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REVIEW AND SYNTHESIS

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Tropical forest and peatland conservation in Indonesia: Challenges and directions

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Abstract

1. Tropical forests and peatlands provide important ecological, climate and socio-economic benefits from the local to the global scale. However, these ecosystems and their associated benefits are threatened by anthropogenic activities, including agricultural conversion, timber harvesting, peatland drainage and associated fire. Here, we identify key challenges, and provide potential solutions and future directions to meet forest and peatland conservation and restoration goals in Indonesia, with a particular focus on Kalimantan.
2. Through a round-table, dual-language workshop discussion and literature evaluation, we recognized 59 political, economic, legal, social, logistical and research challenges, for which five key underlying factors were identified. These challenges relate to the 3Rs adopted by the Indonesian Peatland Restoration Agency (Rewetting, Revegetation and Revitalization), plus a fourth R that we suggest is essential to incorporate into (peatland) conservation planning: Reducing Fires.
3. Our analysis suggests that (a) all challenges have potential for impact on activities under all 4Rs, and many are inter-dependent and mutually reinforcing, implying

that narrowly focused solutions are likely to carry a higher risk of failure; (b) addressing challenges relating to Rewetting and Reducing Fire is critical for achieving goals in all 4Rs, as is considering the local socio-political situation and acquiring local government and community support; and (c) the suite of challenges faced, and thus conservation interventions required to address these, will be unique to each project, depending on its goals and prevailing local environmental, social and political conditions.

4. With this in mind, we propose an eight-step adaptive management framework, which could support projects in both Indonesia and other tropical areas to identify and overcome their specific conservation and restoration challenges.

KEYWORDS

fire, forest, Kalimantan, peat-swamp forest, restoration, revegetation, revitalization, rewetting

1 | INTRODUCTION

Tropical forests and peatlands provide globally important ecological and climate benefits, plus national to local scale socio-economic benefits for people in countries such as Indonesia. For example, Sumatra and Borneo are part of the Sundaland biodiversity hotspot (Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000), and their flora and fauna is particularly rich, with Borneo estimated to be home to 10–15,000 species of flowering plants, plus 37 endemic bird and 44 endemic mammal species (MacKinnon, Hatta, Halim, & Mangalik, 1996) and a total 415 terrestrial species classified as threatened by the IUCN. The extensive and poorly studied forests of West Papua also house rich flora and fauna, including high numbers of endemic species (Beehler, 2007; Roos, Keßler, Robbert Gradstein, & Baas, 2004). Although they support generally lower biodiversity levels than forests on mineral soils (Paoli et al., 2010), South-east Asia's peat-swamp forests are now recognized as being of particular importance for biodiversity (Posa, Wijedasa, & Corlett, 2011), which includes the largest proportion of the remaining critically endangered Bornean orangutan population (*Pongo pygmaeus*: Wich et al., 2008). The Indonesian government recognizes 149,056 km^2 of peatland in the country, with extensive deposits covering both remote areas and neighbouring major population centres on its three largest islands (Kalimantan: 28–-32% of the total Indonesian peatland area; Sumatra: 34%–43%; Papua: 25%–38%; Warren, Hergoualc'h, Kauffman, Murdiyarso, & Kolka, 2017). These forests store vast amounts of carbon locked away in their trees and particularly peat, with the Indonesia peat carbon store estimated to range between 13.6 and 57.4 Gt (Page, Rieley, & Banks, 2011; Warren et al., 2017). Peatlands also deliver numerous important ecosystem services to local people, including maintaining air and water quality, providing timber and non-timber forest resources, and supporting fish populations for local consumption (Dommain et al., 2016; Harrison, 2013; Thornton, 2017).

Despite this importance, forest loss rates in Indonesia are among the highest globally (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014). We illustrate this here using examples from Kalimantan (Indonesian Borneo), where it is estimated that a total 144,000 km^2 of forest was lost between 1973 and 2015 (Gaveau, Sheil, et al., 2016). Loss and degradation of peatlands has been particularly acute, with only 4,260 km^2 of the total 57,817 km^2 of peatland in Kalimantan (7.4%) considered to remain in a "pristine" condition in 2015 (Miettinen, Shi, & Liew, 2016), and data from East Kalimantan suggesting that peat-swamp forest has the largest proportion of degraded areas of all forest types (Budiharta et al., 2014). This loss and degradation can be attributed to agricultural expansion, especially for oil palm and pulp wood, timber harvesting, mining and, particularly in peatland areas, consequent drainage and associated fire (Dohong, Aziz, & Dargusch, 2017; Gaveau, Sheil, et al., 2016; Gaveau, Sloan, et al., 2014; Miettinen et al., 2012, 2016). Large areas of forest have been impacted by industrial activities, with Gaveau, Sloan, et al. (2014) estimating that 266,257 km^2 of the 1973 forest cover on Borneo has been logged, of which 179,917 km^2 remained standing in 2010. Oil palm and timber plantations covered 75,480 km^2 on Borneo in 2010, equivalent to 10% of the island's land area (Gaveau, Sloan, et al., 2014). From 2000 to 2017, the area of industrial plantations on Borneo is estimated to have increased by 170% (6.2 Mha), of which 88% can be attributed to palm oil expansion, with 3.06 Mha of forest converted to plantation (Gaveau et al., 2019). Two thirds of the Borneo forest area lost to plantations between 1973 and 2015 had been selectively logged prior to conversion (Gaveau, Sloan, et al., 2014). This has occurred despite recent research that has called the oft-justification of poverty alleviation for oil palm development into question, particularly in remote areas with high forest cover, where oil palm development is associated with reductions in wellbeing indicators (Santika, Wilson, Budiharta, Law, et al., 2019). Road and rail infrastructure developments pose an additional serious threat, with recent estimates suggesting that if all imminently planned projects proceed, landscape connectivity in Kalimantan will decline from 89% to 55%, and will impact 42 protected areas (Alamgir et al., 2019).

Under natural high water table hydrological conditions, both historical (Cole, Bhagwat, & Willis, 2015) and contemporary (Cattau et al., 2016) peatland fires are relatively rare, but drainage of Indonesia's peatlands for agriculture and/or timber extraction over the last several decades has led to increased potential for peat subsidence (Hooijer et al., 2012) and fire risk during dry periods (Wösten et al., 2006; Wösten, Clymans, Page, Rieley, & Limin, 2008), particularly during El Niño drought years (Fuller & Murphy, 2006; Spessa et al., 2015). High emissions from biomass burning in Indonesia, linked in many cases to drained peatlands, contributed substantially towards the highest observed annual increase in global CO_2 emissions during the strong El Niño of 2015 (Liu et al., 2017). This is of particular concern given projections from modelling studies, which indicate that the frequency of such extreme El Niño events may double as a result of global warming (Cai et al., 2014). Such fires are not limited to years with El Niño events, however, with significant burning and CO_2 emissions now occurring even in non-drought years (Gaveau, Salim, et al., 2014; Langner & Siegert, 2009; MoEF, 2018a,b; van der Werf et al., 2008). This situation is likely to worsen under further deforestation, as this has been shown to lead to higher local temperatures and reduced precipitation, especially in southern Borneo (McAlpine et al., 2018).

A schematic illustrating the feedback links between these threats, and their proximate and ultimate impacts is provided in Figure 1. As indicated in this figure, the above disturbances are associated with a wide range of adverse impacts, ranging from the local to global level. This includes negative impacts on biodiversity (Posa et al., 2011), which coupled with the impacts of climate

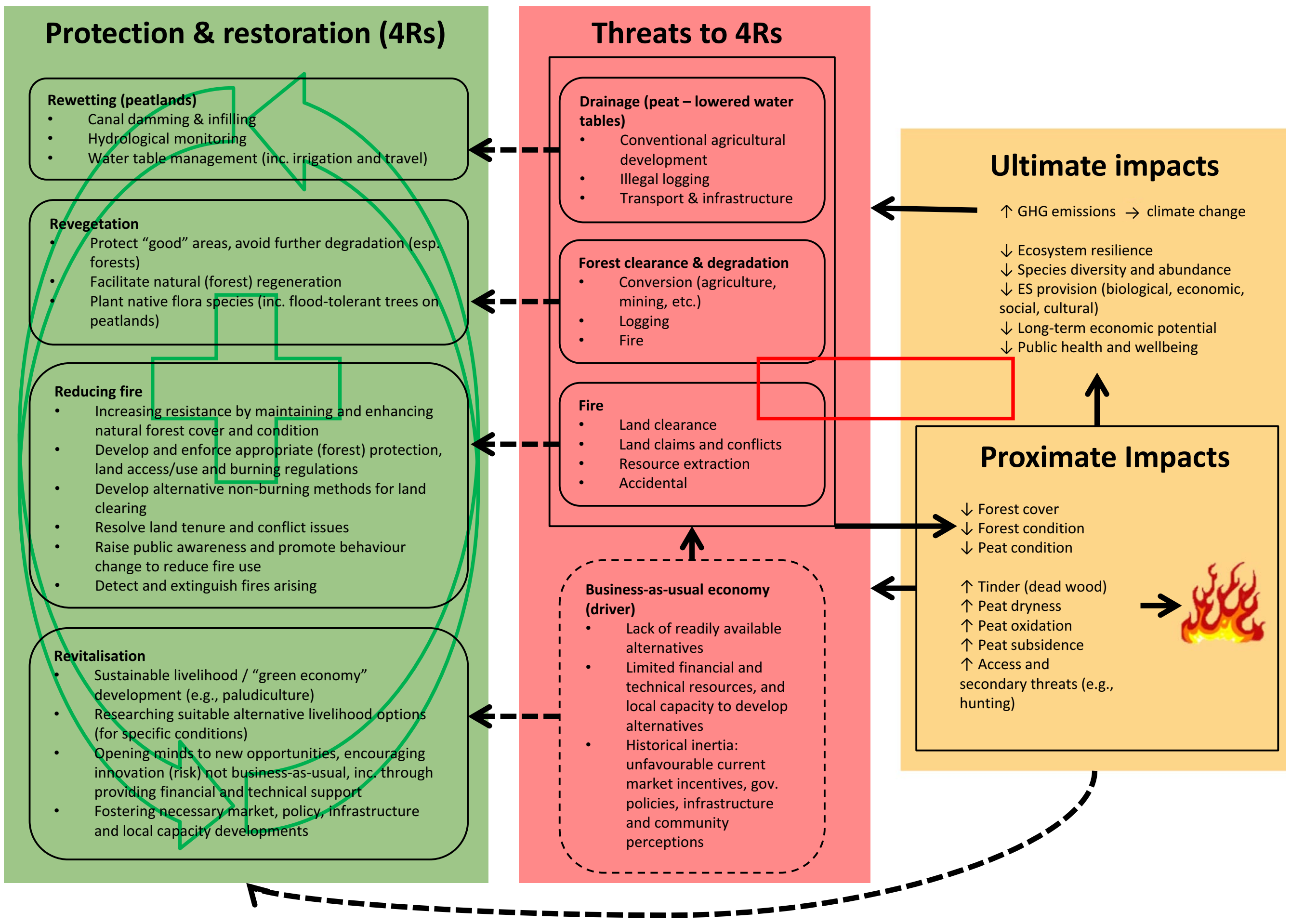

FIGURE 1 Overview of chains of impacts and feedback loops between the 4Rs of protection and restoration, plus threats faced and their impacts. Rounded rectangles represent categories, within which specific potential conservation interventions, threats or impacts are listed. Hard rectangles indicate instances where multiple categories are influenced by the same factor/s. Solid arrows represent positive (reinforcing) feedbacks and dashed arrows indicate negative (compromising) feedbacks. The rounded-dashed threats rectangle indicates that these are drivers behind the other threat categories listed. Background plus and minus symbols indicate positive and negative influences towards achieving goals of forest/peatland protection and eliminating fire from the landscape. The 4Rs all strengthen and support each other, creating positive feedback loops. Monitoring and evaluation is not indicated in the figure, but should form an essential component of all 4Rs (see text). The negative proximate and ultimate impacts arising from the threats serve to both exasperate the threats (positive feedback) and compromise achievement of goals under the 4Rs (negative feedback). Note that some threats and impacts overlap. For example, fire is both a threat that directly impacts the 4Rs (e.g. by destroying replanted seedlings) and a proximate impact (in the form of increased fire incidence and severity) resulting from failure to address other threats

change on forest cover, have been projected to result in 30%–49% of Bornean mammal species losing ≥30% of their habitat by 2080 (Struebig, Wilting, et al., 2015) and an even higher level of habitat loss (74%) projected over this period for Borneo's most iconic animal species: the orangutan (Struebig, Fischer, et al., 2015). Fire in peatlands is believed to be a particularly severe threat for biodiversity as, in addition to the obvious associated habitat loss and fragmentation, evidence suggests the toxic haze has negative impacts on both animal (Erb, Barrow, Hofner, Utami Atmoko, & Vogel, 2018) and tree health/condition (Harrison et al., 2016), and may lead to reduced pH in already acidic peatland rivers, resulting in decreased fish captures (Thornton, Dudin, Page, & Harrison, 2018). In line with this, decreased bioacoustic activity – an indicator of biodiversity and ecosystem functioning – has been observed during haze periods in a forest corridor in Singapore, where documented air pollution levels reach only one-fifteenth of those recorded in fire-source areas in Kalimantan (Lee et al., 2017). Peat fires also produce a thick toxic haze, which is a major public health hazard that has been linked to decreased adult height attainment for people exposed to haze from the 1997 fires during their prenatal period (Tan-Soo & Pattanayak, 2019) and is estimated to have caused 100,300 or more premature mortalities in Equatorial Asia in 2015 (Koplitz et al., 2016; see also Crippa et al., 2016); release vast amounts of carbon into the atmosphere (estimated 0.89 Gt CO_2e from Indonesia in 2015: Lohberger, Stängel, Atwood, & Siegert, 2018); lead to local social disruption and livelihood losses (Chokkalingam et al., 2007; Suyanto, Khususiyah, Sardi, Buana, & Noordwijk, 2009); and result in large economic losses, estimated at USD 16.1 billion for Indonesia in 2015, which is equivalent to 1.9% of the country's GDP (WB, 2016).

In light of the substantial benefits that Indonesia's forests and peatlands provide and the threats that they face, and particularly in response to the major 2015 El Niño fires, the Indonesian government has developed various regulations, targets and initiatives to protect and restore these ecosystems. Foremost among these is the creation of the Indonesian Peatland Restoration Agency in 2016 (*Badan Restorasi Gambut*, BRG), which has been tasked with restoring 2 Mha of damaged peatlands in Indonesia by the end of 2020. Following this, in 2017, a national strategy for fire prevention was published (RoI, 2017). Indonesia also issued a moratorium on the clearing of primary forests and conversion of peatlands in 2011, which has currently been extended up to 2019 (Widodo, 2017). It made commitments under the Paris Agreement to reduce its carbon emissions from 2010 levels by 25% under its own efforts and 41% with international support by 2020, with an unconditional target of 30% reduction by 2030 (RoI, 2015), for which Land Use, Land-Use Change and Forestry (LULUCF) is expected to contribute nearly two-thirds (Grassi et al., 2017; MoEF, 2018b). And it has made commitments to protect endangered species, such as the orangutan (MoF, 2009). Despite all of this, MODIS/VIIRS satellites detected a total of 19,801 fire hotspots in Central Kalimantan in the 2018 dry season (July-October), for example, up from 2,765 to 4,186 in the much wetter dry seasons of 2017 and 2016, respectively (39,095 hotspots were detected in 2015; GFW, 2018). There thus appears to be a strong negative relationship between dry season precipitation in a given year and the number of fire hotspots, at least for Central Kalimantan in 2015–2018. Media reports also indicate large numbers of fires in Indonesia and thick haze in 2019, coinciding with the first El Niño event since 2015 (Jong, 2019). This indicates that current measures are insufficient, especially in light of the predicted increase in strong El Niño events and reduced dry season precipitation under climate change (Cai et al., 2014, 2018).

Given the scale of the challenge of reversing recent trends to meet these commitments, and the serious negative consequences associated with failure to do so, we convened a workshop involving a group of Indonesian and international academic, NGO and government partners. Our aim in this workshop – and subsequently in this paper – was to identify some of the key challenges, and illustrate potential solutions and future directions, associated with achieving forest and peatland conservation and restoration goals in Indonesia, with a particular focus on Kalimantan where most of our collective experience has been accrued. In so doing, we consider both published/verified reports, in addition to the (unpublished) experiences of participants, in particular those working “at the coal face”. We hope that the challenges and recommendations provided may facilitate policy and intervention enhancements to improve forest and peatland conservation and restoration success in Indonesia, thus contributing to achieving the country's ambitious targets in these areas. Further, the recent discoveries of very large tropical peatland areas in both Africa (Dargie et al., 2017) and South America (Gumbricht et al., 2017), for which comparatively little information exists, particularly regarding sustainable management, suggests that such an analysis could provide important additional benefits beyond Indonesia.

2 | MATERIALS AND METHODS

The original idea and content outline for this paper originated at a workshop convened by the University of Exeter (UoE) and Borneo Nature Foundation (BNF), which was held at the UoE’s Cornwall campus, UK, on 18–19 October 2017 (Harrison & van Veen, 2017). This workshop brought together 34 scientists, NGO workers and Indonesian government representatives, to discuss challenges and opportunities relating to peat fire and other forest-related conservation issues in Indonesia in general and (Central) Kalimantan in particular, where the work of the majority of participants is focused. According to the University of Exeter's Research Ethics Framework, because the participants were not treated as research subjects, and we did not link any of the information gathered to any person or personal attributes such as age or nationality, our workshop was exempt from requiring review by the university ethics committee. Participants were informed of the goals of the workshop and provided either oral or written consent regarding their participation. All participants had professional experience relevant to forest and peatland conservation issues in Indonesia, with over half of the participants having over 15 years’ experience. A total ten participants were Indonesian nationals (30%) and 18 were female (55%).

Participants were selected by the lead authors on the basis of a combination of experience in conservation/research work in Indonesia, with an attempt to include academics, NGOs and government representatives; subject expertise, with an attempt to include social, physical and biological scientists, and including some participants without experience in Indonesia but with extensive experience of research topics of direct relevance to conservation in the region (e.g. influence of fire on earth systems, fish reproduction and eco-toxicology, etc.); and nationality, with as many Indonesian participants present as our budget could support. While our perspectives might therefore show some bias towards challenges and issues that are unique to (Central) Kalimantan, we do not restrict our review to these provinces and suggest that generally similar ecological, social and political contexts of other provinces will mean that our findings are also relevant to policy makers and practitioners working in other tropical peatland and forest areas in Indonesia and beyond.

Our initial list of challenges to forest and peatland conservation and restoration in the region was generated during a dual-language (English and Bahasa Indonesia) round-table discussion session from 1100 to 1600 hr on 19 October 2017, in which perspectives from all participants were invited and considered (see Author Contributions for individuals' roles in this process). In light of our goal to support Indonesia's national commitments and its contemporary policy relevance, this discussion was structured around the BRG's '3Rs' approach to peatland restoration, which includes the following three key elements: Rewetting, Revegetation and Revitalization of livelihoods (BRG, 2018; Figure 1; see also Dohong, Abdul Aziz, & Dargusch, 2018). Key discussion points and challenges identified were recorded during the session by the chairs on a flip-chart, which was documented photographically and then transferred to an Excel database. The challenges database was then iteratively reviewed via email by all authors, based on subjective assessments of relevance (to forest and peatland conservation and restoration goals in Kalimantan) and reliability (supporting evidence from literature and/or reported personal experience deemed sufficiently robust by the authors), with eight draft versions discarded before final submission. To reduce the risk of desire to conform with peers influencing contributions, in addition to replying to the whole group, individuals were also able to reply solely to the first author to incorporate input anonymously from the rest of the group.

This post-workshop review process resulted in the combining of some listed challenges that substantially overlapped at a practical level, the removal of some potential challenges that could not be verified based on published literature or reliable participant experience, the addition of some verifiable challenges that did not arise during the discussion session, and the grouping of challenges into six different primary categories (political, economic, legal, social, logistical and research), though we recognize that many challenges will bridge more than one of these categories. While we make no claim to have identified every single challenge that policy makers and practitioners working in the area may experience, this approach nevertheless enabled the identification of a large number of potential challenges, which may represent the majority of (serious) challenges that are likely to be faced. During the post-workshop iterative review process, based on available evidence from the literature and participants' experience, we considered whether each challenge identified would be expected to have a direct or indirect impact on the success of interventions under each of the BRG's 3Rs. Finally, as an illustration, for a sub-set of the challenges selected to span the six primary categories, we provide an expanded justification for identification of the challenge, plus suggested potential solutions to that specific challenge.

Much of our analysis and discussion centres around challenges to peatland and peat-swamp forest conservation and restoration, and solutions associated with these. We therefore attempt to indicate wherever this may be the case. Such instances frequently relate to challenges and associated solutions that either directly or indirectly link to peat hydrology, reflecting previous assertions regarding the critical distinguishing role of water in peat-swamp forest ecosystem processes and functioning (Harrison, 2013). This notwithstanding, many of the challenges and proposed solutions discussed in the context of peatlands will inevitably also apply in non-peatland areas, including those relating to government policy, project financing, land tenure, laws and law enforcement, balancing conflicting desires and incentives, knowledge gaps and capacity development.

3 | RESULTS

An initial list of 81 potential challenges to peat/forest conservation was produced during the workshop. While attempting to follow the BRG's 3Rs approach, it became evident that many of the challenges identified related directly or indirectly to fire, which does not (currently) fall under the direct remit of the BRG and thus is not specifically incorporated into their 3Rs approach. For example, difficulties in developing sustainable funds for village fire-fighting teams compromise fire-fighting efforts. This, in turn, decreases the chances that any fires arising are tackled effectively, thus risking major damage to Revegetation and Revitalization initiatives if target areas are burned. We therefore created a fourth R for the purposes of this exercise – 'Reducing Fire' - which was subsequently treated the same as the pre-existing 3Rs in our discussion.

Our post-workshop review of these challenges resulted in a reduced list of 59 challenges, with only six of these considered solely relevant to projects on peatlands. This includes four that were primarily political in nature, 12 economic, nine legal, 13 social, two logistical and 20 research-related (Table 1), though many of these challenges will in practice relate to more than one of these categories (see Section 4). Most challenges (48) were considered directly relevant to more than one of the 4Rs and around half (29) were considered directly relevant to all of the 4Rs. A total of 39 challenges were considered directly relevant to Rewetting goals, 42 to Revegetation, 50 to Revitalization and 36 to Reducing Fire. In all situations where a challenge was not considered directly relevant towards at least one of the 4Rs, it was considered indirectly relevant. Using Challenge 25 (Table 1) as an example: while ongoing

TABLE 1 Challenges identified relating to peatland and forest conservation and restoration goals in Kalimantan

No.	Challenge	Category	Potentially compromises goals relating to...				Applies just to peat?	Sources
			Rewetting	Revegetation	Revitalization	Reducing Fire		
1	Short currently guaranteed BRG timeframe (until 2020) and uncertain medium-term government commitment	Political	D	D	D	D	Y	See Table 2
2	Common over-focus on fire fighting: preparedness and prevention not/insufficiently supported (BRG not previously tasked with prevention)	Political	D	D	D	D	N	Tacconi, Moore, and Kaimowitz (2007), Turetsky et al. (2015), Page and Hooijer (2016), Widodo (2016)
3	Long politically intractable times needed to (fully) reforest/restore degraded (peatland) areas	Political	D	D	D	D	N	See Table 2
4	Conflicting or unclear government policies regarding conservation and development	Political	D	D	D	D	N	Law et al. (2015), Evers, Yule, Padfield, O'Reilly, and Varkkey (2017), Yong and Peh (2016), Nurhidayah and Djalante (2017)
5	Short-term nature of many projects/grants versus need for long-term (funding of) interventions (damming, cultivation, etc.)	Economic	D	D	D	D	N	Iftekhar, Polyakov, Ansell, Gibson, and Kay (2017); see #3
6	Difficulty in demonstrating proof of concept for different intervention options	Economic	D	D	D	D	N	See Table 2
7	Accessing sustainable markets for necessary materials for interventions	Economic	D	D	D	D	N	See Table 2
8	Difficulties in obtaining start-up funding for smallholder/community initiatives	Economic	I	D	D	I	N	Barlow and Jayasuriya (1984), Panlibuton and Meyer (2004), Obidzinski and Dermawan (2010), Shibao and Selamat (2018); see also #6
9	Challenges in developing sustainable village fire-fighting funds	Economic	D	I	I	D	N	RoI (2017)
10	Economic assistance to communities potentially tied to maintenance of rewetting infrastructure, replanting and/or fire teams	Economic	D	D	D	D	N	Pers. obs.
11	Understanding and balancing incentives at different levels: national policy, project, community, provincial, international	Economic	D	D	D	D	N	Murdiyarso and Lebel (2007), Carmenta, Zabala, Daeli, and Phelps (2017)
12	Ensuring appropriate dispersal of funds among communities/institutions - who benefits and is distribution fair?	Economic	D	D	D	D	N	Dewi, Belcher, and Puntodewo (2005), Jewitt, Nasir, Page, Rieley, and Khanal (2014), Suwarno, Hein, and Sumarga (2015)
13	Challenges to developing new markets: limited market accessibility and value chains, unsupportive regulatory environment	Economic	I	D	D	I	N	Fisher, Maginnis, Jackson, Barrow, and Jeanrenaud (2005), Tata, van Noordwijk, Jasnari, and Widayati (2015), Giesen and Sari (2018)

(Continues)

TABLE 1 (Continued)

No.	Challenge	Category	Potentially compromises goals relating to... Rewetting	Revegetation	Revitalization	Reducing Fire	Applies just to peat?	Sources
14	Market/crop price fluctuations and associated risks (new markets, flooded markets, over-production, decreased prices)	Economic	I	D	D	I	N	Salafsky, Dugelby, and Terborgh (1993), Belcher, Ruíz-Pérez, and Achdiawan (2005), Giesen and Sari (2018)
15	Un(der) developed Reduced Emissions from Deforestation and Degradation, domestic carbon and Payments for Ecosystem Services markets in Kalimantan; issues in monetizing these ecosystem services	Economic	D	D	D	D	N	Phelps, Webb, and Koh (2010), Angelsen, Brockhaus, Sunderlin, and Verchot (2012), Phelps, Friess, and Webb (2012), Enrici and Hubacek (2018)
16	Underlying growth-based (neoliberal) economic model that directly conflicts with and mis-frames the notion of sustainability	Economic	I	I	D	I	N	Klooster (2010), Büscher, Sullivan, Neves, Igoe, and Brockington (2012), Maxton-Lee (2018)
17	Law enforcement often lacking or ineffective, in particular identifying and prosecuting burners	Legal	D	I	I	D	N	See Table 2
18	New canals still being built (some illegally), even in areas where canal closure occurring	Legal	D	I	I	I	Y	Wösten et al. (2006), Dohong, Aziz, et al. (2017), Gokkon (2018)
19	Lack of clarity of land tenure and conflicting land claims in some areas	Legal	D	D	D	D	N	See Table 2
20	Lack of clarity on jurisdiction and responsibility for rewetting and fire-fighting in some areas	Legal	D	I	I	D	N	Suryadiputra et al. (2005), Suyanto (2007), Atmadja, Indriatmoko, Utomo, Komalasari, and Ekaputri (2014), Medrilzam, Dargusch, Herbohn, and Smith (2014); see also #20
21	Difficulties in securing long-term legal protection of conservation and revitalization areas	Legal	D	D	D	D	N	Brockhaus, Obidzinski, Dermawan, Laumonier, and Luttrell (2012), Dohong et al. (2018)
22	Assessing and ensuring legality, control and usage of different conservation and revitalization options/zones in different areas	Legal	D	D	D	D	N	Wunder et al. (2008), Galudra et al. (2011)
23	Environmental Impact Assessments (*AMDAL*) often inaccurate and ineffective for identifying important conservation areas	Legal	D	D	D	D	N	Zen, McCarthy, and Barlow (2005), McCarthy amd Zen (2010)
24	Ensuring fair and equitable benefit sharing and protecting rights	Legal	D	D	D	D	N	Luttrell, Loft, Gebara, and Kweka (2012), Suwarno et al. (2015)
25	Ongoing community use of canals: access, conflict (economic and ownership), (potentially misguided) social perceptions of adverse impacts of rewetting, e.g. on fish	Social	D	I	I	I	Y	See Table 2
26	Insufficient preparedness of land managers and communities for fire management (structures, systems, knowledge)	Social	I	I	I	D	N	Tacconi et al. (2007), Nurhidayah and Djalante (2017)

(Continues)

TABLE 1 (Continued)

No.	Challenge	Category	Potentially compromises goals relating to... Rewetting	Revegetation	Revitalization	Reducing Fire	Applies just to peat?	Sources
27	Obtaining FPIC (free prior informed consent) for rewetting initiatives	Social	D	I	I	I	Y	van Beukering, Schaafsma, Davies, and Oskolokaite (2008), Suyanto et al. (2009)
28	Conflict and integration of rewetting and revitalization activities with village development plans	Social	D	I	D	I	N	Werner (2001), Sutiyono, Muluk, Mafira, and Rakhmadi (2018)
29	Immediate/short-term attention around disasters; waning attention during (long) non/low-fire periods	Social	D	D	D	D	N	Byron and Shepherd (1998), Tacconi et al. (2007), Page and Hooijer (2016)
30	Encouraging "pro-conservation" behaviour change and overcoming barriers to this	Social	D	D	D	D	N	DeCaro and Stokes (2008), Nilsson et al. (2016)
31	Identifying and engaging with, plus understanding and meeting the needs of all relevant stakeholders, from local communities and businesses, to national government and international funders	Social	D	D	D	D	N	Carmenta et al. (2017), Sterling et al. (2017), Enrici and Hubacek (2018)
32	Securing social acceptance of replanted species, and choosing between "ecological" versus "economic" plant species for revegetation	Social	I	D	D	I	N	See Table 2
33	Limited community capacity and/or enthusiasm to develop capacity for (alternative) agricultural practices	Social	I	I	D	I	N	Giesen and Sari (2018), Silvius et al. (2018)
34	Limited capacity for and availability/accessibility of good practice guidelines for conservation interventions and new alternative economic options (esp. paludiculture)	Social	D	D	D	D	N	Graham et al. (2017), Dohong, Cassiophea, et al. (2017), Dohong, Aziz, et al. (2017), Wibisono and Dohong (2017)
35	Challenges in developing (responsible) ecotourism as a livelihood option in forest/peatland areas; lack of knowledge of positive and negative impacts of ecotourism locally	Social	I	I	D	I	N	Macfie and Williamson (2010), Russon and Susilo (2014)
36	"Fish mania" - understanding and mitigating impacts of seasonal influx of fishermen on rural resource availability and harvesting	Social	I	I	D	I	N	Thornton (2017), Höing (in prep)
37	Ensuring equality and equity across supply chains and all revitalization/intervention activities	Social	I	D	D	I	N	Blom, Sunderland, and Murdiyarso (2010), Suwarno et al. (2015)
38	Difficulties of transportation and access to many target sites	Logistical	D	D	D	D	N	Dohong, Cassiophea, et al. (2017), Dohong, Aziz, et al. (2017), Wibisono and Dohong (2017)
39	Challenges in developing infrastructure for processing new/emerging commodities	Logistical	I	I	D	I	N	See Table 2
40	Establishing who is burning, why they are burning and what potential alternatives to burning might exist	Research	I	I	I	D	N	Dennis et al. (2005), Suyanto et al. (2009), Cattau et al. (2016), Gaveau, Pirard, et al. (2016)

(Continues)

TABLE 1 (Continued)

No.	Challenge	Category	Potentially compromises goals relating to… Rewetting	Revegetation	Revitalization	Reducing Fire	Applies just to peat?	Sources
41	Current lack of capacity, including English language, among Indonesian institutions to realize full research and conservation potential	Research	D	D	D	D	N	Nurweni and Read (1999), Adnan (2009)
42	Limited/no scientific knowledge available for many areas and consequent difficulties in assessing (conservation) potential	Research	D	D	D	D	N	Yule (2010), Posa et al. (2011), Harrison and Rieley (2018)
43	Difficulty in identifying appropriate conservation/restoration targets, and (minimum) intervention levels needed to meet these; e.g. what is an appropriate water level increase target for a drained area within a given time-frame and how many dams are needed to achieve this hydrological restoration target?	Research	D	D	D	D	N	See Table 2
44	Uncertain cost/benefit analysis of (extra) interventions; e.g. what is the additionality of building more dams per unit length/volume of canal, or of (different types) of active versus passive revegetation strategies?	Research	D	D	D	D	N	Page et al. (2009), van Eijk, Leenman, Wibisono, and Giesen (2009), Jaenicke, Wösten, Budiman, and Siegert (2010), Graham et al. (2017)
45	Establishing what level/type of rewetting/revegetation is desired/needed for biodiversity in an area and balancing this with community/gov. desires	Research	D	D	D	D	N	Jewitt et al. (2014), Law et al. (2015), Dommain et al. (2016), Evers et al. (2017)
46	Lack of understanding of (heterogenous) community needs and desired benefits, and understanding desires for rewetting/revegetation/revitalization	Research	D	D	D	D	N	Wright et al. (2015), Höing and Radjawali (2017), Thornton (2017)
47	Understanding conflicting immediate individual benefits from drainage versus long-term/dispersed benefits of rewetting for communities	Research	D	I	D	I	Y	Suyanto et al. (2009), Sumarga, Hein, Hooijer, and Vernimmen (2016), Thornton (2017)
48	Limited understanding of ecological, social and economic impacts of fire	Research	D	D	D	D	N	Harrison et al. (2016), Koplitz et al. (2016), WB (2016), Erb et al. (2018)
49	Current lack of (easily accessible) standards and capacity/ability to reliably measure effectiveness and impacts (on e.g. H_2O, GHGs, fish stocks, biodiversity, livelihoods) of protection/restoration efforts, particularly on a large scale	Research	D	D	D	D	N	See Table 2
50	Establishing land suitability for different revegetation and revitalization targets (where to do what): species zones, type of land/soil, hydrology (including the level of hydrological restoration needed to revegetate with swamp species), availability of resources/species	Research	D	D	D	I	N	Page et al. (2009), Graham et al. (2017), Wibisono and Dohong (2017), Giesen and Sari (2018)

(Continues)

TABLE 1 (Continued)

No.	Challenge	Category	Potentially compromises goals relating to… Rewetting	Revegetation	Revitalization	Reducing Fire	Applies just to peat?	Sources
51	Establishing best species to use in different revegetation/ revitalization scenarios and completing species trials	Research	I	D	D	I	N	Graham (2009), Giesen (2015), Graham et al. (2017), Wibisono and Dohong (2017), Giesen and Sari (2018)
52	Understanding (variations in) seedling morphology, survival rates, germination rates and optimum growing techniques	Research	I	D	D	I	N	Graham et al. (2017), Wibisono and Dohong (2017)
53	Identifying how to overcome problems of flooding, high water & air temps, algae, competition from invasive plant species and consequent seedling mortality in degraded areas	Research	I	D	D	I	Y	Wösten et al. (2006), van Eijk et al. (2009), Dommain et al. (2016)
54	Lack of understanding of resilience of tree species (for replanting/ paludiculture) in the face of climate change	Research	I	D	D	I	N	Reyer, Guericke, and Ibisch (2009), Keenan (2015), Dohong, Aziz, et al. (2017)
55	Underdeveloped or inappropriate crop management practices (esp. paludiculture)	Research	I	D	D	I	N	Joosten, Tapio-Biström, and Tol (2012), Giesen (2015), Giesen and Sari (2018)
56	Attaining adequate diversification for pest management and nutrient cycling during revitalization (crop growing/ paludiculture)	Research	I	D	D	I	N	Thrupp (2000), Frison, Cherfas, and Hodgkin (2011)
57	Revitalization – identifying how best to establish community collectives/cooperatives, plus identify and exploit associated markets and supply chains	Research	I	I	D	I	N	Rasyid (1982), Ros-Tonen and Wiersum (2005), Giesen and Sari (2018)
58	Establishing appropriate thresholds for mobilization and emergency responses to fire	Research	I	I	I	D	N	Qadri (2001), de Groot, Field, Brady, Roswintiarti, and Mohamad (2007), RoI (2017)
59	Understanding and mitigating potential negative impacts of different R's on each other; e.g. revitalization hindered by rewetting/dam building that may restrict access, influence fish stocks, etc.	Research	D	D	D	D	N	CKPP (2008), Suyanto et al. (2009), Thornton (2017)

Note: Challenge numbers are for reference only and do not reflect rankings. "Category" refers to the primary category under which each challenge was considered to fall. D = direct influence; I = indirect influence. See Section 2 for details.

community use of canals has direct impacts on only peat Rewetting goals, successful Revegetation, Revitalization and fire reduction in peatlands all depend upon successful peat rewetting, thus implying that ongoing community canal use may also compromise progress towards goal attainment for these other three R's. An illustration of how these designations were reached for a sub-set of 11 of the challenges identified, plus suggestions for potential solutions to these challenges, is provided in Table 2.

4 | DISCUSSION

Our list of 59 challenges influencing attainment of peat/forest conservation and restoration goals is the most extensive of which we are aware, and incorporates challenges that span across work sectors (policy, economics, research, etc.) that have been identified by a wide range of stakeholders. This formidable list of challenges is potentially highly concerning, particularly because verifiable solutions to each challenge are not always identifiable, obtaining some necessary solutions may be beyond the scope of individual projects and it is unlikely that our list includes all potential challenges that may be encountered by all projects in all locations (see also, e.g. Dohong, Aziz, et al., 2017; Padfield et al., 2014). Indeed, with the exception of 2016 and 2017, when wetter conditions prevailed and fire incidence was subsequently reduced in Indonesia (MoEF, 2018a), recent historical trends relating to forest and peatland loss and degradation in the region are not encouraging with regard to the overall effectiveness of interventions implemented to date (Gaveau, Sloan, et al., 2014; Miettinen et al., 2016). Nevertheless, we remain optimistic that increased awareness of these challenges will facilitate development of more effective solutions, and that there are thus valuable lessons that can be learned from this exercise that will improve peat/forest conservation prospects in the region. In outlining these lessons, for ease we refer principally to 'projects'. This should be interpreted in its broadest sense, to include implementation of conservation interventions by industrial concession holders (e.g. management of High Conservation Value Forest blocks in an oil palm concession) and development of conservation policy by government, in addition to NGO and community initiatives.

Potentially most important among these is that all of the challenges identified were considered to have either potential direct or indirect impacts on goal attainment under each of the 4Rs and that goal attainment under each of the 4Rs may be impacted by challenges under all of the different themes. This implies that narrowly focused solutions that focus on only one theme or solution, and/or do not attempt to consider the diversity of challenges from across different themes that may influence attainment of goals under the 4Rs, face potential exposure to higher risk of failure (see also Figure 1). For example, a reforestation project may focus on identifying the most appropriate tree species and cultivation/replanting methods, and securing agreements to replant an area, but if pre-existing problems of high fire risk are not considered or cannot be addressed, then the project will be at high risk of failure, as many years of effort/progress could be lost in a single major fire event (Dohong et al., 2018; Graham, Giesen, & Page, 2017). Conversely, this also suggests that addressing many of the challenges identified will help deliver enhanced outcomes towards multiple R's. For example, one challenge identified for Revegetation projects was a lack of clarity and subsequent conflicts over land ownership/tenure in many areas, which is also a challenge for Rewetting, Revitalization and Reducing Fire projects, thus implying that resolving these issues could help deliver benefits under all 4Rs. This particular example also highlights why our primary categorization of challenges in Table 1 for presentation purposes should not be considered exclusive, as in practice land tenure conflicts arise from a complex inter-play of legal, political, social and economic factors (Galudra et al., 2011; Suyanto, 2007).

The first example provided in the paragraph above hints at our second key conclusion relating to peatlands; i.e. that rewetting and our "fourth R" of fire reduction are critical requirements for overcoming challenges under all 4Rs. The link between peat water levels and fire risk has been demonstrated at a site level (Putra, Cochrane, Vetrita, Graham, & Saharjo, 2018; Usup, Hashimoto, Takahashi, & Hayasaka, 2004), corresponding with observations that fire ignition density in peat-swamp forests in Central Kalimantan is approximately 10 times lower than in typically much more heavily drained non-forest and oil palm concession areas on peat (Cattau et al., 2016). Because peatland fires are very difficult to control, can rapidly burn large areas of standing forest, replanted forest and other plantations, and lead to loss of actual peat substrate, a single fire event can not only wipe out many years of restoration progress in a matter of hours, but also leads to further habitat degradation such that future restoration becomes even more difficult (Harrison, Page, & Limin, 2009; Page et al., 2009). Challenges relating to reducing fire are therefore of direct or indirect relevance to, and thus should consequently be a priority of, any Revegetation or Revitalization project. Similarly, failure to address challenges relating to peat rewetting can also negatively impact any Revegetation or Revitalization initiatives. This is because of the links described above between peat water levels and fire risk, plus the link between peat water levels and peat subsidence (Hooijer et al., 2012), which further compromises Revegetation and Revitalization efforts (Page et al., 2009). Further research is also needed to identify the species most tolerant of the prevailing high water table conditions associated with peat paludiculture (Revegetation and Revitalization) initiatives (see Challenge #51, Table 1).

Likewise, we consider that any project that does not fully consider the local socio-political situation and fails to obtain local government and community support also runs a high risk of failure. This suggestion is supported at a broad level by recent studies demonstrating that the impacts of both oil palm development (Santika, Wilson, Budiharta, Law, et al., 2019) and community forest designation (Santika, Wilson, Budiharta, Kusworo, et al., 2019) on villager well-being vary depending on the local socio-economic and environmental context, suggesting different conservation approaches may be required in different locations. At the individual project level, if for example local people are heavily dependent upon

TABLE 2 Selected challenge justifications and potential solutions

#	Challenge Justification and Potential Solution/s
1	*Short currently guaranteed BRG timeframe (until December 2020) and uncertain medium-term government commitment* The Indonesian Peatland Restoration Agency (*Badan Restorasi Gambut*, BRG) is a non-structural institution that works directly under and reports to the President. It was established on 6 January 2016, through Presidential Regulation No. 1/2016, as a response to the large-scale peatland fires that occurred in Indonesia in the second half of 2015. The agency is tasked with accelerating the recovery and restoration of hydrological function and vegetation of 2 Mha of damaged (drained/degraded/burned) peatland in seven provinces in Indonesia, including Central Kalimantan. According to Presidential Regulation No. 1/2016, the BRG has a 5-year timeframe, ending on 31 December 2020. It is currently unclear what will happen after that date, with the fate of the BRG resting on the decision of the President. This creates uncertainty from the perspective of peatland restoration initiative planning and implementation for all four Rs, particularly regarding government support and facilitation, which in turn is expected to have knock-on effects on funding availability, particularly if no decision regarding the BRG's potential extension is forthcoming soon after the 2019 presidential elections. POTENTIAL SOLUTION/S: Extending the BRG's timeframe in a way that maintains or enhances its potential influence beyond December 2020, for a minimum additional 5-year cycle or preferably as a (semi-)permanent structure, will provide increased certainty and cover a longer time period to facilitate long-term restoration of degraded peat landscapes.
3	*Long politically-intractable times needed to (fully) reforest/restore degraded (peatland) areas* Peat forms under wet conditions, accumulating at an average rate of around 1 mm/year (Page et al., 2004), thus meaning that a "deep" peat-swamp forest (defined as >3 m deep for protection purposes in Indonesia: GoI, 2014) would take potentially 3,000 years to form under natural hydrological conditions. Based upon this rate of formation, even the peat burned during a single fire event (average 17 cm for first burns: Konecny et al., 2016) is likely to take a century or two to re-form, assuming that adequately wet conditions exist for this to occur. Furthermore, many tropical tree species are slow-growing and long-lived, including in Borneo (e.g. King, Davies, Supardi, & Tan, 2005; Kurokawa, Yoshida, Nakamura, Lai, & Nakashizuka, 2003; Lieberman, Lieberman, Hartshorn, & Peralta, 1985), and it is therefore likely to be many years or even decades until many planted trees reach adult height or reproductive age, and potentially centuries until a restored forest acquires the level of complexity of a "mature" forest. Fully achieving restoration of heavily burned/degraded areas to "natural" forest conditions, particularly in peatlands, would require political and financial support over multiple decades or even generations, which in many cases will prove difficult to maintain. POTENTIAL SOLUTION/S: While peat reaccumulation may be accelerated by peat rewetting and tree growth may be accelerated in the early stages by strategies such as adding fertilizer (which may itself lead to adverse impacts on water quality if performed indiscriminately), full regeneration of heavily disturbed sites to pre-disturbed "natural" conditions is never going to be attainable with typical political (election cycle) timeframes. In situations where regeneration is particularly politically dependent, either directly or indirectly in terms of funding, etc., defining earlier succession stages or alternative peat uses that deliver acceptable or desirable ecological and social benefits and can be realistically delivered in shorter, politically relevant timeframes will be required.
6	*Difficulty in demonstrating proof of concept for different intervention options* There are still major gaps in our knowledge and uncertainties regarding the impacts of different anthropogenic disturbances on Kalimantan's forests and peatlands, and particularly regarding the effectiveness of different conservation interventions under all four Rs in mitigating the negative impacts of disturbance and preserving the positive benefits that these ecosystems provide (#43–59). In our experience, this can create difficulties when requesting political or financial support for projects, with grant funders and other stakeholders frequently (and understandably) requesting verifiable proof of concept data regarding project activities. Obtaining such information through research may often be impractical, especially for smaller projects, owing in part to the long periods of time that may be required to demonstrate impacts (#3), the differing influence of multiple confounding factors at different times and locations, and limitations in local research capacity (#41). POTENTIAL SOLUTION/S: This situation may be improved by enhanced monitoring and evaluation by habitat protection and restoration intervention proponents, together with increased publication of findings from such research. This can only be achieved if publication outlets are willing to accept articles reporting on failures as well as successes, are sympathetic that such research by smaller organizations in particular may not always be as comprehensive, if article publication and access costs are not prohibitive (and ideally are free), and if industry/financial backers support investment of resources over multi-year timeframes towards producing such outputs. An Indonesian-language journal under a similar concept to the English-language *Conservation Evidence* journal may be particularly useful in this regard.
7	*Accessing sustainable markets for necessary materials for interventions* Most conservation interventions under all four Rs require some acquisition of materials, for which ensuring a sustainable supply can frequently be difficult or (currently) impossible. For example, current methods of building dams to block drainage channels typically require relatively strong wood that will resist decay when submerged for prolonged periods (Dohong et al., 2018; Dohong, Aziz, et al., 2017; Dohong, Cassiophea, et al., 2017). In a country with high levels of illegal logging and poor traceability of locally available wood at mills, how can projects ensure that the wood they need is harvested responsibly and not contributing to forest degradation elsewhere, while working under limited budgets? Similar challenges exist regarding obtaining seeds for revegetation or paludiculture projects, for which plastic poly-bags are typically used to grow seedlings, owing to their low price. Similarly, there are currently no locally accessible alternative options to items such as petrol-powered fire pumps and boat engines used by fire-fighting teams. POTENTIAL SOLUTION/S: Wider initiatives to improve ecological and social safeguard standards across industries, adoption of and adherence to such standards (e.g. Forestry Stewardship Council), and development of alternative energy sources and alternatives to plastics are of clear importance in addressing this challenge. While increased awareness among project proponents and increased requirements from project backers to demonstrate the origins and sustainability of supplies may ultimately help drive this change, this is unlikely to be effective on a small scale (i.e. if there is relatively small market incentive for production of such "sustainable products") and may even prove counter-productive, at least from the perspective of protection/restoration of a particular project site, if projects are unable to source or afford such products and therefore complete their activities. Increased long-term political and financial support for peat/forest conservation in the region is therefore likely to be particularly important here, if this helps drive the development of secondary industries focusing on sustainable production of suitable timber species for use in dam-building and seedlings for use in revegetation initiatives, etc.

(Continues)

TABLE 2 (Continued)

#	Challenge Justification and Potential Solution/s
17	*Law enforcement often lacking or ineffective, in particular identifying and prosecuting burners* Ineffective enforcement of existing laws is frequently regarded as a major barrier towards achieving conservation and restoration efforts in Indonesia, including in relation to enforcement of (protected) area boundaries and prevention of illegal activities such as illegal logging within these (Curran et al., 2004; Enrici & Hubacek, 2018; Nellemann, Miles, Kaltenborn, Virtue, & Ahlenius, 2007), fire use and management (Nurhidayah & Djalante, 2017; Varkkey, 2014), wildlife killing (Meijaard et al., 2011) and trade (Freund, Rahman, & Knott, 2017; Nijman, 2017), plus bypassing of laws stipulating that forests in concessions are permanent by re-zoning as concessions for plantation development (Gaveau, Sloan, et al., 2014). For example, Indonesia's Government Regulation (PP No. 4/2001) on the *Control of Natural Damage and or Pollutions Related to Land and Forest Fire* states that setting land and forest fires is banned, yet the annual occurrence of widespread forest and peatland fires on Kalimantan indicates that fire use is still widespread (Uda, Schouten, & Hein, 2018). While some successful prosecutions have been made in Indonesia against large companies perpetrating fire, obstacles to more widespread prosecutions include the high burden of assembling sufficient evidence to support prosecution and the potential impacts of prosecutions on smallholders (Dennis et al., 2005). Correspondingly, ineffective enforcement of regulations, combined with inconsistencies between them, is regarded as a key driver of peatland deforestation and degradation in the region (Dohong et al., 2018; Dohong, Aziz, et al., 2017). Problems of law enforcement are further amplified by limited awareness of many peatland users regarding peatland regulations and alternatives for peatland best practice (Uda et al., 2018). POTENTIAL SOLUTION/S: Enforcing existing regulations is obviously required. For example, Estrada et al. (2018) identified improved governance and law enforcement as critical for primate conservation in Indonesia, and strict enforcement of zero-burn policies has been recommended to prevent fires on peatlands (Page & Hooijer, 2016; WB, 2016). This involves addressing issues of coordination, management, corruption and resource availability, plus development and implementation of technological solutions with potential to increase efficiency and cost effectiveness of patrols (e.g. use of drones for detecting and monitoring illegal activities: Wich & Koh, 2018). Problems may frequently arise from lack of clarity and awareness at either an official or local level regarding land tenure/status and permitted activities. With external support where needed, it is therefore key for government to continue and expand its work to improve clarity in this regard. To this end, the following actions are needed: enhanced stakeholder liaison and socialization, including between industry and local communities, resolving associated disputes and licence issues, transparently defining legal boundaries and allowable uses, including publishing continually-updated authoritative maps (in particular under the One Map policy) together with their underlying databases (Murdiyarso et al., 2011; Sloan, 2014; Uda et al., 2018; WB, 2016). Research into and provision of (alternative) technologies to facilitate transitions to a zero-burning culture are also required (Uda et al., 2018).
19	*Lack of clarity on jurisdiction and responsibility for rewetting and fire-fighting in some areas* Lack of clarity in and conflicts over land tenure are widely acknowledged as important drivers of fire use in Indonesia (Medrilzam et al., 2014; Suyanto, 2007). These same issues also threaten achievement of rewetting and fire-fighting goals for specific peatland and (in the case of fire-fighting) non-peatland forest areas (Medrilzam et al., 2014; Suyanto, 2007), as land tenure uncertainties and conflicts inevitably lead to uncertainties, conflicts and potential motivational impediments regarding who is responsible for protecting and restoring an area, including paying for this and assuming responsibility in the event of failures. POTENTIAL SOLUTION/S: Adoption of wider recommendations for improving clarity of land tenure and resolving associated conflicts (see, e.g. #17) is of critical importance with regards to clarifying responsibilities for rewetting and fire-fighting in specific peatland areas. This is supported by reports demonstrating that clarifying land tenure and agreements made with local communities can facilitate completion of rewetting initiatives (Atmadja et al., 2014; Suryadiputra et al., 2005). Once land tenure and conflict issues have been resolved, further agreements between stakeholders may then be reached regarding responsibilities for implementing and financing different aspects of rewetting and fire-fighting activities (indeed, such agreements may be developed as part of conflict resolution processes).
25	*Ongoing community use of canals: access, conflict (economic and ownership), (potentially misguided) social perceptions of rewetting impacts e.g. impacts on fish* In addition to drainage for agriculture, peatland canals are frequently used for transport of local people and materials, including use for accessing plantations, fishing areas and forests, and to transport timber and other forest products. Such canals can therefore become important for local trade and economies, which may lead to local resistance to canal blocking activities and even dam vandalism (Jaenicke et al., 2010; Morrogh-Bernard, 2011; Ritzema, Limin, Kusin, Jauhiainen, & Wösten, 2014; Suyanto et al., 2009). Likewise individual canals are often claimed to be owned by particular individuals or companies, who may charge for its use, and who may or may not also be recognized as the land managers for that area, leading to potential for conflict (Suyanto et al., 2009). Finally, local communities and other stakeholders may not fully understand rewetting objectives and may develop (mis-)conceptions relating to these that may further hamper rewetting initiatives. For example, perceptions exist around local communities in Sebangau, Central Kalimantan that dam construction negatively impacts local fish populations and thus fishing livelihoods, as fish are apparently trapped behind dams and die when water levels recede in the dry season (Thornton, 2017). To our knowledge, no empirical evidence exists on this topic and it is indeed also plausible that dams are beneficial to local fish populations through restoring the natural swamp hydrology to which local fish are adapted and through preventing fire. Nevertheless, such local (mis?)perceptions have potential to seriously compromise rewetting efforts. POTENTIAL SOLUTION/S: The first step in addressing these myriad different potential issues is for project proponents to fully socialize and open up dialogue with local community members, to understand how and why they use canals, and what (they perceive) the impacts of canal blocking may be in their community (Dohong, Aziz, et al., 2017; Dohong, Cassiophea, et al., 2017). Once such understanding has been gained and trust established, further research and discussions should be initiated to establish and explore together with community members whether fears regarding potential negative impacts of rewetting activities are justified and, if so, how such negative impacts may be avoided or mitigated through either changes in rewetting plans (e.g. use of limited-depth spillways to permit boat transport; Dohong, Aziz, et al., 2017; Dohong, Cassiophea, et al., 2017) and/or community behaviour (Giesen & Sari, 2018).

(Continues)

TABLE 2 (Continued)

#	Challenge Justification and Potential Solution/s
32	*Social acceptance of replanted species, and choosing between 'ecological' versus 'economic' plant species for revegetation* Revegetation of degraded and burned forest and peatland areas, which may contain as few as two remaining tree species in extreme cases (Page et al., 2009), involves selecting tree species for replanting based upon either an ecological, economic or mixed approach. Indonesian government regulations state that peatland with depth exceeding 3 m is to be considered a protected area prohibited from use (GoI, 2014). In shallower peat areas, different actors are likely to have different preferences in relation to this, with conservationists (and potentially also outside funders) likely to favour revegetation towards more natural forest conditions and local communities (and governments?) likely to prefer selection of species that relatively rapidly provide economic benefits (Giesen, 2015; Graham et al., 2017; Giesen & Sari, 2018). Furthermore, planting of many alternative crop species used in peatland revitalization programmes is associated with only partial, rather than full, rewetting and may therefore be unsustainable in the long term (Giesen & Sari, 2018). Potential therefore exists for conflict to arise in selection of species for revegetation of particular areas, particularly if local people are inadequately involved in decision making processes and/or perceive species selection choices as likely to impact negatively upon their livelihoods. POTENTIAL SOLUTION/S: Multi-stakeholder analyses are an essential pre-requisite prior to initiating any revegetation project, which must include consideration of both the prevailing ecological conditions at the site and existing restoration barriers, in addition to local community needs and desires (Giesen & Sari, 2018; Graham et al., 2017; Page et al., 2009; Wibisono & Dohong, 2017). Such an analysis is important for establishing not only which species may be able to survive in an area, but also for agreeing upon revegetation goals that are acceptable for all parties, given the current ecological-social-economic context and within the time and resources available (see also #3). Research and development to enhance potential for paludiculture species that grow under fully rewetted peat conditions is also needed.
39	*Challenges in developing infrastructure for processing new/emerging commodities* Although a wide variety of non-timber floral forest products (NTFPs) have been identified as potentially suitable in tropical peatlands (Giesen, 2015), the area under paludiculture development in Indonesia remains very limited, owing to knowledge gaps, uncertain market conditions and unsupportive regulatory environments (Giesen & Sari, 2018). Lack of development of the necessary industry infrastructure represents an additional challenge to the economic exploitation of alternative NTFPs (Giesen & Sari, 2018). While many local mills exist to process palm oil, no such facilities exist and are accessible to most rural communities in Kalimantan for processing and selling the vast majority of the 81 potential paludiculture species identified by Giesen (2015). Development of such facilities will, of course, become more likely as these markets develop, yet the current lack of such facilities may also be hindering the development of these markets. POTENTIAL SOLUTION/S: Further proof of concept research is important for providing evidence regarding feasibility and economic potential of different options for new/emerging NTFP commodities, including via paludiculture on peatlands, which in turn will increase investor and market confidence, ultimately facilitating infrastructure development. Government grant, loan or insurance schemes, including to smallholders, community initiatives and small businesses willing to "take a risk" to develop a new NTFP (paludiculture) commodity may further facilitate such development.
43	*Difficulty in identifying appropriate conservation/restoration targets, and (minimum) intervention levels needed to meet these; e.g. what is an appropriate water level increase target for a drained area within a given timeframe and how many dams are needed to achieve this hydrological restoration target?* Identifying appropriate, precise conservation/restoration targets is exceedingly difficult. This is because there are no universally agreed definitions specifying what constitutes 'effective protection or restoration' of forest and peatland areas, and because the appropriateness of any such definitions would vary depending on the particular circumstances and goals of each individual project, which in turn will be determined by a variety of constantly evolving ecological, social, political and economic factors (Budiharta et al., 2014; Gardner, 2010; Page et al., 2009). For example, it is generally considered that (regular) drops in peat water tables exceeding 40 cm below the surface leads to increased fire risk (Usup et al., 2004; Wösten et al., 2008), though more recent studies suggest that retaining water levels above 30 cm below the surface is needed to reduce fire risk (Putra et al., 2018) and this level is suggested to provide additional benefits in terms of reducing carbon dioxide emissions (Page et al., 2009). Peat subsidence rates continue to decrease up to the point where the water table is at the surface (Couwenberg, Dommain, & Joosten, 2010; Hooijer et al., 2012). Further, even if a definitive target water table depth were agreed, there is no readily available formula that can be adapted (based upon number and size of existing canals, current peat water level, etc.) by conservation managers to establish exactly how many dams are needed at what spacing along which proportion/length of a canal to achieve this target. This leaves such decisions largely up to guess work by project proponents, and increases the risk that either insufficient dams will be built and targets will not be reached, or more dams than needed to reach the target will be built and resources will have been 'needlessly' squandered. The costs of implementing restoration interventions also varies between forest types and degradation levels (Budiharta et al., 2014), which may further influence decision making to achieve different conservation goals (Budiharta et al., 2018). POTENTIAL SOLUTION/S: Further modelling and field research to identify and monitor the impacts of different conservation and restoration initiatives on ecological, social and economic variables will provide a more robust evidence base to support decision making regarding conservation and restoration targets. Effective engagement and consultation with all stakeholders, including at the local community level, is ultimately needed to identify and agree upon the most appropriate targets for a particular area. Regarding rewetting specifically, initial modelling work to predict the numbers of dams needed in particular target areas (Jaenicke et al., 2010) should be built upon and verified through further modelling and field testing, in order to generate user-friendly formulae or recommendations to provide general guidance to project managers regarding number of dams needed to reach different rewetting targets.

(Continues)

TABLE 2 (Continued)

#	Challenge Justification and Potential Solution/s
49	*Current lack of standards and capacity/ability to reliably measure effectiveness and impacts (on e.g. H_2O, GHGs, fish stocks, biodiversity, livelihoods) of protection/restoration efforts, particularly on a large scale* Our understanding of the ecological, social and economic impacts of different anthropogenic threats, and conservation and restoration interventions in Kalimantan is limited (#43–45, 48, 50–52, 59), creating difficulties with regards to proof of concept (#6) and consequently project funding (#5, 8–9). Two related factors underlying this are a lack of widely accepted standards and local capacity/ability to measure many of the impacts of such initiatives, particularly on a large spatial scale. For example, many researchers have estimated carbon emissions from peatland fires (e.g. Lohberger et al., 2018; Page et al., 2002) and methodological standards for this have been produced (Krisnawati, Imanuddin, Adinugroho, & Hutabarat, 2015), but no standard exists to support project proponents in estimating the carbon emission reductions that might be obtained through deploying fire-fighting teams to extinguish fires, despite the fact some of the authors of this paper have been requested to provide such information for funders. This is particularly pertinent with regards to supporting local community driven initiatives – which are likely to be led by people without formal scientific education, access to scientific journals or understanding of the English language – in demonstrating the impacts of their (fire-fighting) interventions to potential funders and other stakeholders. Likewise, with potential exception of some economically important groups in some instances (e.g. trees and fish) there is a generally low capacity for identification of many flora and fauna taxa within Kalimantan institutions, despite some of these having been identified as potentially useful indicators of anthropogenic disturbance (e.g. ants: Schreven et al., 2018; fruit-feeding butterflies: Houlihan, Harrison, & Cheyne, 2013), thus limiting our ability to evaluate the impact of conservation interventions on local biodiversity. POTENTIAL SOLUTION/S: Further research is needed to evaluate the different potential monitoring methods relating to different variables (e.g. how best to monitor impacts of peat rewetting on local fish stocks? Thornton, 2017). Importantly, this should include consideration of how to make these more accessible for use by local project leaders who may have access to only very limited budgets and may not possess formal scientific training. This should be supported by increased investment in local scientist and student training and development, including provision of support by both international scientists and government. The ongoing production and subsequent continual refinement of field manuals for identifying forest biodiversity (e.g. peat-swamp forest trees: Thomas, 2013), and monitoring direct impacts of conservation interventions on biodiversity (e.g. canopy-dwelling butterflies: Purwanto et al., 2015) and other variables is also of importance.

a particular peatland canal for transport and access to the forest or fishing grounds, a project attempting to dam that canal is likely to be met with local resistance, to the point where dams may be destroyed and thus rendered ineffective (CKPP, 2008; Suyanto et al., 2009). Local perceptions of negative impacts of peatland canal dams on fish populations – a vital source of protein in many rural areas in Kalimantan – have also been reported, which may potentially complicate damming efforts, despite a lack of formal scientific evidence relating to this (Thornton, 2017).

While we therefore contend that any peat conservation or restoration project must consider peat rewetting, fire prevention and the local socio-political context as essential components of their project planning, this does not necessarily imply that active measures will always be required in this regard. Indeed, the nature and importance of the challenges faced by any particular project – both related and not related to rewetting and fire reduction – will vary between locations and over time. This variability will be critically dependent upon the threat history of the area and conservation and restoration goals of the project in question, which themselves should be expected to evolve over time if adaptive management processes are adopted as recommended (Gardner, 2010; Lindenmayer et al., 2008; Sayer et al., 2013). The varying cost of implementing restoration interventions between forest habitats, together with the varying impact that restoration in these different forest types has in achieving different conservation goals may also influence decision making in any particular area (Budiharta et al., 2014, 2018). Any conservation or restoration project must therefore be site and goal specific, tailored to the particular challenges and targets associated with the focal area at the time. It is for this reason that we do not attempt to rank the challenges identified in terms of importance or priority levels.

Our approach is subject to a number of limitations, which should be born in mind when interpreting our results and conclusions. First, as is apparent from the number of challenges that relate to lack of knowledge/information, verifiable, rigorous published analysis of all potential challenges outlined is to our knowledge not (publically) available. Consequently, the identification and verification of many of the challenges listed is based in whole or part on the (unpublished) experiences of the workshop participants. In this respect, it is also pertinent to note that many of our workshop participants are based, or conduct a large amount of their work, in the province of Central Kalimantan, which may lead to some bias in perceptions towards this locale. Despite this, most of the participants also have experience working in other parts of Kalimantan and Indonesia, and all are well connected within the wider research and conservation networks in the region, so we consider the likely influence of this bias to be minimal. Further, our workshop participants were biased towards scientists and senior members of local NGOs, government and academic institutions, and included no local village community members or industry representatives. Although many workshop participants work closely with such stakeholders, it is likely that additional challenges would have been identified and/or some challenges may be perceived differently by these important actors. Despite these limitations, we nevertheless consider our approach justifiable as a rapid horizon-scanning exercise to identify known and potential challenges that are likely to prove important for conservation and restoration projects to consider and overcome. Finally, with respect to biodiversity conservation, it is important to note that our analysis was conducted from a habitat conservation perspective and does not cover challenges associated with wildlife trade, conflicts or hunting. Such non-habitat threats may be of great importance for the conservation of some species (e.g. killing of orangutans: Meijaard et al., 2011; trade in primates, fruit bats and turtles: Nijman, Spaan, Rode-Margono, & Wirdateti & Nekaris, 2015; Harrison et al., 2011; Schoppe, 2009), and will create additional pressure on species' populations beyond the habitat threats discussed herein.

We did not attempt to provide potential solutions for all challenges identified during this exercise, in part for reasons of space, but moreover because verifiable evidence pertaining to the effectiveness of the various potential solutions for each challenge is not available, because we do not claim to "know all the answers", and because the composition and precise nature of solutions required to overcome the particular set of challenges facing any particular project will vary substantially on a case-by-case basis depending on its situational context. Despite this, at a broad level, we present (a) a synthesis of key factors underlying the challenges identified through our analysis, and general recommendations to address these; and (b) a step-by-step consideration of how to do this, which will be of use to policy makers and practitioners.

4.1 | Synthesis: key underlying factors (barriers) and recommendations to address these

Five key underlying factors behind the challenges identified are highlighted in italics, with explanations and recommendations to address them provided in normal font. Importantly, this synthesis highlights the inter-dependent and mutually reinforcing nature of many of the challenges.

Disparity and resultant conflict between (long-term) ecological and (short-term) social-economic-political timeframes (relates to, e.g. Challenges #1-3, 5, 9, 21, 28–30, 32, 47 in Table 1). Many ecological processes are very long-term in nature (e.g. trees taking decades to grow and peat taking many centuries to accumulate: #3), meaning that ecological timeframes for restoration will frequently far eclipse those of government policies, village plans and project timeframes that typically last only a few years (#1, 5, 9, 21, 28), or even individual human lifespans. Coupled with inequities in cost–benefit distributions from conservation and restoration initiatives (#24, 47, see below) and short-term attention around disaster periods (#29), this may result in prioritization of short-term (economic) gains that are attainable within an election cycle, or timeframe acceptable to the public or donors (#32), above long-term ecological restoration initiatives that may ultimately lead to greater and more stable benefits within a more resilient system. While it is unlikely to ever be possible to completely resolve this disparity in timeframes, the level of conflict can nevertheless be reduced through improved local awareness of socio-economic benefits from conservation (#30, 32), accounting for such benefits within policy planning, increasing long-term land-use designations for conservation and restoration purposes (e.g. extending Ecosystem Restoration Concession area leases from the current 60 to hundreds of years), and improved collaborations between the conservation community and business and community stakeholders to enhance compatibility between short-term economic and long-term ecological land use objectives.

Balancing conflicting and evolving needs and desires of different actors to agree mutually acceptable, and socio-politically and ecologically feasible, conservation and restoration targets (relates to, e.g. Challenges #3–4, 11, 16, 27–28, 31, 43, 45–46). The huge variety of different actors that may hold stakes in any particular conservation or restoration target area – potentially ranging from relatively poor local communities, to local government, large corporations and conservation NGOs, among many others – will inevitably approach the target area with varying preconceptions and aspirations (#11, 28, 31, 45–46). Further, such aspirations may not always be consistent even within the same category of actor (e.g. conflicting government policies on conservation and development #4), and may vary within the same actor over time, depending on changes in circumstances, policies, knowledge, perceived values and other factors. This may, for example, compromise the ability of projects to acquire local support for Rewetting (#27) or Revegetation (#32) initiatives. Coupled with existing uncertainties regarding the level of intervention (and thus investment) needed to obtain specific restoration goals in different forest types (#43–45, 50–51) and of failure to achieve these (#48), potential inequities in benefit distribution (#12, 24), disparities in ecological and human-centred timeframes (see above), and mis-alignment between underlying growth-based economic models and the notion of ecological sustainability (#16), this makes establishment of conservation targets that are feasible and agreeable to all stakeholders extremely difficult. We suggest that the chances of satisfying a greater number of stakeholders will be increased by more research into differing perspectives, resolving the aforementioned uncertainties and improving understanding of how interventions to achieve one goal may compromise attainment of other goals; improved dialogue between all stakeholders in an area and understanding of their needs and constraints; improved recognition of the diversity of benefits and weighting of benefit types obtained through conservation projects (e.g. economic vs. conservation or cultural benefits); and consequently increased representation of these different perspectives in land use policies.

Acquiring (long-term) project financing and tackling financial disincentives (relates to, e.g. Challenges #2, 5, 8–15, 24, 35, 39, 47, 57). Because many restoration projects must by nature be very long term (see above), obtaining project funding over long time periods is a frequent challenge (#5, 9–10). This challenge is compounded by a variety of financial disincentives, including potential over-focus on fire-fighting and under-focus on fire prevention (#2), differing balances of incentives at different levels (#11) and among individual actors (#47), community members potentially becoming reliant on having a degraded ecosystem to restore for receiving wages to assist restoration projects (#10), challenges in ensuring equitable benefit distribution (#12, 24), market underdevelopment and associated risk and consequent lack of infrastructure, including in relation to eco-tourism (#14-15, 35, 39, 57), plus perceived risks and uncertainties relating to novel restoration initiatives that may compromise obtaining start-up funding (#8). Addressing the first two underlying factors outlined above will contribute to overcoming these issues, as will further development and more widespread implementation of benefit distribution systems, currently under development within the context of REDD+ (Indonesian REDD+ Task Force, 2012). Promotion of supportive government policies and improving access to funding or loans for innovation and start-up Revitalization projects (e.g. paludiculture and eco-tourism), including via industry collaboration, will help to promote market development, improve market access and facilitate the required infrastructure development (e.g. processing factories for paludiculture crops). Accompanying research to evaluate market potential and overcome implementation barriers will also be important.

Frequent lack of clarity regarding legal status and responsibility for different areas and activities, conflicting/unclear laws and ineffective law enforcement (relates to, e.g. Challenges #4, 17–22). Conservation projects must overcome a variety of legal challenges, such as conflicting or unclear government policies on conservation and development, including relating to fire prohibition and customary fire use within local communities (#4); weak or ineffective law enforcement (#17-18); lack of clarity of land tenure and resulting uncertainty in jurisdiction and conflicts (#19-20); difficulties in securing legal protected status (#21); and ensuring legality of conservation and restoration interventions (#22). Many conservation projects and local community members will lack full understanding of these often complex legal issues and advice from different sources may be conflicting, thus increasing the difficulty of overcoming these challenges. Ultimately, increased coordination between government departments and non-government stakeholders is needed to reduce such conflicts (including through Indonesia's One Map policy development), with increased political pressure and resource provision required to effectively enforce anti-burning and other laws in all forest and peatland areas. Alongside this, promoting the study of environmental law, providing incentives to legal professionals to assist conservation projects and otherwise increasing access to legal assistance by conservation projects will aid in successfully navigating these legal complexities.

Currently limited scientific knowledge across multiple areas and in relation to all 4Rs (relates to, e.g. Challenges #6, 23, 41–56, 59). This factor can be considered as having two strongly related components. First, there is a lack of adequate scientific studies and evidence in many areas, including data to provide proof of concept for different restoration options (#6, 52, 54); assess conservation potential (#42) and fire impacts (#48), and thus to conduct cost–benefit analyses (#44-47, 50), define targets (#43), develop appropriate standards (#49, 51, 53, 55–56) and predict the potential impacts of different conservation interventions on each other (#59). Second, this is compounded by a limited local scientific capacity to acquire such evidence and conduct such analyses (#41), including environmental impact assessments (#23). For the former, increased national and international promotion of and support for research on peatland/forest conservation and restoration is required, including promoting pilot and modelling studies, facilitating international and cross-sector (e.g. academia-industry) research collaborations, mandating monitoring and evaluation in field projects, and providing standards and training opportunities to facilitate this. The latter was perceived by workshop participants as a particularly important barrier; i.e. the limited capacity within many institutions in Indonesia to lead internationally excellent research to assess the impacts of fire and other conservation threats, identify and test novel solutions to these threats, and accurately measure the effectiveness of protection and restoration efforts. This was considered particularly pertinent by Indonesian participants, who also perceived limited English language abilities within their institution as a particularly important component of this barrier. Non-Indonesian scientists working with colleagues in Indonesia can help address this through collaborative research, training and student supervision, but such interventions typically occur only towards the end of or after formal education has been completed, which may limit their potential impact. Increasing the quality of scientific and English language training throughout the Indonesian education system, particularly as relates to forests and peatlands, and increasing opportunities, including through scholarships for Indonesian scientists to study in high-quality institutions abroad, would therefore be important steps in fully overcoming this key underlying barrier.

4.2 | Step-by-step: an adaptive management framework to overcome project challenges

As noted above, all challenges – and indeed all underlying factors – identified in this paper will not be relevant, and/or will vary in importance, to each individual project at any particular point in time. Yet, given the inter-linked nature of many challenges and (unexpected) knock-on impacts across the 4Rs, it remains important for projects to regularly review the challenges they face and consider any adjustments to their intervention package that may subsequently be required. To aid projects in tackling this need from a challenge-orientated perspective, we offer a step-by-step adaptive management framework (Box 1).

5 | CONCLUSIONS

From our compilation of information from the literature and combined professional experiences working in the region, we identify a large variety of challenges facing peatland and forest conservation projects in Indonesia. These relate to all 3Rs of the BRG's peatland restoration goals (Rewetting, Reforestation and Revitalization), plus a fourth R that we suggest is essential to consider alongside these (Reducing Fire). The challenges cover political, economic, legal, social, logistical and research themes, and we identify five underlying factors behind these. Importantly, our analysis indicates that:

1. All challenges have either a direct or indirect potential for impact on activities under each of the 4Rs, and many are inter-dependent and mutually reinforcing, implying that narrowly focused solutions are likely to be exposed to higher risk of failure;
2. Ensuring that two of the 4Rs – Rewetting and Reducing Fire – are addressed is critical to consider for addressing challenges under all 4Rs, as is considering the local socio-political situation and acquiring local government and community support; and

BOX 1 A step-by-step adaptive management framework for identifying project challenges, planning and regularly evaluating project interventions

We strongly recommend incorporating multiple stakeholders in the process outlined below, including scientists, local officials, local communities, project partners and (potential) funders. This will both ensure an enhanced knowledge base to better inform decision-making, in addition to increasing the potential for the project and its associated interventions to be accepted and supported by all necessary stakeholders. Steps relating to project monitoring follow previously published recommendations (e.g. Gardner, 2010; Harrison, 2013; Harrison et al., 2012; Lindenmayer & Likens, 2010; Mascia et al., 2014).

1. *Define project conservation/restoration goals and associated targets* in relation to the 4Rs (Rewetting, Revegetation, Revitalization and Reducing Fire), and incorporate SMART objectives.
2. *Review and identify the potential challenges that the project may face in achieving its goal and targets* in relation to all relevant Rs, and gauge the level of risk that each challenge is likely to present towards achieving each target (e.g. low/medium/high impact level with low/medium/high certainty). Precise approaches in relation to this will vary between projects, depending on needs and the availability of prior information relating to project targets and site conditions, but will likely need to include a combination of stakeholder consultation (including with local officials and communities), literature reviews and field research. Our list of challenges identified in Table 1 may serve as a useful reference or starting point in this regard, though individual initiatives may need to add extra challenges that have not been identified in our list.
3. Particularly if many challenges are identified, *group challenges together and identify potential underlying factors spanning across these*. It may be more efficient to develop interventions to target these underlying factors than to target each individual challenge independently.
4. *Consider the interventions required to address the challenges identified*. In cases where large numbers of challenges are identified and/or resources are limited, prioritize those interventions that are (a) anticipated to address the key underlying factors behind multiple individual challenges and/or address the individual challenges with highest associated risk level; and (b) are most politically, socially, economically and ecologically feasible given the project situation.
5. *Review whether any of the interventions identified are likely to have unintended negative repercussions* in relation to any other planned interventions or on progress in relation to any of the 4Rs. Revise if necessary.
6. *Develop a scientifically rigorous project monitoring plan*, including indicators relating to both implementation of project interventions and progress towards its specific goals and targets. For example, in a project aiming to prevent fire to protect orangutan habitat and increase their population, continuous monitoring of the following variables will be important: fire-fighting interventions, fire incidence and areas burned, plus annual change in forest area, habitat condition and orangutan population density. Ideally all variables will be measured before and after implementation of interventions, and data compared to a suitable control area not subject to project interventions. This should be considered as an integral part of the project to enable an objective documentation of project impacts and adaptation of interventions to maximize success.
7. *Discuss and review plans with all relevant stakeholders before finalizing*, and obtain any relevant financial and other support needed to implement intended interventions and achieve targets identified through the above.
8. *In dialogue with stakeholders, regularly review and where necessary adapt project targets, associated interventions and monitoring protocols*. Such reviews should consider changes in the ecological and socio-political condition of the site (and any adjacent areas that may influence the site), available resources and funding potential, international or local policies and regulations, and advances in scientific understanding. While changes in monitoring protocols may be desirable in relation to changes in any of the above, it is also important to ensure consistency in monitoring approaches to facilitate reliable comparisons and, where methodological changes must be made, to quantify any differences in measurements that may arise through such changes. Minimum annual reviews are recommended.

3. The suite of challenges faced – and thus the suite of conservation interventions required to address these – will be unique to each project, depending on its goals and prevailing local ecological, social and political conditions.

With this in mind, we propose an eight-step adaptive management framework to aid conservation and restoration projects in identifying and overcoming these challenges. While our analysis and interpretation are centred around the peatlands and forests of Kalimantan, many of the challenges, relationships and underlying factors identified, plus the general approach outlined in our adaptive management framework, are expected to be applicable to projects working in other tropical regions. Although the challenges facing peatland and forest conservation and restoration projects in Indonesia and further afield are numerous and complex, the need to overcome these challenges has never been greater. We hope that the analysis and framework provided in this paper will therefore serve as a "call to action" for projects to tackle these problems, and assist them in plotting a course to achieve their conservation and restoration goals.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

F.J.F.v.V., S.J.H. and M.E.H. initiated the University of Exeter workshop, at which the roundtable discussion session of conservation challenges that formed the core of this paper occurred. J.B.O. and L.J.D. chaired this workshop session, to which all authors contributed ideas and observations. S.M.C. and M.E.H. compiled discussion session notes, and M.E.H. led the post-workshop challenges database iterative review process, which involved all authors. M.E.H. conceived the paper and wrote the initial draft, to which all authors provided iterative critical contributions and approved submission. A.D. translated the Indonesian language abstract.

DATA AVAILABILITY STATEMENT

No data were generated during the course of this study, aside from that presented herein.

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