations in these countries can cause OP production losses and reduce the long-term sustainability of the industry. Prolonged waterlogged soil conditions can lead to oxygen and nutrient deficits for the plants causing lower yields, and prolonged inundation lead tree death (Abram et al., 2014).

Increased flooding has negatively affected plantations in Malaysia. In two OP plantations located in the Kedah state, a 7-day flood in 2003 at 25 cm led to an annual productivity loss of 20% (Ahamad et al., 2009). In Johor, during a flood event in 2008, a loss of about 30% was reported (Sabari et al., 2014). In West Kalimantan, Indonesia, Sumarga et al.

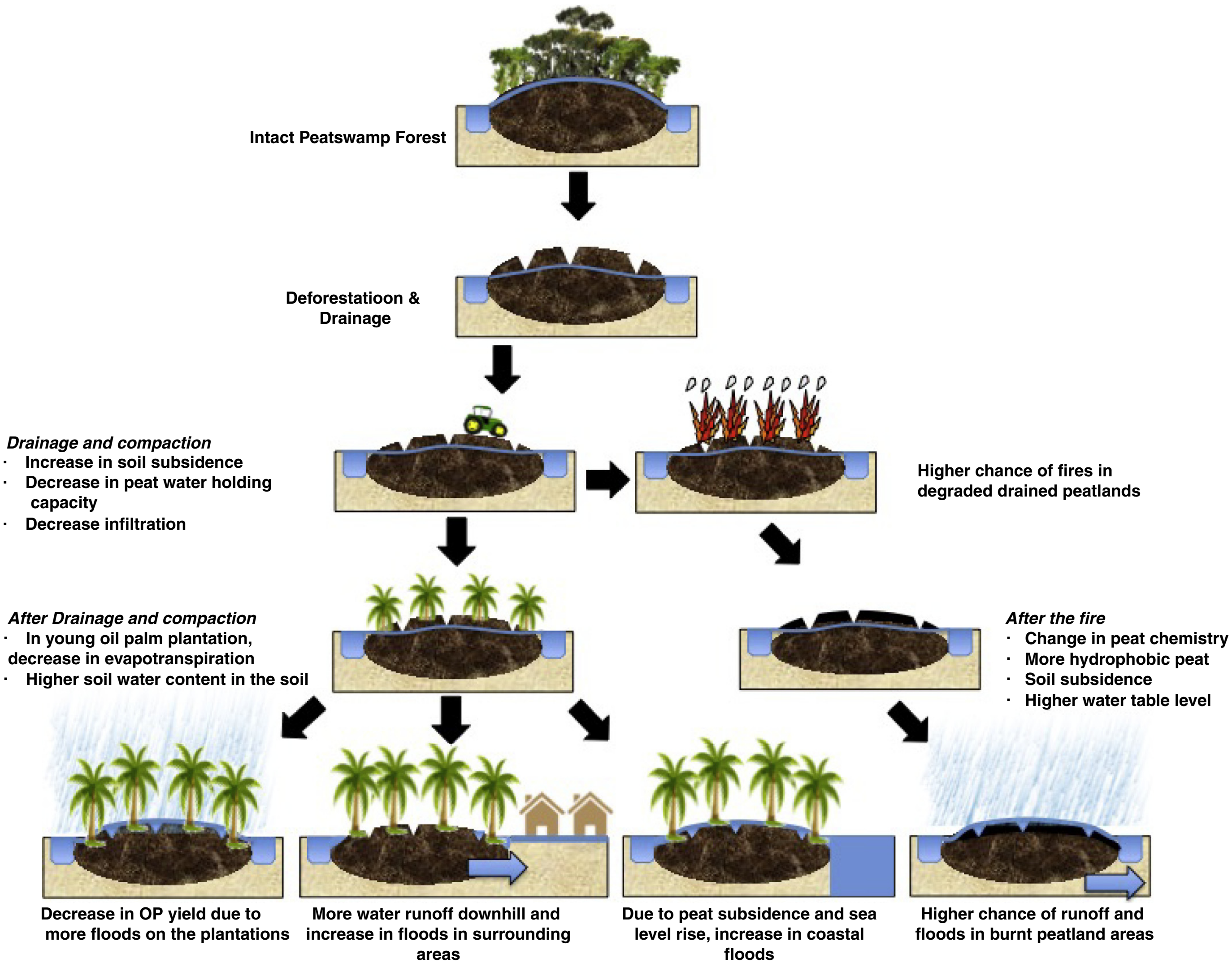

Fig. 1. Schematic of the occurrence of unregulated flood in tropical peatlands areas after change in agricultural land-use.

(2016) predicts a production loss of 50% in the case of annual prolonged flooding, and of 100% in the case of near-permanent inundation.

Flood mitigation measures can be retrospectively implemented after plantation areas are affected by floods. Studies in the floodplains of Sabah (Abram et al., 2014) and Central Kalimantan (Sumarga et al., 2016) found that these measures have been costly and largely ineffective due to the irreversible nature of peat subsidence. This poses a serious financial risk to both the large-scale OP industry and smallholders (where the latter accounts for ~40% of the total planted area, both in Malaysia and Indonesia (Varkkey et al., 2018). In the face of floods, smallholders are unlikely to have the budget or expertise to invest in flood mitigation measures. Larger companies may be able to afford conversion of their inundated areas to different land-uses but elevated costs compared to revenues may not be sustainable into the future (Sumarga et al., 2016), especially considering that flooding could potentially cause the end of agricultural production of 30% to 69% of SE Asian coastal peatlands within 50 years (Hooijer et al., 2012a, 2012b).

While land use change is the main factor affecting flooding risk in drained peatlands, fire, climate change and sea-level rise also exacerbate the problem. Fire is commonly used in SE Asia to clear regrowing vegetation and maintain land for crops (Sanchez et al., 2005). During prolonged dry-conditions associated with the El-Niño, which are expected to increase in the future (Wang et al., 2017), these fires can become more frequent and spread beyond the intended areas (Varkkey, 2016). In burnt degraded peatland, the total flooded area can expand up to five times, as shown in a 2006 study in Indonesia's Jambi province (Wösten et al., 2006).

Mean and extreme precipitation projections for 2100 are expected to increase in SE Asia (Endo et al., 2013), resulting in increased extreme events such as flooding in this region (Hirabayashi et al., 2013). SE Asia is also considered one of the world's most threatened regions in terms of sea-level rise (Nicholls and Cazenave, 2010). Clearly, sea-level rise will affect coastal agriculture through floods and salt-water intrusion. Such problems will be even worse for agriculture developed on peatland because of soil subsidence leading to unsuitable conditions for OP production (Faizal et al., 2013; Hooijer et al., 2012a, 2012b).

Based on the studies mentioned in this section, it is clear that flooding on degraded peatland can represent a major problem. Policymakers, however, do not see it as a potential hazard. Consequently, oversimplifications of the relationship between floods, commercial plantations and peatland sustainability have been a source of major disagreement among policymakers at different levels in governments, companies, environmental groups and society (van Dijk et al., 2009). As a result, peatland policies are largely disconnected from flood hazards considerations.

For the first time, through an in-depth analysis of current flood policies coupled with expert discussions, this study identifies whether flood policies are integrated into peatland management both in Indonesia and Malaysia. It also suggests alternatives on how to better integrate flooding within a broader policy framework tailored for the Anthropocene epoch we live in.

2. Methodology

The method used in this paper is qualitative policy analysis. Policies are frameworks that can optimize the general well-being. A policy analysis framework allows researchers to understand a policy in depth, uncover its (stated and unstated) purpose and objectives, link it to historical or current values and ideologies, and estimate its consequences in terms of economic gains and losses, including rights and privileges. This framework can generally be broken down into five parts, namely (1) defining the problem, (2) assessing policy objectives and its target populations, (3) studying effects of the policy, (4) studying the policy implications, and (5) considering alternative policies (Jimenez et al., 2015).

The paper first defines the problem of floods in peat areas (part 1, introduction). Next, it goes on to assess how floods affect target populations, in this case peat plantations (part 2). It then focuses on the existing flood and peatland management policies, their gaps and implications (part 3 and 4), including that floods have not been adequately recognised. Finally, the paper suggests alternatives (part 5) on how revised policies can better address peatland and flood management concurrently.

Suitable to the policy analysis framework, the main method for this paper has been document analysis and experts' interviews. For document analysis, the main types of documents for this paper were publicly available policy papers, government reports, and other official documents published by relevant organizations that discuss flooding, and/or more in general hydrology, in peatlands (both in English and Bahasa).

The information obtained through the official policy papers and government reports were useful to provide the official stance of the concerned governments (Malaysia and Indonesia) on peatland and flood management (Table 2 and Supplementary Tables 1, 2). Other documents such as reports, strategy papers and studies published by non-

Table 2
Relevant Malaysian and Indonesian policies and legislation to flooding.

Malaysia	Indonesia
1. 8th Malaysia plan	1. 2015–2019 National medium term development plan (Rencana Pembangunan Jangka Menengah Nasional)
2. National land code 1965	
3. National wetlands policy & ramsar site declarations	2. Presidential instruction no. 32 year 1990 on the management of protected areas (Article 9)
4. Water Act 1920	3. Law no. 27 year 2007 on spatial planning
	4. National spatial layout plan 2008 (Rencana Tata Ruang Wilayah Nasional)
	5. Presidential instruction no. 8 year 2015
	6. Presidential instruction no. 6 year 2013
	7. Presidential instruction no. 10 year 2011
	8. Ministry of agriculture decree no. 14 year 2009

Source Malaysia:
1. https://policy.asiapacificenergy.org/node/1281.
2. https://www.ramsar.org/sites/default/files/documents/library/hbk4-02.pdf.
3. http://palmoilis.mpob.gov.my/akta/NLC1956DIGITAL-VER1.pdf.
4. faolex.fao.org › docs › texts › mal33533.
Source Indonesia:
1. https://policy.asiapacificenergy.org/node/3364.
2. http://www.bphn.go.id/data/documents/90kp032.pdf.
3. https://bnpb.go.id/uploads/migration/pubs/3.pdf.
4. https://www.perumnas.co.id/download/prodhukum/pp/PP-26-2008%20RENCANA%20TATA%20RUANG%20WILAYAH%20NASIONAL.pdf.
5. http://www.apbi-icma.org/uploads/files/old/2016/04/Inpres-8-Yr-2015-English-Version-.pdf.
6. http://extwprlegs1.fao.org/docs/pdf/ins160808.pdf.
7. https://forestsnews.cifor.org/3003/indonesia-releases-presidential-instructions-for-logging-moratorium?fnl=en.
8. http://perundangan.pertanian.go.id/admin/p_mentan/Permentan-14-09.pdf.

Table 3
Relevant Malaysian policies and legislation to flooding.

Policies/legislations	Details
8th Malaysia plan	- It mentions the conservations of wetlands (which includes peatlands by definition) in Malaysia's general flood control measures, as part of its Integrated River Basin Management approach (the whole river basin is planned in an integrated manner and all factors are taken into consideration when a certain development plan is proposed)
National wetlands policy & ramsar site declarations	- It is based closely on the 8th Malaysia Plan. - "Continuing to recognize wetlands as unique and critical habitats, as well as their importance in stabilizing water flows and in mitigating floods"
National land code 1965	- "All water bodies must be provided with reserves through a land acquisition process". - Peat is classified as 'rock material' with no discussion of its hydrological function - The National Land Council is empowered to ensure states comply with the Land Code, however there are limitations to this due to the two-tiered government system
Water act 1920	- It imposes licensing requirements for water abstraction, effluent discharge, felling of trees and building of structures, but not for peat areas (which is classified as "rock material") - "where the state Authority is satisfied that the bed of any river in such State is insufficient to contain the waters thereof in time of such floods as may be reasonably expected, he may by notification in the Gazette declare any land abutting on such river and extending to such a distance from either or both banks as may be specified in such notification to be a flood channel for such river, and may at any time in like manner revoke or vary any such declaration".

governmental organizations (NGOs) like the Global Environment Centre (GEC) and international organizations like the United Nations Developmental Programme (UNDP) were useful in filling gaps not available in government documents.

Document analysis was then triangulated with data obtained from several (7) semi-structured discussions via skype or in person with policymakers, representatives from non-governmental organizations and academics working specifically on peatland water management like Global Environment Centre, various relevant state departments, the Malaysian Ministry of Energy, Science, Technology, Environment and Climate Change, Wetlands International Indonesia, Centre for International Forestry Research and several Indonesian universities, supplemented by a search of academic literature. Triangulation is essential in better understanding the circumstances surrounding particular pieces of information, and also to verify the accuracy of the information obtained from all sources. Interviews conducted were both useful in confirming 'objective facts' (Crouch and McKenzie, 2006), understanding the purpose of actions, and to elicit the response of staff and officials towards them. This helps illuminate different aspects of phenomena, enabling richer descriptions (Knowx and Burkard, 2009).

Due to the somewhat sensitive nature of the policies analysed (Table 2 and Supplementary Tables 1, 2), not all the persons with whom we held discussions allowed us to use their real names for this research. We were also unable to engage with stakeholders from the oil palm industry, and hence their input were not able to be included in this paper. Interview data that corroborated directly with data from documentation did not reference the interviewees, but it was used primarily to triangulate and confirm facts. Those interviews that revealed data not found in documentation have been referenced accordingly, either as an anonymous or named source.

3. Results and discussion

3.1. Analysis of current flood policies in peatland management in Malaysia and Indonesia

Flooding from peatland conversion, while problematic, is viewed as a local natural phenomenon linked to the rainy season. Increasing severity of floods is more gradually noticeable only over long periods of time (Rengasamy, 2018). Instead, forest fires have been the most immediate and visible threat and have been a priority of current governments in recent years. Fires cause local and transboundary haze that affect public health within and beyond their borders (Varkkey, 2016). Based on these premises, this study analyses the reasons that have led to the current failure of flood integration in peatland-management policies.

3.1.1. Thematic separation of floods, plantations, and peatlands

Neither in Indonesia nor in Malaysia, major flood-related policies or laws mention the importance of peatlands in flood mitigation.

In Malaysia, the two main laws pertaining to floods are the National Land Code of 1965 and the Water Act of 1920. Neither document mentions the importance of peatlands in flood mitigation or acknowledges peatland's hydrological and flood-mitigation functions. In the 8th Malaysia Plan, peatlands are addressed only indirectly as general flood control as part of the Integrated River Basin Management approach. This has been linked to Malaysia's Ramsar site declaration and it is related to the National Wetlands Policy (DID, 2018) (Table 3).

In Indonesia, flood policy is governed by the Government's 2015–2019 National Medium-Term Development Plan (Djalil, 2014). The Plan focuses on flash-flood management in urban areas but does not consider the role of peatlands in flood mitigation. There are specific

Table 4
Relevant Indonesian policies and legislation to flooding.

Type of policy/legislation	Name	Key messages
General flood	1. 2015–2019 National medium term development plan (Rencana Pembangunan Jangka Menengah Nasional)	It identifies water security as a central pillar and promotes Flood Risk Management to reduce flood damage
Peatland-specific	2. Presidential instruction no. 32 year 1990 on the management of protected areas (Article 9) 3. Law no. 27 year 2007 on spatial planning 4. National spatial layout plan 2008 (Rencana Tata Ruang Wilayah Nasional)	Article 9 states: "The protection of peatland areas are for hydrology control, as it functions as a water catchment and prevents flooding, as well as protecting the special ecosystem in the area" (reiterated in item 2 and 3)
Oil palm-specific	5. Presidential instruction no. 8 year 2015 6. Presidential instruction no. 6 year 2013 7. Presidential instruction no. 10 year 2011 8. Ministry of agriculture decree no. 14 year 2009	Item 1, 2 and 3 focus on the 2 year moratorium of new concessions. Item 4 restricts palm oil cultivation to areas with peat depth of less than 3 m. However, none make a clear link between peatlands and flood control.

regulations on OP development on peatland that recognize their importance in flood regulation. However, they do not include a direct linkage to flood policies (e.g. Presidential Instruction No. 32 Year of 1990) (Table 4) as reiterated in other official documents (e.g. State of Indonesia's Forest Report 2018, Strategy Paper 2016–2020; policies and laws in Supplementary Table 1).

These flood-related policies are also not coordinated with policies related to OP-development on peatland, resulting in conflicting approaches to hydrological management. Guidelines on drainage, fire management, and compaction, where they exist (Ministry of Natural Resources and Environment, 2011, PP 57/2016), do not consider how these practices affect flood regulation on peatlands.

Looking at important peatland policies such as the forest moratorium, the latest extension, INPRES 5/2019, includes no more granting permits issued on forest-clearing for plantations and logging. Nevertheless, there is no mention of water tables or floods.

The importance of the peatland "hydrological function" is mentioned in the new regulation PermenLHK10/2019 issued by the Ministry of Environment and Forestry (MOEF) of Indonesia, which serves as technical guidelines for the integration of the efforts to conserve and manage the function of damaged peatland ecosystems. Under the regulation though, concession holders are now only required to operate on peat domes landscapes, where the peat layer is so thick that the centre is topographically higher than the edges. While the new regulation does not specifically reference the importance of peatlands in regulating floods, it mentions that management of peat domes will consider water carrying capacity of the ecosystem based on water balance calculations. Another interesting point in this regulation, is that it mentions that, if there is more than one peat dome within a hydrological unit, the same peat dome can be exploited if its hydrological function can be replaced by other peat domes. In the areas where permits have been issued, it is the responsibility of the permit holder to maintain the hydrological function of peat domes, which involves monitoring water table levels but not floods specifically, and conduct restoration, if necessary, once the permits expire. Overall, the problem with this new regulation is that concession holders can continue to exploit the peat dome in their concessions as long as there is more than one "top" or peak and manage the water level. Under previous regulations, peatlands that were 3 m deep or more were prohibited for exploitation, and any companies with such areas in their concessions were obliged to restore and protect them. With this new regulation, these peatlands areas are now open to exploitation, as long as they are not considered part of the peat dome (Jong, 2019). It is evident that protecting only the peat domes is not enough to prevent the entire peat hydrological areas from being drained, and that this perpetuates the current problems described earlier.

Generally, policymakers are not fully aware of the relation between hydrology and forests, and the meaning of this linkage for climate, forest, water and socio-economic development (at both local and national scales) (Ellison et al., 2017). Thus, policies and regulations related to peatland development are disconnected from, and confined within their own thematic sectors (e.g. peatland-specific vs. OP-specific), which often result in conflicts among them. Lack of coordination between government sectors, together with overlap and even rivalry among institutions managing water, forest and peatlands mean that appropriate policies are not always formulated, much less implemented (Wishart, 2017). The two-tiered governance systems in both Malaysia and Indonesia further complicate decision-making. These are explained below.

3.1.2. Two-tiered governance systems

Both Malaysia and Indonesia have two-tiered governance systems, where powers are separated between the central and state levels. In Malaysia, the Ninth Schedule of the Malaysian Constitution provides for the general distribution of legislative powers between federal and state governments, with the individual states retaining the power to formulate their own policies related to natural resources such as water (Hezri and Nordin Hasan, 2006). Furthermore, the states of Sarawak and Sabah have also been granted special conditions under the 1963 Malaysia Agreement (Cooke, 1997), and they are free to interpret national policies and declarations on natural resources as they choose. This explains the vastly different approaches to water management in the peatland-rich states of Sarawak, Pahang, Selangor, Johor, and Sabah. For example, Selangor (with 7.5% of Malaysian peatlands) is considered a success story in sustainable peatland management. It clearly acknowledges the importance of peatlands in flood regulation. In 2010, Selangor declared a moratorium on all logging activity on peatlands in the state as drainage, required for logging, causes peat oxidation and makes the soil susceptible to fires and floods (Rengasamy, 2018). At the same time, the state encouraged continuous rehabilitation programmes and activities to be carried out in the degraded peatlands under permanent reserved forest. It is currently the only state to have such a moratorium. Furthermore, the state's own Integrated Peatland Management Plan 2014–2023 for the North Selangor Peatswamp Forest, one of the biggest peatland areas in the state, identify key practices of flood regulation (Dahalan, 2018).

Instead, in Sarawak (with 63% of Malaysia's peatlands) there is a strong push for development of its peatlands into OP-plantations. The state is generally not in agreement with the Ramsar approach of imputing high importance on peatlands for flood regulation. Furthermore, unlike other states, soil-type (including peatlands) is not given much consideration during the zoning process (Anonymous, 2018). This also reflects the problem of thematic separation as described above. As a result, up to 300,000 ha of peatlands have being zoned for development of OP-plantation and other crops along the state's coastal zone by 2020 (DID, 2018). Although a moratorium to prevent conversion of new forests into large-scale OP plantations has been recently announced, the authors were unable to find this translated into formal policy. This is especially worrying considering that coastal peatlands are highly susceptible to sea-rise. Furthermore, when these areas are drained for development, Sarawak is not obliged to follow the National Environmental Quality order [1987, 4.3], which calls for an environmental impact assessment for the development of areas over 100 ha.

In Indonesia, although the central government maintains decision-making power on 'policies on natural resources utilisation' [Article 7, Regional Autonomy Law No 22/1999], the management of these policies remains with the local government [Article 10, Regional Autonomy Law] (Rajenthran, 2002). This is the case for flood regulation in peatlands, which is recognised in national policies and strategies (Tables 3 and 4), but implementation is left to the local government. Problems arise when local governments have differing priorities; in this case, fire management over flood regulation resulted in local policies being developed and implemented in relation to fire-only, as in the Riau and Jambi provinces (Supplementary Table 2). There are no local laws pertaining to flood regulation on peatlands, highlighting the gap between legislation at the national level and implementation at the local level.

Local policies in Indonesia have focused on fire suppression instead of preventive measures (Varkkey, 2016). Regulating floods is also an important preventive strategy to reduce fire risks, but this would entail limiting plantations on peatlands and thus to reduce the degradation they cause, which would further call for a more moderate economic strategy. This, however, is not encouraged with decentralised governance because local administrations are responsible for most of their own administrative budgets. Issuing new plantation permits and licenses represent a strategy to fill regional government coffers (Duncan, 2007; McCarthy et al., 2012). Hence, preventive strategies, including fire and flood regulation, which limit commercial expansion, would in turn limit potential revenue for local authorities.

Many of the differences in peatland management approaches can be traced back to the different sources of 'horizontal knowledge' (the process of learning and gaining knowledge that is applicable across various domains and scenarios), or other voices beyond academia that have been most influential in the shaping of policy in these states. This is discussed below.

3.1.3. Horizontal knowledge for short-term gains

In newly democratic countries, there are now a plurality of environmental knowledge producers that have a voice in shaping policies, such as those related to land, but do not necessarily come from the academic world (Goldstein, 2016). While this can be positive, as it provides a diversity of views, it can also result in policies shaped by short-term economic interests.

The academic work on floods in peatlands is relatively scattered and limited compared to other topics like carbon storage and fires. This implies that with limited knowledge of the understanding of the effects of peatland flooding, some stakeholders may differentially utilise scientific knowledge in pursuit of their own self-interests and in the shaping of land-policies.

In Sarawak, most knowledge used to shape peatland-related policies is developed by scientists based in the Tropical Peat Research Institute (TROPI) funded by the state government. The local institute only recommends avoiding the development of areas, which are already prone to periodic flooding, to minimise the costs and management time involved in flood mitigation (Melling et al., 2011). In this business-as-usual scenario, there is little consideration of the likelihood that more areas will be flooded in the future. This prioritization of "local" knowledge has led to many of the federal-level peatlands policies and plans being deemed 'not relevant' for Sarawak because of the supposed 'uniqueness' of Sarawak's peatlands (Anonymous, 2018).

Hydrology and flood mitigation fall within the remit of Sarawak's Department of Irrigation and Drainage (DID). The DID's influence is limited to retrospective involvement. While the DID is well aware of the importance of pristine peatlands for flood regulation, it is unable to recommend its non-development as the state has identified peatland development as an important strategy to improve the Sarawak people's welfare. The DID can only advise the State Planning Authority on how to mitigate floods that are likely occur into a potential project area (Anonymous, 2018). To this end, the DID has developed water management practices for agricultural development on peat but they are limited to preventing floods through timely drainage of excess rainfall (DID, 2018). They do not, however, address peat development in the interest of long-term flood mitigation and agricultural sustainability.

In Indonesia, interestingly, horizontal knowledge has not been a major factor guiding policy (at least for peatland-related policies). Much of the knowledge adopted by policymakers has been in line with mainstream academia. For example, a National Peatland Management Working Group Report includes the benefits of flood management and climate change mitigation among the benefits of intact peatlands, a contribution by the academia (Ministry of Home Affairs, 2006). Most recently, the Peatland Restoration Agency's Strategy Paper 2016–2020 identified peatland degradation as a major factor in the recent increase of flood occurrences, and listed floods as a 'threat' in its SWOT analysis (Supplementary Table 1). In addition, in a clear effort to make the industry's voice more influential in policymaking, the Indonesian Palm Oil Producers Association has invited TROPI scientists to meet Indonesian ministers to advise on peat-management policy (Wardhana, 2016).

3.2. Connecting flooding and peatland management policies

This analysis compiled policy evidence that indicates a lack of integration of flood policies into peatland management. This is summarised in our SWOT analysis (Table 5).

Policymakers still require the appropriate understanding of flood mitigation services in the sense that intact peatlands benefit populations well beyond the local or catchment scale, often far from where actual decisions on development and/or conservation are made. There is an urgent need to seamlessly combine good hydrological-management to mitigate floods with land-management policies, especially considering the upward trajectory of the OP plantation sector in these countries (Varkkey et al., 2018).

This study suggests a policy design and implementation that is suited to the Anthropocene epoch we live in, where policies should link across boundaries and themes (e.g. floods, plantations, and peatlands) to avoid potential conflicts in the present and the future (Sterner et al., 2019). Current thematically separated policies tackle one problem, or dimension, but often lead to secondary consequences somewhere else (e.g. plantation policies that lead to unregulated flooding). A win-win approach would be to acknowledge the dynamic aspects of a socio-ecological system (stakeholders and peatlands) where variation and connectivity, as well as processes with different timescales and feedback mechanisms are included (e.g. drainage-subsidence-fire-floods).

Despite the complexity of such an approach, there are numerous well-known policy instruments (e.g. subsidies, tariffs, zoning, green certifications etc.) that would be operational at both local and national levels to ensure not only efficient outcomes but also jurisdiction and governance (Sterner et al., 2019). The task of policymakers is not to create completely new approaches, but to design and implement suitable policies within specific societal, political and scientific contexts. The knowledge that informs such policies should not be confined to certain

Table 5
SWOT analysis of the current Indonesian and Malaysian policies on floods and peatlands.

STRENGHTS	OPPORTUNITIES
- Some floods acknowledgment by BRG or Selangor state - Indirect benefits on water management from other policies on fire and carbon	- Combine hydrological-management to mitigate floods with land-management policies - Acknowledge the dynamic aspects of a socio-ecological system (stakeholders and peatlands) - Design and implement suitable policies within specific societal, political and scientific contexts - Consultation of different knowledge producers prior to policy development - Account for the diverse range of players in peatland management - Account for potential costs of non-development and downstream benefits
WEAKNESSES	**THREATS**
- No clear mention of floods as a potential threat - No direct linkages between floods, peatlands, OP - Lack of awareness of the problem by policy makers - Lack of coordination between government sectors - Ambiguous language in current policies - Conflicting approaches to hydrological management - Peatlands benefits poor understood - More science needed	- Difficulty of interdisciplinary work to solve the problem - Resistance to change environmental practices - Loss of political interest - Competing interests - Misuse of current knowledge - Decision-making at the national level vs. implementation at the local level - Lack of a long-term policy vision

voices such as policymakers, private sector or the academia. A variety of knowledge producers such as national- and state-level government institutions, academia, private sector, NGOs, should be consulted and comprehensively considered prior to policy development.

Specifically, peatland development policies should sufficiently account for the diverse range of players they affect and the problems they face. For example, while peatland-related policies mainly focus on large OP-plantations, many times, policymakers forego generalised approaches and devise strategies that consider, if only partially, the needs of certain stakeholders such as smallholders (Fan et al., 2013).

Along with policies targeted at peatland players, policies should be designed and implemented to be enforceable, especially at the state and local levels (e.g. the strictly-enforced logging moratorium by the Selangor State Forestry Department detailed above). Even though many local administrations prioritise economic development on peatlands, trade-offs should be taken into account (e.g. costs of non-development and downstream or downwind benefits) (Ellison et al., 2017).

With respect to decentralisation, this study suggests revisiting the flood governance framework in order to ensure more checks and balances in decision-making including efficient monitoring and greater transparency. Even though peatland development for OP is permissible under present policies, and formal approvals can be easily obtained from various government agencies, a reassessment is required as it is evident that present practices have contributed to serious degradation and flooding (CPPS, 2017). Current legislation in Malaysia for example, does allow for such retrospective considerations, particularly at the state level (e.g. Water Act 1920; Table 3).

4. Conclusions

This analysis highlights the importance of integrating flooding into peatland management policies as they can affect livelihoods of populations living near the plantations and oil palm production. Failure of implementation of ad hoc peatland flood policies is due to a lack of a complete understanding of peatland processes. While participation of a variety of knowledge producers is positive, it is also important to acknowledge that many times their voices are contrasting, creating the lack of common understand that this necessary. Furthermore, separation by thematic sector between peatlands, plantations and flood policies does not acknowledge the intersection between the three, denying the potential cascading effects that one action in a sector can have on the others. Additionally, decentralisation of the governments in Malaysia and Indonesia further complicates decision-making, allowing a diversity of interests that can result in policies focusing in short-term economic profits rather than a long-term vision.

Future policies should have a more holistic approach that recognises the dynamic aspects of socio-ecological systems and which includes all the players in the government, industry, and society, with a common vision, and that is backed up by more effective law-enforcement and greater disclosure of information required by all stakeholders in service of collective action.

To our knowledge, this is the first study that analyses flood policies within peatland management, although with certain limitations. While we analysed major policy documents and official reports both in English and Bahasa, other important material might be available at the provinces level. However, their access can be difficult as both Indonesia and Malaysia are still moving towards having government official documents on line. Furthermore, our analysis lacks an open discussion with officials from the oil palm industry, whom potentially could have contributed to shape this study in another direction.

Under prevailing conditions, it is evident that agriculture on peatlands that face increasingly unregulated floods cannot be sustainable over the long-term, even with currently promoted best management practices. While we acknowledge that economic development cannot and should not be stopped, and that adequately addressing all the themes discussed in the paper is challenging, there is urgency for action, and complexity is no excuse. To overcome this problem, intersectoral, intergovernmental and interdisciplinary collaboration is needed among stakeholders at all levels of policymaking and implementation.

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Credit authorship contribution statement

Massimo Lupascu: Conceptualization, Data curation, Formal analysis, Writing - original draft. **Helena Varkkey:** Data curation, Formal analysis, Writing - original draft. **Cecilia Tortajada:** Formal analysis, Writing - original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Abram, N.K., Xofis, P., Tzanopoulos, J., MacMillan, D.C., Ancrenaz, M., Chung, R., Peter, L., Ong, R., Lackman, I., Goossens, B., Ambu, L., Knight, A.T., 2014. Synergies for improving oil palm production and forest conservation in floodplain landscapes. PLoS One 9, e95388.

Acreman, M., Holden, J., 2013. How wetlands affect floods. Wetlands 33, 773–786. https://doi.org/10.1007/s13157-013-0473-2.

Adnan, A.N., Atkinson, P.M., 2011. Exploring the impact of climate and land use changes on streamflow trends in a monsoon catchment. Int. J. Climatol. 31, 815–831. https://doi.org/10.1002/joc.2112.

Ahamad, M.S.S., Ali, R., Zakaria, N.A., Ghani, A.A., Chang, C.K., 2009. Flood loss assessment of the 2003 Muda river flood. River 2011: Third International Conference on Managing Rivers in the 21st Century, Penang, Malaysia, 6–9 December 2009.

Andriesse, J., 1988. Nature and Management of Tropical Peat Soils. Rome, Italy.

Anonymous, 2018. Personal Communication, Department of Irrigation and Drainage, Sarawak, 10 June.

Bourgault, M., Larocque, M., Roy, M., 2014. Simulation of aquifer–peatland–river interaction under climate change. Hydrol. Res. 45, 425–440. https://doi.org/10.2166/nh.2013.228.

Carlson, K.M., Heilmayr, R., Gibbs, H.K., Noojipady, P., Burns, D.N., Morton, D.C., Walker, N.F., Paoli, G.D., Kremen, C., 2017. Effect of oil palm sustainability certification on deforestation and fire in Indonesia. Proc. Natl. Acad. Sci. 115, 201704728. https://doi.org/10.1073/pnas.1704728114.

Chisholm, R.A., Wijedasa, L.S., Swinfield, T., 2015. The need for long-term remedies for Indonesia's forest fires. Conserv. Biol. 30, 5–6. https://doi.org/10.1111/cobi.12662.

Comte, I., Colin, F., Whalen, J.K., Grüberger, O., Caliman, J.-P., 2012. Agricultural practices in oil palm plantations and their impact on hydrological changes, nutrient fluxes and water quality in Indonesia: a review. Advanced Agronomy, pp. 71–124.

Cooke, F., 1997. The politics of “sustainability” in Sarawak. J. Contemp. Asia 27, 217–241.

Couwenberg, J., Hooijer, A., 2013. Towards robust subsidence-based soil carbon emission factors for peat soils in south-east Asia, with special reference to oil palm plantations. Mires Peat 12.

Couwenberg, J., Dommain, R., Joosten, H., 2010. Greenhouse gas fluxes from tropical peatlands in south-east Asia. Glob. Chang. Biol. 16, 1715–1732. https://doi.org/10.1111/j.1365-2486.2009.02016.x.

CPPS, 2017. Policy Fact Sheet: Malaysia's Flood Management. Kuala Lumpur, Malaysia.

Crouch, M., McKenzie, H., 2006. The logic of small samples in interview-based qualitative research. Soc. Sci. Inf. 45, 483–499. https://doi.org/10.1177/0539018406069584.

Dahalan, M.P., 2018. Personal Communication, Selangor State Forestry Department, 7 June.

DID, 2001. Water Management Guidelines for Agricultural Development in Lowland Peat Swamps of Sarawak. Sarawak, Malaysia.

DID, 2018. Water Management Guidelines for Agriculture Development in Lowland Peat Swamps of Sarawak (Sarawak, Malaysia).

Djalil, S.A., 2014. Rencana Pembangunan Jangka Menengah Nasional 2015–2019 (Jakarta).

Duncan, C., 2007. Mixed outcomes: the impact of regional autonomy and decentralization on indigenous ethnic minorities in Indonesia. Dev. Chang. (4), 711–733.

Ellison, D., Morris, C.E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., Gutierrez, V., Noordwijk, M. van, Creed, I.F., Pokorny, J., Gaveau, D., Spracklen, D.V., Tobella, A.B., Ilstedt, U., Teuling, A.J., Gebrehiwot, S.G., Sands, D.C., Muys, B., Verbist, B., Springgay, E., Sugandi, Y., Sullivan, C.A., 2017. Trees, forests and water: cool insights for a hot world. Glob. Environ. Chang. 43, 51–61. https://doi.org/10.1016/j.gloenvcha.2017.01.002.

Endo, H., Kitoh, A., Ose, T., Mizuta, R., Kusunoki, S., 2013. Future changes and uncertainties in Asian precipitation simulated by multiphysics and multi-sea surface temperature ensemble experiments with high-resolution Meteorological Research Institute atmospheric general circulation models (MRI-AGCMs). J. Geophys. Res. Atmos. 118, 2303. https://doi.org/10.1002/jgrd.50267.

Faizal, M., Baharuddin, T., Taib, S., 2013. Assessment of seawater intrusion to the agricultural sustainability at the coastal area of Carey Island, Selangor, Malaysia. Arab. J. Geosci. 6, 3909–3928. https://doi.org/10.1007/s12517-012-0651-1.

Fan, S., Brzeska, J., Keyzer, M., Halsema, A., 2013. From Subsistence to Profit: Transforming Smallholder Farms. Washington DC, USA.

Gao, J., Holden, J., Kirkbv, M., 2016. The impact of land-cover change on flood peaks in peatland basins. Water Resour. Res. 52, 3477–3492. https://doi.org/10.1002/2015WR017667.

Giam, X., Koh, L., Tan, H.H., Miettinen, J., Tan, H.T.W., Ng, P., 2012. Global extinctions of freshwater fishes follow peatland conversion in Sundaland. Front. Ecol. Environ. 10, 465–470.

Goldstein, J.E., 2016. Knowing the subterranean: land grabbing, oil palm, and divergent expertise in Indonesia's peat soil. Environ. Plan. 48, 754–770. https://doi.org/10.1177/0308518X15599787.

Hergoualc'H, K., Verchot, L.V., 2011. Stocks and fluxes of carbon associated with land use change in Southeast Asian tropical peatlands: a review. Glob. Biogeochem. Cycles 25. https://doi.org/10.1029/2009GB003718.

Hezri, A., Nordin Hasan, M., 2006. Towards sustainable development? The evolution of environmental policy in Malaysia. Nat. Res. Forum 30, 37–50. https://doi.org/10.1111/j.1477-8947.2006.00156.x.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., Kanae, S., 2013. Global flood risk under climate change. Nat. Publ. Group 3, 816–821. https://doi.org/10.1038/nclimate1911.

Hirano, T., Segah, H., Kusin, K., Limin, S., Takahashi, H., Osaki, M., 2012. Effects of disturbances on the carbon balance of tropical peat swamp forests. Glob. Chang. Biol. 18, 3410–3422. https://doi.org/10.1111/j.1365-2486.2012.02793.x.

Hooijer, A., 2005. Hydrology of tropical wetland forests: recent research results from Sarawak peatswamps. In: Bonell, M., Bruijnzeel, L.A.E. (Eds.), Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management, International Hydrology Series. Cambridge University Press, pp. 447–461. https://doi.org/10.1017/CBO9780511535666.023.

Hooijer, A., Page, S., Jauhiainen, J., Lee, W.A., Lu, X.X., Idris, A., Anshari, G., 2012a. Subsidence and carbon loss in drained tropical peatlands. Biogeosciences 9, 1053–1071. https://doi.org/10.5194/bg-9-1053-2012.

Hooijer, Aljosja, Triadi, B., Karyanto, O., Page, S.E., van der Vat, M., Erkens, G., 2012b. Subsidence in drained coastal peatland in SE Asian: implications for sustainability. Proceedings of the 14th International Peat Congress. Stockholm, Sweden, pp. 1–8.

Hooijer, A., Vernimmen, R., Mawdsley, N., Page, S., Mulyadi, D., Visser, M., 2015a. Assessment of impacts of plantation drainage on the Kampar Peninsula peatland, Riau. Deltares Report 1207384 to Wetlands International, CLUA and Norad.

Hooijer, A., Vernimmen, R., Visser, M., Mawdsley, N., 2015b. Flooding Projections from Elevation and Subsidence Models for Oil Palm Plantations in the Rajang Delta Peatlands, Sarawak, Malaysia. (Deltares Report 1207384).

Jaafar, Z., Loh, T., 2014. Linking land, air and sea: potential impacts of biomass burning and the resultant haze on marine ecosystems of Southeast Asia. Glob. Chang. Biol. 20, 2701–2707.

Jimenez, J., Pasztor, E.M., Chambers, R.M., Fuji, C.P., 2015. Social Policy and Social Change: Toward the Creation of Social and Economic Justice. 2nd ed. SAGE, Long Beach, California.

Jong, H.N., 2019. 'Dangerous' new regulation puts Indonesia's carbon-rich peatlands at risk. Mongabay News.

Joosten, H., Clarke, D., 2002. Wise Use of Mires and Peatlands. International Mire Conservation Group and International Peat Society.

Katimon, A., Shahid, S., Wahab, A.K.A., Ali, M.H., 2013. Hydrological behaviour of a drained agricultural peat catchment in the tropics. 1: rainfall, runoff and water table relationships. Hydrol. Sci. J. 58, 1297–1309. https://doi.org/10.1080/02626667.2013.815759.

Knowx, S., Burkard, A.W., 2009. Qualitative research interviews. Psychother. Res. Method 30, 566–575. https://doi.org/10.1080/10503300802702105.

Koh, L.P., Miettinen, J., Liew, S.C., Ghazoul, J., 2011. Remotely sensed evidence of tropical peatland conversion to oil palm. Proc. Natl. Acad. Sci. U. S. A. 108, 5127–5132. https://doi.org/10.1073/pnas.1018776108.

Lawson, I.T., Kelly, T.J., Aplin, P., Boom, A., Dargie, G., Draper, F.C.H., Hassan, P.N.Z.B.P., Kaduk, J., Large, D., Murphy, W., Tansey, K., Waldram, M., Page, S.E., Roucoux, K.H., Sjo, S., Wedeux, B.M.M., Wheeler, J., 2015. Improving estimates of tropical peatland area, carbon storage, and greenhouse gas fluxes. Wetl. Ecol. Manag. 23, 327–346. https://doi.org/10.1007/s11273-014-9402-2.

Lim, K.H., Lim, S.S., Parish, F., Suharto, R., 2012. RSPO Manual on Best Management Practices (BMPs) for Existing Oil Palm Cultivation on Peat. RSPO, Kuala Lumpur, Malaysia.

Manoli, G., Meijide, A., Huth, N., Knohl, A., Kosugi, Y., Burlando, P., Ghazoul, J., Fatichi, S., 2018. Ecohydrological changes after tropical forest conversion to oil palm. Environ. Res. Lett. 13. https://doi.org/10.1088/1748-9326/aac54e.

Marlier, M.E., DeFries, R.S., Voulgarakis, A., Kinney, P.L., Randerson, J.T., Shindell, D.T., Chen, Y., Faluvegi, G., 2013. El Niño and health risks from landscape fire emissions in Southeast Asia. Nat. Clim. Chang. 3, 131–136. https://doi.org/10.1038/nclimate1658.

McCarthy, J., Gillespie, P., Zen, Z., 2012. Swimming upstream: local Indonesian production networks in "globalized" palm oil production. World Dev. 40, 555–569.

Merten, J., Roll, A., Guillaume, T., Meijide, A., Tarigan, S., Agusta, H., Dislich, C., Dittrich, C., Faust, H., Gunawan, D., Hein, J., Hendrayanto, Knohl, A., Kuzyakov, Y., Wiegand, K., Hölscher, D., 2016. Water scarcity and oil palm expansion: social views and environmental processes. Ecol. Soc. 21. doi:https://doi.org/10.5751/ES-08214-210205

Melling, L., Chua, K.H., Lim, K.H., 2011. Agro-management of peat soils under oil palm in Sarawak. In: Goh, K.J., Chiu, S.B., Paramananthan, S. (Eds.), In: Agronomic Principles And Practices Of Oil Palm Cultivation, pp. 695–728.

Miettinen, J., Shi, C., Liew, S.C., 2016. Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990. Glob. Ecol. Conserv. 6, 67–78. https://doi.org/10.1016/j.gecco.2016.02.004.

Ministry of Home Affairs, 2006. Kelompok Kerja Pengelolaan Lahan gambut Nasional. Strategi dan Rencana Nasional Pengelolaan Lahan Gambut Berkelanjutan. Jakarta: Kementerian Dalam Negeri. Kementerian Dalam Negeri, Jakarta.

Ministry of Natural Resources and Environment, 2011. National action plan for peatlands [WWW document]. URL. http://www.nre.gov.my/ms-my/PustakaMedia/Penerbitan/National Action Plan for Peatlands.pdf.

Nicholls, R.J., Cazenave, A., 2010. Sea-level rise and its impact on coastal zones. Science 328. https://doi.org/10.1126/science.1185782 (80-.).

Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.V., Jaya, A., Limin, S., 2002. The Amount of Carbon Released From Peat and Forest Fires in Indonesia during 1997. 1999, pp. 61–65.. https://doi.org/10.1038/nature01141.1.

Page, S.E., Rieley, J.O., Banks, C.J., 2011. Global and regional importance of the tropical peatland carbon pool. Glob. Chang. Biol. 17, 798–818. https://doi.org/10.1111/j.1365-2486.2010.02279.x.

Parker, R.J., Boesch, H., Wooster, M.J., Moore, D.P., Webb, A.J., Gaveau, D., 2016. Atmospheric CH4 and CO2 enhancements and biomass burning emission ratios derived from satellite observations of the 2015 Indonesian fire plumes. Atmos. Chem. Phys. 16, 10111–10131. https://doi.org/10.5194/acp-16-10111-2016.

PermenLHK10/2019, 2019. Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia,Tentang Penentuan, Penetapan dan Pengelolaan Puncak Kubah GambutBernasis Kesatuan Hidrologis Gambut.

Posa, M., Wijedasa, L., Corlett, R., 2011. Biodiversity and conservation of tropical peat swamp forests. Bioscience 61, 49–57.

PP, 2016. Perubahan Atas Peraturan Permerintah Nomor 71 Tahun 2014 Tentang Perlidugan dan Pengelolaan Ekosistem Gambut.

Rajenthran, A., 2002. Indonesia: an overview of the legal framework of Foreign Direct Investment. Paper Presented at the ISEAS Working Papers: Economics and Finance, 849 Singapore.

Rengasamy, N., 2018. Personal Communication, Global Environment Centre, 28 June.

Rieley, J.O., 2007. Tropical peatland – the amazing dual ecosystem: coexistence and mutual benefit. Proceedings of the International Symposium and Workshop on Tropical Peatland. EU CARBOPEAT and RESTORPEAT Partnership, Gadjah Mada Universit, pp. 1–14.

Ritzema, H., 2007. The role of drainage in the wise use of tropical Peatlands. Proceedings of the International Symposium and Workshop on Tropical Peatland Yogyakarta, Indonesia.

Roggeri, H., 1995. Tropical Freshwater Wetlands. Springer, Dordrecht, the Netherlands https://doi.org/10.1007/978-94-015-8398-5.

Sabari, N.S., Harun, S., Ahmad, A., 2014. The effect of flood hazard on palm oil yield in Sungai Simpang Kiri Estate. The 13th International Conference on Urban Drainage. Sarawak, Malaysia, 7–12 September 2014.

Sanchez, P.A., Cheryl, A., Palm, S.A.V., Tomich, T.P., Kasyok, J., 2005. The problem and approach. In: Palm, C.A., Vosti, S.A., Sanchez, P.A., Ericksen, P.J. (Eds.), Slash-and-Burn Agriculture: The Search for Alternatives. Columbia University Press, New York, NY, USA, p. 488.

Silvius, M., Oneka, M., Verhagen, A., 2000. Wetlands: lifeline for people at the edge. Phys. Chem. Earth 645–652.

Stephens, J.C., Allen, L.H., Chen, E., 1984. Organic soil subsidence. Geol. Soc. Am. Rev. Eng. Geol. 6, 107–122.

Sterner, T., Barbier, E.B., Bateman, I., van den Bijgaart, I., Crépin, A.-S., Edenhofer, O., Fischer, C., Habla, W., Hassler, J., Johansson-Stenman, O., Lange, A., Polasky, S., Rockström, J., Smith, H.G., Steffen, W., Wagner, G., Wilen, J.E., Alpízar, F., Azar, C., Carless, D., Chávez, C., Coria, J., Engström, G., Jagers, S.C., Köhlin, G., Löfgren, Å., Pleijel, H., Robinson, A., 2019. Policy design for the Anthropocene. Nat. Sustain. 2, 14–21. https://doi.org/10.1038/s41893-018-0194-x.

Stockwell, C.E., Jayarathne, T., Cochrane, M.A., Ryan, K.C., Putra, E.I., Saharjo, B.H., Nurhayati, A.D., Albar, I., Blake, D.R., Simpson, I.J., Stone, E.A., Yokelson, R.J., 2016.

Field measurements of trace gases and aerosols emitted by peat fires in Central Kalimantan, Indonesia, during the 2015 El Niño. Atmos. Chem. Phys. 16, 11711–11732. https://doi.org/10.5194/acp-16-11711-2016.
Sumarga, E., Hein, L., Hooijer, A., Vernimmen, R., 2016. Hydrological and economic effects of oil palm cultivation in Indonesian peatlands. Ecol. Soc. 21. https://doi.org/10.5751/ES-08490-210252.
van Dijk, A., van Noordwijk, M., Calder, I.R., Bruijnzeel, S., Schellekens, J., Chappell, N., 2009. Forest flood relation still tenuous-comment on 'Global evidence that deforestation amplifies flood risk and severity in the developing world' by CJA Bradshaw, NS Sodhi, KS-H Peh and BW Brook. Glob. Chang. Biol. 15, 110–115.
Varkkey, H., 2016. The Haze Problem in Southeast Asia: Palm Oil and Patronage. Routledge, London and New York.
Varkkey, H., Tyson, A., Choiruzzad, S.A.B., 2018. Palm oil intensification and expansion in Indonesia and Malaysia: environmental and socio-political factors influencing policy. Forest Policy Econ. 92, 148–159. https://doi.org/10.1016/j.forpol.2018.05.002.
Wang, G., Cai, W., Gan, B., Wu, L., Santoso, A., Lin, X., Chen, Z., McPhaden, M.J., 2017. Continued increase of extreme El Ninõ frequency long after 1.5 C warming stabilization. Nat. Clim. Chang. 7, 568–572. https://doi.org/10.1038/NCLIMATE3351.
Wardhana, B., 2016. 'BRG's Roadmap for Peatland Restoration,' Presented at CBD & FAO Workshop "Forest Ecosystem Restoration." Bangkok, Thailand.
Warren, M., Hergoualc'h, K., Kauffman, J.B., Murdiyarso, D., Kolka, R., 2017. An appraisal of Indonesia's immense peat carbon stock using national peatland maps: uncertainties and potential losses from conversion. Carbon Balance Manag. 12. https://doi.org/10.1186/s13021-017-0080-2.
Wells, J.A., Wilson, K.A., Abram, N.K., Nunn, M., Gaveau, D.L.A., Runting, R.K., Tarniati, N., Mengersen, K.L., Meijaard, E., 2016. Rising floodwaters: mapping impacts and perceptions of flooding in Indonesian Borneo. Environ. Res. Lett. 11. https://doi.org/10.1088/1748-9326/11/6/064016.
Wishart, M.J., 2017. Project Information Document - Peatland Environment Accelerated Transformation Project - P162960 (Washington DC, USA).
World Bank, 2014. https://data.worldbank.org/indicator.
Wösten, J.H.M., Ismail, A.B., van Wijk, A.L.M., 1997. Peat subsidence and its practical implications: a case study in Malaysia. Geoderma 78, 25–36.
Wösten, J.H.M., Van Den Berg, J., Van Eijk, P., Gevers, G.J.M., Giesen, W.B.J.T., Hooijer, A., Idris, A., Leenman, P.H., Rais, D.S., Siderius, C., Silvius, M.J., Suryadiputra, N., Wibisono, I.T., 2006. Interrelationships between hydrology and ecology in fire degraded tropical peat swamp forests. Int. J. Water Resour. Dev. 22, 157–174. https://doi.org/10.1080/07900620500405973.
Xu, J., Morris, P.J., Liu, J., Holden, J., 2018. Hotspots of peatland-derived potable water use identified by global analysis. Nat. Sustain. 1, 246–253. https://doi.org/10.1038/s41893-018-0064-6.