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Characterising policy responses to complex socio-ecological problems: 60 fire management interventions in Indonesian peatlands

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1. Introduction

Pressing socio-ecological problems, such as climate change, deforestation and chronic wildfire, present unique governance challenges (Padt et al. 2014; Jordan et al. 2015). They occur at multiple scales, affect diverse sectors, and have uncertain, controversial, and unevenly distributed impacts (e.g., Barlow et al, 2018; Marino and Ribot 2012; Ostrom 2010).

These challenges have elicited a broad range of interventions and, over the past two decades, many new governance arrangements have complemented, competed with, and occasionally transformed traditional government interventions (Jordan et al. 2005; Cashore et al. 2004; Doelle et al. 2012; Lambin et al. 2014; Obidzinski and Kusters 2015). Faced with this increasing governance "messiness", there is an urgent need to document and analyse these interventions. Despite a wealth of case studies, there are few large-scale, structured descriptions and comparative analyses of the diverse interventions that respond to complex socio-ecological problems. Such contributions are prerequisite to identifying which types of interventions lead to improved environmental and social outcomes, asking for example whether factors like non-state involvement or "multi-level" decision-making (i.e. involving a variety of scales or sectors) improve outcomes (Koontz and Thomas 2006; Newig and Fritsch 2009; Huitema et al. 2009).

Scholars across contexts have explored variables that might shape intervention performance (see Table 1; IFRI 2018). This has included, for example, recognising the mismatch between traditional centralized, hierarchically-ordered approaches to rulemaking and program design, and the real-world complexity of environmental problems (Ostrom 2010; Young 2002; McCarthy and Zen 2009; Termeer et al. 2010; Stewart et al. 2013). Scholars have highlighted the benefits of more diverse interventions that better reflect the complexity of socio-ecological problems (Young 2002; McCarthy and Zen 2009; Padt et al. 2014; Termeer et al. 2010; Stewart et al. 2013). Scholars have prescribed greater involvement of non-state actors, including arguments that private sector participation may improve intervention performance through market incentives and greater public participation (e.g., Anderson and Leal 1991, Forsyth 2010). Further, studies have highlighted that intervention outcomes can improve when diverse institutions with overlapping jurisdictions address a problem (e.g., Cash et al. 2006; Ostrom 2010). Importantly, scholars have identified the relevance of "targeting" to improve the performance of interventions: essentially, narrowing the parameters in which interventions apply in order to allocate resources to the specific stakeholders, sites, and times where they will be most impactful (see references in Table 1). For example, interventions from non-government or multilevel institutions are often more targeted, which can improve outcomes but may also introduce higher transaction costs and scaling challenges (e.g., Ostrom, Tiebout and Warren 1961; Wünscher et al. 2006; Wünscher et al. 2008; Sattler et al. 2013).

There is a need to make greater sense of the ensuing crowded intervention arenas — of interventions that engage different scales, sectors, and strategies. Such efforts should identify relevant interventions and systematically document their characteristics. This paper undertakes that work for Fire Management Interventions (FMI) to address chronic peat fires in Indonesia. Uncontrolled tropical fires are increasing in prevalence globally (Jolly et al.), including severe fires in the Brazilian Amazon and Indonesian peatlands at the time of writing. Peat fires in Indonesia

are a complex socio-environmental problem that have motivated a large number of diverse fire management interventions (FMI) from government, industry, and civil society over the past three decades (Dennis 1999; Padfield et al. 2016; Tacconi, 2016). We describe “who is doing what” to address Indonesia’s peat fires, by (1) identifying and categorizing FMI, (2) grouping FMI according to their institutional characteristics, and (3) investigating how institutional types differed in terms of the design of the FMI they mandated. We anticipated that FMI would have low levels of targeting overall, specifically when it came to differentiating between types of landholders. We anticipated higher levels of targeting among some types of FMI, notably among those involving multi-level institutions and civil society. We also hypothesised that certain intervention strategies would be strongly associated with certain sectors, notably that the government interventions would primarily rely on regulatory strategies and industry on incentives. Where incentives were used, we anticipated that these would be limited to the private sector and that few would include elements of conditionality.

“Stock-taking” of this intervention arena is timely, given the recent proliferation of new interventions as fires worsen. This study also contributes to the rapidly developing literatures on multi-level and polycentric governance by comparing interventions from diverse institutions responding to a single problem. It lays the groundwork for future studies assessing the comparative performance of different types of FMI, as it examines design variables suspected to affect performance (Table 1). Our comprehensive scope allows comparisons to be made across scales — geographic, political, and temporal — to an extent rare in the literature on the governance of complex socio-ecological problems (Newig and Fritsch 2009).

Peat fire in Indonesia

Extensive and increasingly frequent peat fires in Indonesia are causing severe carbon emissions, transboundary toxic smoke pollution (haze), ecosystem degradation, public health problems, economic losses, and diplomatic tensions in the ASEAN region (Yule 2008; Van der Werf 2015; Huijnen et al. 2016; Koplitz et al. 2016; Lohberger et al. 2017; Turetsky et al, 2014; Wijedasa et al. 2017). Although numerous interventions have attempted to address them since the 1980s, these peat fires have evaded a simple or universal solution (Dennis et al. 2005; Carmenta et al. 2017).

Large-scale wildfires are historically rare in moist tropical environments including Indonesia’s peat swamp forests (Turetsky et al. 2014). Undisturbed peat is waterlogged and resistant to fire, but peatland which has been drained for plantation agriculture is highly flammable (Sloan et al, 2017). Historically, peatland has been widely regarded as unproductive marginal land in Indonesia (Persoon and Simarmata 2014), but advances in agricultural technology, rising international demand for commodities such as palm oil, and a lack of economic alternatives to cash crops have made peatland drainage and development profitable (McCarthy et al. 2012). Land use change on peatlands has created the conditions for large-scale conflagrations in Indonesia. Fires spread easily due to the high organic material content of peat soil, can smoulder for long periods at low intensities (making them difficult to detect using remote sensing), and can follow coal seams underground, creating conditions that challenge attempts to extinguish them (Whitehouse et al. 2004; Turetsky et al. 2014). These fire events were previously associated with El Niño Southern Oscillation (ENSO) years but have recently begun to occur in non-ENSO years as well (Gaveau et

al. 2014; Sloan et al. 2017). Peat fires contribute disproportionately to toxic haze and carbon emissions, as compared to fires on mineral soils, and affect an extensive land area and large numbers of people in the ASEAN region (Miettinen et al. 2012; Marlier et al. 2015).

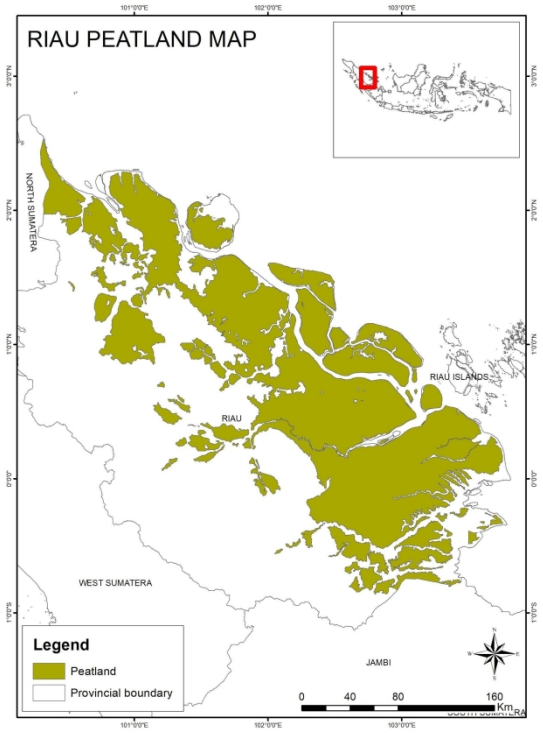
Traditionally, fire has been used in the agricultural practices of small-scale farmers in Indonesia, almost exclusively on mineral soils (Dove 1985). In contrast, today fire is used by new types of actors (e.g., immigrant farmers and absentee investors), at larger scales, and on new substrates with distinct ecological parameters — notably including peat soil (Chokkalingam et al. 2006; Cattau et al. 2016; Gaveau et al. 2017; Jelsma and Schoneveld 2016). Uncontrolled fire on peatland is exacerbated by failures of land use planning and law enforcement: fire is no longer used only for traditional agriculture but now may be used as retribution in land disputes, or where tenurial uncertainty removes incentives for careful management (Stolle et al. 2003; Dennis et al. 2005; Varkkey 2013). Fire remains the cheapest and most accessible method of land clearance and preparation (Ding et al. 2016), and a blanket ban on its use is not likely to be effective, efficient, or equitable (Carmenta et al, 2018). In order for FMI to succeed, controls on ignition and substrate flammability must contend with the perceived benefits of peatland conversion (FAO 2006

2. Methods

2.1 Scope and inclusion criteria

We gathered data on the institutional characteristics and design of all FMI addressing peatland fires in Riau Province, Sumatra (Figure 1), begun between January of 1999 and December of 2016 (n=60). We compiled our sample and dataset through a desk review of policy content, project documents, and sustainability reports, and then expanded and verified them through expert consultations in Jakarta and Pekanbaru with representatives from academia, civil society, government and industry (Supplementary Table A). We included international- and national-level FMI that apply in Riau, and those that were specific to Riau. Riau was selected because it is a site of dramatic land use change for oil palm and pulpwood cultivation (Miettinen et al. 2016), where frequent fires have prompted numerous FMI from diverse actors (Gaveau et al. 2014; Supplementary Table B).

Figure 1. Map of peatland extent in Riau, Sumatra. Source: Global Forest Watch derived from Ministry of Agriculture.



We included FMI with a stated intention to address peat fire, including those that addressed drivers (e.g., land tenure uncertainty) or undesirable outcomes (e.g., transboundary haze). We included FMI mandated by government, industry, and civil society, with geographic scales ranging from international to district-level. We included government regulations, decrees, and programs with provisions for enforcement and/or implementation (see section 2.2). We excluded enabling statutes (to avoid double-counting and counting unimplemented statutes), corporate sustainability pledges that were not clearly actioned, and advocacy campaigns. Our dataset contains no information on implementation or outcomes.

2.2 Characterising FMI design

To characterise FMI design, we assessed the literature to identify variables that were salient to the performance of FMI and of interventions addressing complex socio-ecological problems more broadly (Table 1). Through an iterative process, we refined our selection of variables to those that were also present in our dataset. We identified six variables for which information was available in the documentation of all 60 FMI: four describing FMI design (see Table 1) and two describing the institutional characteristics of FMI (Table 2).

2.2.1. Intervention design

We characterized each FMI according to its design (Table 1). The first design variable characterised FMI strategy according to four broad types: regulation and enforcement, incentives, technical solutions, and reform (adapted from Carmenta et al. 2017). Among FMI that used incentives, we also recorded whether the incentives were conditional; whether conditional incentives were triggered by inputs or results (e.g., fire occurrence or haze levels), and whether they involved “new” economic policy instruments such as eco-labelling (see Jordan et al. 2005).

The second design variable captured the overall approach to fire mitigation by identifying whether FMI focused on preventing fires or responding to them (i.e. via fire-fighting) (or both). Thirdly, we identified the primary geographic scale of FMI implementation.

Finally, the fourth design variable recorded the degree to which FMI were designed to target high-risk soil types (i.e., peat soil), differentiate between types of landholders that have different relationships to fire; and target time periods of particularly high fire risk (e.g., ENSO years, dry seasons, midday). Research on the causes of fires and analyses of FMI performance have consistently emphasized that narrowing FMI applicability to these areas, actors and time periods would improve their effectiveness, efficiency, and equity (see Table 1).

Table 1: **FMI intervention design variables**

Variable	Description	Values	Explanation and justification
Type of intervention strategy	Regulation: Does the FMI use regulatory strategies?	yes, no	Regulation-based interventions included legislation, but also non-state interventions that support enforcement through watchdog activities (e.g., the NGO Jikalahari)
	Incentives: Does the FMI use incentives?	yes, no	This includes all FMI that attempt to change behavior through the distribution of conditional and unconditional benefits, either in cash or in kind. Incentives are often identified as a mechanism driving improved performance among private environmental interventions (e.g., McCarthy and Zen 2009; Dryzek 1997; Humphreys 2008).
	If the FMI uses incentives, are these conditional?	conditional, unconditional	Conditional refers to the release of incentives based on meeting a predefined requirement, condition for the reward. Conditional cash transfers are expected to be related to improved performance (Wunder et al, 2018; Wunder 2005).
	If the FMI uses incentives, what triggers their disbursement?	[input-based, results-based, mixed]	“Trigger” refers to the conditions that must be met before conditional incentives are disbursed. “Input-based” triggers require conditions to be met that are indirectly related to the desired result. “Results-based” triggers disburse incentives when a desired result is achieved (Sattler et al. 2013).

	Are eco-labels used to verify sustainable practices?	yes, no	Eco-labels seek to promote sustainable behaviours by providing consumers with information about the social and environmental impacts of their purchases. They are one of the "'new' economic policy instruments" (NEPI) becoming increasingly popular in environmental governance (Cashore et al. 2004; Jordan et al. 2005).
	Reform: Does the FMI use institutional reforms to address fires?	yes, no	This includes FMI making changes in jurisdiction, administration, and resourcing directly intended to improve fire management (e.g., the 2007 version of the RSPO establishing a complaint process, or Presidential Instruction 11/2015 restructuring the Regional Disaster Management Agency with the goal of better responding to fires)
	Technical solutions: Does the FMI use technical solutions?	yes, no	Examples of technical solutions to peat fires include fire fighting and peatland rewetting
Approach to fire mitigation	Does the FMI attempt to prevent fires, or respond to them?	prevention, response, both	Studies of FMI frequently distinguish preventative from reactive measures (e.g., Vayda 2010; Nurhidayah 2014). Diverse stakeholders agree that preventative instruments should be prioritized on peat soil (Carmenta et al. 2017).
Geographic scale	At what geographic scale is FMI implementation planned?	district, provincial, national, international	This variable refers to the geographic scale upon which FMI are designed to be implemented.
Evidence of targeting	Soil type targeting: Does the FMI treat peat soil distinctly from mineral soil?	yes, no	Peat soil... ● is more flammable when drained than mineral soil (Turetsky et al. 2014); ● undergoes combustion that is uniquely difficult to extinguish (Turetsky et al. 2014; Whitehouse et al. 2004); ● has been the main source of toxic smoke pollution and carbon emissions from wildfires in Indonesia (Koplitz et al, 2016; Sargeant 2001; Marlier et al. 2015); and

			● is less frequently used for small-scale or traditional agriculture than mineral soils in Indonesia (Tacconi and Ruchiat 2006).
	Landholder targeting: If the FMI targets landholders, how many categories of landholder does it distinguish?	1, 2, 3	Landholder type (e.g., plot size, land title, residence type) is linked to... ● land use dynamics and land clearance behaviors (Ekadinata et al. 2013; Jelsma and Schoneveld 2016); ● landholder capacity and motivation to manage fire safely (Bompard and Guizol 1999; Stolle et al. 2003; Dennis et al. 2005; Hidayat et al. 2015; Jelsma et al. 2017); and ● expressed preferences for effective FMI (Carmenta et al, 2017). Failure of FMI to differentiate among actors... ● disproportionately negatively affects smaller farmers (Tan 2005); ● can create scope for rent-seeking (Mathews 2005); ● impedes efforts to prosecute serious offenders (Mayer 2006); ● limits scalability of interventions (Jelsma et al. 2017); ● can unnecessarily illegalize and disarticulate landholders (Mathews 2005; Jelsma and Schoneveld 2016); and ● contributes to biased discourses of blame (Harwell 2000).
	Temporal targeting: Does the FMI target high-risk time periods (e.g., according to weather conditions, month, time of day)?	yes, no	Risk of wildfire varies with weather conditions, time of year, time of day, and cyclical climatic phenomena like ENSO (Gaveau et al. 2014; Marlier et al. 2015; Taufik et al, 2018). Targeting high-risk time periods is part of fire management strategies worldwide, from national schemes (e.g. Monzón-Alvarado et al. 2014) to community fire-based agriculture practices (e.g. Carmenta et al. 2013).

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2.2.2 Institutional characteristics

We used two variables to characterize the institutions behind FMI. Firstly, we classified the lead (i.e., mandating) institution(s) of each FMI as either government, industry, or civil society (Table 2). Secondly, we recorded whether FMI decision-making structures were multi-level or monocentric. FMI were coded as multi-level if decision-making structures involved multiple jurisdictional levels (i.e., district, provincial, national, international), multiple functional sectors (i.e. agriculture, forestry, environment, public works), or multiple societal sectors (i.e. government, industry, civil society). Most FMI coded as multi-level had several of these characteristics. Although somewhat crude, this measure was most practical for our purposes, as there is no agreed-upon framework for evaluating governance properties such as polycentricity, adaptivity and multilevel character (Hooghe and Marks 2003; Huitema et al. 2009).

Table 2. FMI lead institution and decision-making structure in Riau, Indonesia (full membership list in Supplementary Table B)

Lead institution sector / Decision-making structure	Monocentric	Multilevel*
Government	23	15
Industry	6	7
Civil society	5	4

* Involving multiple jurisdictional levels, functional sectors or societal sectors

2.3 Method of analysis

We used descriptive statistics to present the diversity of FMI, and non-parametric statistical tests to analyze relationships among variables describing FMI design (Table 1) and FMI institutional characteristics (Table 2). Nonparametric tests were most suitable due to the relatively small size of the dataset and the uneven distribution of observations among the variables. We used Fisher's exact test to evaluate the relatedness of categorical variables (e.g. the relatedness of our targeting variables with sector), and examined adjusted residuals using the Bonferroni correction to determine which categories were significantly related to sector. Finally, we used Kruskal-Wallis H tests for relationships between variables describing FMI institutional characteristics and FMI design, and the geographic scale at which FMI were intended to apply. All statistical analyses were conducted in SPSS 22.0.

3. Results

3.1 Design of Fire Management Interventions

We identified a total of 60 FMI which addressed fire in Riau Province. FMI strategies were diverse, as captured by our four broad strategic categories (Figure 2; Table 3). They were dominated by regulation and enforcement-based strategies (68%), almost all of which sought to

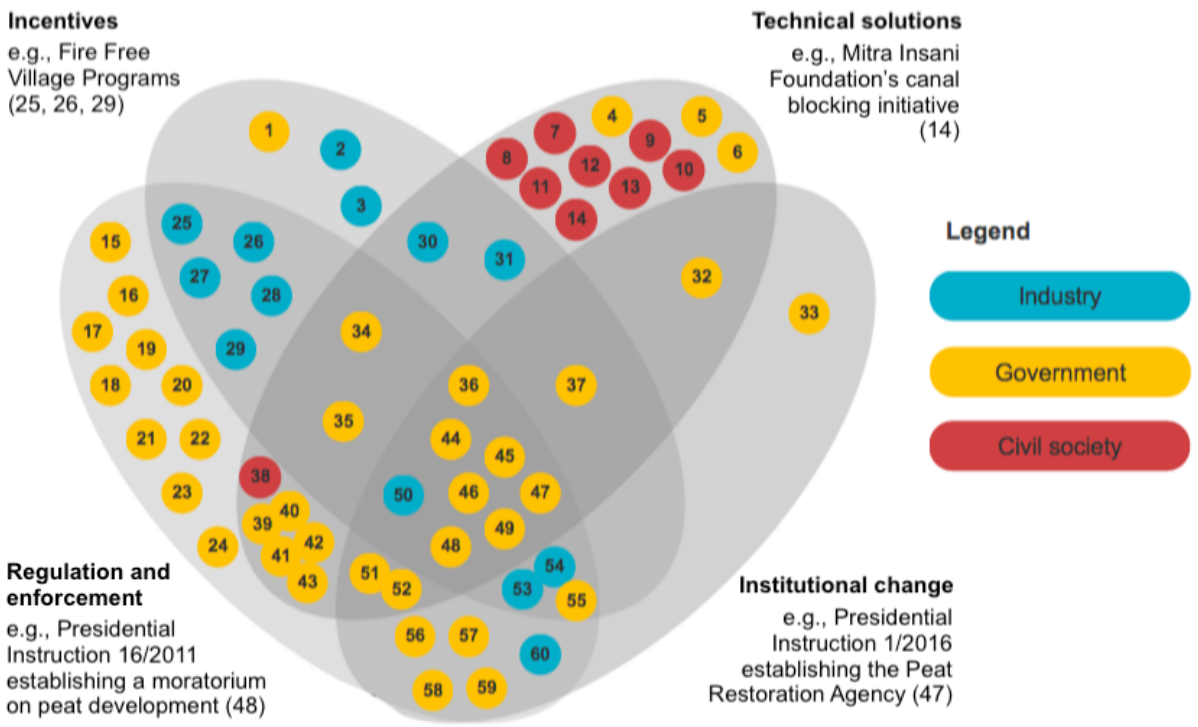
restrict and deter fire use. Technical solutions were the second most common strategy (55%), followed by incentive-based strategies (38%) and reform (35%). Importantly, most FMI employed a mix of strategies (58%, Figure 2). Almost all FMI (92%) included some aspect of fire prevention (e.g., canal blocking to reflood peatlands). Many (70%) took a responsive approach to fire mitigation (e.g., fire fighting), and the majority of FMI included measures to both prevent and fight fires (62%).

Of incentive-based FMI, a larger number than expected (50%) employed elements of conditionality. However, the majority disbursed benefits based on the completion of an “input” action expected to reduce fire occurrence, such as the use of prescribed fire-free land-clearing methods (67%). The remaining 42% of FMI using conditional incentives disbursed benefits based on the occurrence of a desired environmental result, such as haze severity falling below a specified threshold or a year passing without fire events (21% of incentive-based FMI). A small number of FMI used “new economic policy instruments”, primarily eco-labelling schemes.

Nearly half of FMI were government-led interventions, although the dataset contained FMI from relatively diverse sectors, including a recent wave of industry-led FMI (77% of industry-led FMI appeared since 2013) (Table 3; Supplementary Table B). Nearly half of FMI (43%) were characterized as “multi-level”. There was no significant relationship between multi-level decision making and sector.

Over half of FMI (63%) distinguished between interventions on peat versus mineral soils, and around one third of FMI focused exclusively on peat soils (33%). Most FMI (>90%) treated landholders differently based on whether they were “smallholders” or “businesses”, but did not distinguish additional categories, and inconsistently specified the definitions used to classify landholder types. Only 12% of FMI targeted high-risk time periods.

Figure 2. Fire Management Interventions (FMI) in Riau Province, Sumatra (1999-2016; n=60), presented by type of FMI strategy and lead sector (definitions in Table 1).



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1. Indonesia-Malaysia Collaboration in Rokan Hilir
2. Integrated Forestry and Farming System Project
3. Minamas/Sime Darby fire response program
4. UNDP canal blocking
5. Indofire System
6. Southeast Asia Fire Danger Rating System
7. Perkumpulan Elang canal blocking and peat re-wetting
8. Seruni gender-based community empowerment
9. Eyes on the Forest hotspot monitoring and investigation
10. PM.Haze peatland restoration
11. Wetlands International peatland mapping
12. Greenpeace research and investigation
13. World Resources Institute research and investigation
14. Mitra Insani Foundation canal blocking
15. ASEAN ATHP Guidelines 2004
16. ASEAN ATHP Guidelines 2003
17. Government Regulation 71/2014
18. Ministry of Agriculture Regulation 11/Permentan/OT.140/3/2015
19. Ministry of Agriculture Regulation 14/Permentan/PL.110/2/2009
20. Ministry of Agriculture Regulation 26/Permentan/OT.140/2/2007
21. Ministry of Agriculture Regulation 98/2013
22. Ministry of Environment Instruction S.494MENLHK-PHPL2015
23. Ministry of Environment Regulation 7/2014
24. Riau Provincial Regulation 8/2014
25. APRIL Group Fire Free Village program
26. Asian Agri Fire Free Village program
27. Asosiasi Amanah
31. Riau Ecosystem Restoration Project
32. Indonesian National Board for Disaster Management Rapid Response Brigade
33. ASEAN Panel of Experts
34. Ministry of Forestry Regulation P.12/Menhut-II/2009
35. SEApeat project
36. ASEAN Agreement on Transboundary Haze Pollution
37. Perdes 7/2009 Sepahat/Bengkalis
38. Jikalahari hotspot monitoring, watchdog activities
39. Government Regulation 57/2016
40. Government Regulation 45/2004
41. Presidential Instruction 10/2011
42. Presidential Instruction 6/2013
43. Presidential Instruction 8/2015
44. ASEAN Peatland Forests Project
45. Fire Care Communities
46. Ministry of Agriculture Regulation 47/Permentan/OT.140/4/2014
47. Presidential Instruction 1/2016
48. Presidential Instruction 16/2011
49. Riau Governor Regulation 5/2015
50. Indonesian Palm Oil Pledge
51. Directorate General of Forest Protection and Nature Conservation 21/KTPS/DJ-IV/2002
52. Presidential Instruction 11/2015
53. RSPO 2005
54. RSPO principles and criteria 2007
55. Government Regulation 4/2001
56. Governor Regulation 11/2014

28. FSC deforestation monitoring
29. Musim Mas Fire Free Village program
30. Giam Siak Kecil Bukit Batu Biosphere Reserve
57. Minister of Agriculture 19/Permentan/OT.140/3/2011
58. Ministry of Environment Regulation 10/2010
59. REDD+ Management Agency auditing program
60. RSPO principles and criteria 2013

226
227 **3.2 Differences in FMI design across institutional types**
228 As we anticipated, design differed significantly between FMI from government, industry, and civil
229 society. For example, different sectors employed distinct types of intervention strategies: sector
230 was significantly associated with use of regulation and enforcement, incentives, technical
231 solutions, and reform ($p = 0.000$, 0.000, 0.001, and 0.026, respectively, $\alpha=0.05$). Specifically, as
232 expected, government-led FMI were associated with the use of regulatory or enforcement-based
233 strategies ($p=0.004$, $\alpha=0.008$), and civil society-led FMI with their absence ($p= 0.000$, $\alpha=0.008$).
234 As predicted, industry-led FMI were associated with the use of incentives ($p= 0.000$, $\alpha=0.008$),
235 while civil society-led FMI were associated with technical interventions ($p= 0.004$, $\alpha=0.008$)
236 (Figure 2). There were no significant relationships between FMI design and whether FMI decision
237 making was multi-level.
238
239 Among FMI that used incentives, the use of conditionality was significantly associated with sector
240 ($p= 0.000$, $\alpha=0.05$). Specifically, government-led FMI were associated with the use of
241 unconditional incentives ($p=0.002$, $\alpha=0.008$), and industry-led FMI with the use of conditional
242 incentives ($p=0.000$, $\alpha=0.008$).
243
244 The use of eco-label schemes to verify sustainable practices was also significantly associated
245 with sector ($p=0.000$, $\alpha=0.05$). Specifically, their use was associated with industry-led FMI
246 ($p=0.000$, $\alpha=0.008$), and they were absent from government-led FMI ($p=0.002$, $\alpha=0.008$). The
247 relationships between FMI sector and FMI design variables are summarized in Table 3.
248
249 The use of targeting by FMI was low overall, as hypothesized, and largely did not vary
250 significantly across institutional types. Targeting to peat soils and high-risk time periods were not
251 significantly related to sector. The exception was targeting among landholders, which was
252 significantly associated with sector ($p=0.002$, $\alpha=0.05$). Specifically, government-led FMI tended to
253 treat landholders as a uniform group (54%), or distinguish only between “smallholders” and
254 “businesses” (42%) ($p=0.001$, $\alpha=0.005$). In contrast, industry-led FMI always targeted
255 smallholders and businesses separately ($p=0.003$, $\alpha=0.005$). FMI that used eco-labelling were the
256 most nuanced, with distinct rules and programs for “businesses”, “independent smallholders”, and
257 “schemed smallholders” (i.e. smallholders operating within a cooperative system within large
258 agricultural concessions (Jelsma and Schoneveld 2017).
259
260 There were significant relationships between sector and the geographic scale on which FMI were
261 designed to operate ($p=0.00$): notably, FMI led by civil society were exclusively district-level
262 (Table 3). Incentive-based intervention strategies were also significantly associated with

geographic scale (p = 0.00). Specifically, the use of incentives was associated with smaller geographic scales, with 54% of incentive-based FMI operating at the district level, and incentives triggered by results operating exclusively at the district level. That said, eco-labelling schemes were notably designed to operate on an international scale. There were no significant relationships between geographic scale and FMI targeting by soil type, landholder type or time period.

Table 3. Relationships between FMI design and lead sector (Percent by sector; asterisks indicate significant relationships, $p < 0.05$; □ totals equal >100% because each FMI can fit into >1 category)

	Government n (%)	Industry n (%)	Civil society n (%)	Total n (%)
Type of intervention strategy*□				
Regulation and enforcement	31(82)	9(69)	1(11)	41(68)
Technical solutions	21(55)	3(23)	9(100)	33 (55)
Reform	17(45)	4(31)	0	21(35)
Incentives	12(32)	12(92)	0	24(40)
Use of conditionality*	3(8)	9(69)	0	12(20)
Results-based	2(5)	3(13)	-	5(8)
Input-based	2(5)	6(46)	-	8(13)
Use of eco-labels*	0	5(39)	0	5(8)
Geographic scale*				
District	6(16)	8(62)	9(100)	23(38)
Provincial	4(11)	0	0	4(7)
National	23(62)	0	0	23(38)
International	5(13)	5(39)	0	10(17)
Approach□				
Fire prevention	34(89)	13(100)	8(89)	55(92)
Fire response	31(82)	7(54)	4(44)	42(70)
Targeting				

Target peat soils	23 (61)	8(62)	7(78)	38(63)
Differentiate ≥2 landholder groups*	12(32)	12(92)	3(33)	27(45)
Target high-risk time periods	6(16)	0	1(11)	7(12)

4. Discussion

4.1 FMI employed diverse types of intervention strategies

While FMI employed strikingly diverse intervention strategies (Figure 2), a large proportion nonetheless focused on regulation and enforcement. Many of these FMI overlapped in scope, or even conflicted with other regulations (e.g., Ardiansyah et al. 2015), perhaps reflecting a "disjointed incrementalism" in the government's response to fire (see Lindblom 1979). There is evidence from both the media and the scientific literature that environmental regulations in Indonesia have historically underperformed, due to low state capacity and political accountability (e.g., McCarthy and Zen 2009; Tacconi 2016; Varkkey 2013; Nesadurai 2018). Given this evidence, our finding that regulation was a common government response to peat fire, but largely lacked appropriate targeting among landholders, suggests that many FMI are likely to face implementation challenges (e.g., Thung et al. 2019).

Interventions involving institutional reform were less common among FMI, despite the important role that institutional dysfunction has played in the peat fire problem (see Purnomo et al. 2017). For example, government agencies budgets are often tied to traditional firefighting FMI that no longer reflects best practices (Miettinen et al. 2016). This result indicates a key area in which FMI design can be improved, as does our finding that conditionality of incentives is lacking.

In contrast, while commentators on Indonesia's peat fires have long criticized a perceived lack of emphasis on fire prevention (e.g., CIFOR 2015; Purnomo et al. 2017), we found that most FMI adopted preventative approaches. These preventative FMI addressed the drivers of fire through attempts such as changing burning behavior and reducing land flammability through peatland reflooding (see Supplementary Table B). It is possible that this observed neglect has been rectified in recent years, or that fire prevention has been neglected during FMI implementation rather than in FMI design. Importantly, this shows an existing policy base from which to work.

4.2 Intervention design differs among government, industry and civil society

Government, industry and civil society took different approaches to FMI design. They differed significantly in terms of the types of intervention strategies they used, notably the use of incentives, and the forms of targeting they employed (Table 3). Despite these tendencies, FMI from all sectors tended to employ multiple intervention strategies and mixes were more common than single strategy approaches (Figure 2). Contrary to our expectations, our findings indicated no significant design differences between multi-level and monocentric FMI (Table 3).

The results show that government FMI continued to be primarily based on regulation and enforcement (82%), but were also engaged in incentive-based strategies (32%). This reflects the increasing use of market-based tools in environmental policy by governments over the past three decades (Stavins 2003; Jordan et al. 2005; McCarthy and Zen 2009). Similarly, recent work has highlighted that many contemporary market-based environmental initiatives rely on government support and coordination (Vatn 2015). Incentives were, nevertheless, strongly associated with industry FMI, many of which have appeared in the past decade (69% initiated since 2012). Further, where incentives were used, industry FMI were associated with the conditional disbursement of incentives, while government-led incentive schemes tended to be unconditional. This difference is particularly interesting given recent criticisms of incentive schemes that lack conditionality (e.g., Birdsall et al. 2011) and the rarity of conditional disbursement in their design (Wunder et al. 2018).

Another notable design difference among sectors involved the use of landholder targeting. Industry FMI employed significantly more nuanced landholder targeting than other sectors, frequently employing basic distinctions in landholders size, and occasionally distinguishing "independent" from "schemed" landholders. Once again, government FMI represented the opposite extreme, often treating landholders uniformly, irrespective of basic distinctions in size, types of ownership and degree of absenteeism. This finding is likely due to the fact that many industry FMI operate at the district scale allowing greater local nuance, and were led by companies with potentially strong incentives to establish fire mitigation measures with their neighbours. Indeed, industry FMI focused primarily on changing the behaviors of smallholder farmers.

These differences provide a starting point for analysing and comparing FMI performance across sectors and different design configurations (Table 1). There is also scope to test whether, as suggested in the literature, the design variables identified in Table 1 are determinants of particular social and environmental outcomes.

Moreover, our data suggests the need to further explore interactions among FMI from different sectors. For example, certain government interventions (some of which are too recent to feature in our dataset) have scaled up or adapted FMI designs pioneered by industry. This includes the Government of Indonesia's mandatory Indonesian Sustainable Palm Oil (ISPO) standard, which is a clear adaptation of the industry-led Roundtable on Sustainable Palm Oil (RSPO) standard's eco-label model (Hospes 2014). The Government of Indonesia also reportedly plans to implement the "fire free village" model developed by industry in over 700 villages across the country (Sloan et al. 2017). The "fire free village" and eco-label models were notable in our dataset for their high levels of targeting and use of conditional incentives, although both operate at limited scales. Studies of polycentric and multi-level governance systems have identified a trade-off between the nuance and policy fit that can be achieved by "messy" governance systems and the scaling and coordination that monocentric government offers (Ostrom et al. 1961). Case studies of municipal service provision, irrigation systems, and international climate governance suggest that, while multilevel and non-state interventions are often more creative, state involvement may be required for coordination at larger spatial scales (Ostrom et al. 1961; Huitema et al. 2009; Meinzen-Dick

1997; Meinzen-Dick 2007; Bernstein and Hoffman 2018). Whether this type of policy learning is occurring in the case of Indonesia's peat fires will determine the implications of our findings. In addition, since industry FMI have tended to focus on changing smallholder behavior (with notable exceptions such as the short-lived Indonesian Palm Oil Pledge (IPOP)), scholars should monitor whether government adoption of industry intervention models serves to perpetuate blame narratives that overemphasize the culpability of smallholders (e.g., Forsyth 2014). Similarly, scholars should monitor whether complementary interventions that capture additional land users (e.g., medium sized enterprises) are enacted.

4.3 Fire Management Interventions were largely untargeted

As FMI promulgate rapidly, supported by development and private funds deployed after the disastrous 2015 fires, there is a need to evaluate the extent to which FMI have incorporated existing design recommendations. In particular, despite the importance of targeting to shaping outcomes (Table 1), our results showed that targeting high-risk soil types, actors and time periods was rare among the interventions in our dataset.

The most common type of targeting was based on soil type, and most FMI (63%) targeted peat soil as distinct from mineral soil. This is important because of peat soil's specific implications for fire, haze and greenhouse gas emissions, and because of the unique biophysical challenges to fire prevention and fire fighting on peat soil (Hameiri and Jones 2017; Turetsky et al. 2014). Several prominent FMI failed to target peat soil, including the 2015 national ban on all fire use, regardless of soil type. This has limited the land use options of small-scale traditional farmers operating on mineral soil with comparatively low risk of fire escape (Thung et al, 2019; Jelmsa et al. 2017).

Among FMI that targeted landholders, few distinguished among landholder types (45% differentiated 2 or more landholder types). When they did, distinctions were almost always limited to a coarse distinction between "smallholders" and "businesses". There is considerable scope to make this landholder targeting more reflective of land use management on-the-ground; there are at least seven distinct smallholder categories within Riau, ranging from small-scale farmers without tenure to wealthy absentee investors to medium-sized enterprises (Jelsma et al. 2017). Even FMI with the most nuanced approaches to landholder targeting did not differentiate landholders by the size of their landholding (beyond the distinction between "smallholders" and "businesses") or degree of absenteeism. Yet these different types of landholders have distinct motivations for using fire, different levels of access to alternative land-clearing techniques, and different levels of capacity to manage and fight fires (Dennis et al. 2005, Jelsma and Schoneveld 2016; Jelsma et al. 2017). Moreover, they have distinct and often conflicting perspectives on the benefits of using fire, the burdens that result from escaped peatland fires, and the effectiveness of different solutions (Carmenta et al. 2017). Failure to account for these distinctions is likely to undermine FMI performance.

Finally, FMI rarely (20%) targeted the high-risk time periods most associated with escaped fire such as dry seasons, ENSO years, or hot or windy times of day. Yet, this temporal targeting is

used around the world to reduce the likelihood of wildfires while enabling low-risk forms of fire use, including in Malaysia, Brazil, and Australia (Wong et al. 2010; Monzón-Alvarado et al. 2014; Taufik et al. 2018). Temporal targeting can also improve the equity outcomes of FMI by limiting restrictions on fire use among small-scale farmers who lack access to other land clearing options (Kull 2004; Carmenta et al. 2018).

Despite the ban on fire use in land management, there is some qualitative evidence that FMI targeting has tended to improve over time. For example, in 2009, the industry-led RSPO standard began to distinguish independent smallholders from schemed smallholders; the government-led ISPO standard followed suit in 2015. In 2016, the Government of Indonesia established the Peatland Restoration Agency which focuses on peatland restoration as part of its fire management efforts. The ASEAN “zero burn” guidelines for land clearing, which are often referenced by other FMI, introduced new guidelines in 2004 to allow for the managed use of fire by specific actors in specific geographic areas and time periods (ASEAN 2004).

5. Conclusion

As environmental governance arenas become increasingly diverse and “messy”, there is an urgent need to describe and compare interventions. Mapping out the landscape (e.g., Figure 2) allows practitioners to think about "where" their interventions fall in relation to others, including others in their sector. Indeed, while anyone working on Indonesia’s peat fire challenge will be familiar with some of these interventions, the diversity of FMI highlighted in this study is rarely acknowledged. Descriptive work can support policy learning by helping practitioners and emerging FMI consider possible gaps in their intervention design. For example, we highlight gaps associated with the targeting of different stakeholder types and fire risk periods, and the use of conditionality within incentive schemes—design attributes highlighted in the literature as relevant to performance.

Drawing on our documentary work, we demonstrate a method for looking at the relationships between institutional characteristics, intervention design, and--ultimately--social and environmental outcomes. This paper contributes by characterizing the institutional characteristics of fire management interventions in Indonesia, and identifying differences in design between institutional types that the literature suggests are relevant to outcomes. Future research should examine whether the differences we observed translate into differences in outcomes, and under what conditions. In particular, there is scope to explore how different strategies and levels of targeting perform, especially when it comes to the challenge of balancing nuanced intervention design with scalability.

More research is also needed on the patterns of interaction between FMI, and between interventions responding to other complex socio-ecological problems. Weighting interventions by factors such as market footprint, legal force and political power would allow future research to better examine how diverse interventions fit together as a governance system (Morrison 2017). Given the diversity of FMI documented in this paper, future research should evaluate whether Indonesia’s peat fire governance system exhibits polycentric characteristics such as policy learning and mutual adjustment (McGinnis 2016).

Our results underscore the importance of developing and monitoring comprehensive databases of governance activities addressing complex socio-ecological problems (e.g., Jerrells and Ostrom 1995; IFRI 2018; Simonet et al. 2018; LFPFN 2018). This study's categorizations can inform the future development of such datasets, with the ultimate goal of identifying relationships between institutional characteristics, intervention design, and outcomes. By constructing a more complete understanding of environmental governance initiatives addressing tropical peat fires and other complex environmental challenges, we can work towards a better understanding of how best to govern them in the future.

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Competing interests statement

Declarations of interest: none

462 **Supplementary Table A: List of experts consulted**

Institution	**Interview date**
World Resource Institute Indonesia	February 1, 2017
APRIL Group	February 3, 2017
Institut Pertanian Bogor, World Bank, and REDD+ Task Force	February 14, 2017
Jikalahari	May 2, 2017

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464 **Supplementary Table B: Fire Management Interventions and their institutional groupings**

Lead actor / decision-making	**Monocentric**	**Multilevel**
Government	Directorate General of Forest Protection and Nature Conservation 21/KTPS/DJ-IV/2002 on guidelines for the establishment of forest fire control brigades Ministry of Agriculture Regulation no. 14/Permentan/PL.110/2/2009 on guidelines for the utilisation of peatland areas for oil palm cultivation Government Regulation 71/2014 on the protection and management of peatland United Nations Development Program (UNDP): canal blocking in peatlands (2015) Ministry of Environment Instruction S.494MENLHK-PHPL2015 prohibiting peatland development Ministry of Environment Regulation 10/2010 on the mechanisms of environmental pollution and damage prevention related to forest and land fires Governor Regulation 11/2014 on the Forest and Land Fire Control Center of Riau Province	Indonesia-Malaysia Collaboration in Rokan Hilir under the ASEAN Peatland Management Project: air quality monitoring and education in zero-burn farming techniques (2008) Fire Care Communities based on Regulation of The General Director Forest Protection and Natural Conservation No.P. 2IV-SET2014 REDD+ Management Agency: auditing compliance of agroforestry corporations with fire and peat management rules (2014) Ministry of Forestry Regulation P.12/Menhut-II/2009 on forest fire control Presidential Instruction 16/2011 on the improvement of Land and Forest Fire Control ASEAN Agreement on Transboundary Haze Pollution (2002) ASEAN Peatland Forests Project: institutional change, conserving peatlands, and encouraging sustainable management (2009)

	Indonesian National Board for Disaster Management Rapid Response Brigade (2009) Government of Indonesia Regulation 4/2001 on environmental damage and pollution control in relation to forest and land fires Government of Indonesia Regulation 45/2004 on forest protection Ministry of Agriculture Regulation no. 26/Permentan/OT.140/2/2007 on the guidelines for estate crop licensing Presidential Instruction 10/2011 establishing a moratorium on developing peatlands Presidential Instruction 6/2013 establishing a moratorium on developing peatlands Ministry of Agriculture Regulation no. 47/Permentan/OT.140/4/2014 on the establishment of fire brigade and the guidelines for the prevention and control of forest and land fires Ministry of Environment Regulation 7/2014 on environmental loss due to pollution and environmental damages Presidential Instruction 11/2015 on the improvement of forest and land fire control Presidential Instruction 8/2015 establishing a moratorium on developing peatlands Ministry of Agriculture Regulation no. 11/Permentan/OT.140/3/2015	ASEAN Panel of Experts on Fire and Haze Assessment and Coordination (2005) SEApeat project: institutional change, fire monitoring, and incentives and education for sustainable peatland management (2011) Southeast Asia Fire Danger Rating System project (1999) Indofire System under the Indonesia-Australia Forest Carbon Partnership: hotspot monitoring (2009) Perdes 7/2009 Sepahat/Bengkalis ASEAN Agreement on Transboundary Haze Pollution: Guidelines for the Implementation of the ASEAN Policy on Zero Burning (2003) ASEAN Agreement on Transboundary Haze Pollution: Guidelines for the Implementation of Controlled Burning Practices (2004)

	on Indonesian Sustainable Palm Oil (ISPO) Presidential Instruction 1/2016 on Peat Restoration Agency Riau Provincial Regulation 8/2014 on Environmental Management and Environmental Law Compliance Riau Province Ministry of Agriculture Regulation No. 98 of 2013 Minister of Agriculture No.19/Permentan/OT.140/3/2011 creating the Indonesian Sustainable Palm Oil certification Government Regulation No. 57/2016 Riau Governor Regulation No. 5/2015	
Industry	Riau Ecosystem Restoration Project (APRIL Group in partnership with Flora and Fauna International and Bidara): support and incentives for community-based conservation on the Kampar Peninsula (2013) Integrated Forestry and Farming System Project (Asia Pulp and Paper in partnership with Desa Makmur Peduli Api) (2016): support and incentives for community-based forest conservation APRIL Group Fire Free Village program: fire management incentives and education for communities (2014) Asian Agri Fire Free Village program: fire management incentives and education for communities (2016)	Roundtable on Sustainable Palm Oil (RSPO): principles and criteria (2013) Asosiasi Amanah: oil palm smallholders collective providing support for RSPO and ISPO certification (2011) Forest Stewardship Council (FSC): deforestation monitoring (2014) Indonesian Palm Oil Pledge (IPOP): evaluation and audit licensing of peat (2015) Giam Siak Kecil Bukit Batu Biosphere Reserve (Sinar Mas in partnership with civil society and government) (2009) Roundtable on Sustainable Palm Oil (RSPO): principles and criteria (2007)

	Musim Mas Fire Free Village program: fire management incentives and education for communities (2016) Minamas/Sime Darby: fire response and monitoring and fire management education for communities (2015)	Roundtable on Sustainable Palm Oil (RSPO) (2005)
Civil society	Wetlands International: peatland mapping in consultation with Deltares (2015) Greenpeace: research and investigation (2013) Indonesian Women's Union (Seruni): gender-based community empowerment (2015) Riau Forest Rescue Network (Jikalahari): hotspot monitoring and watchdog activities (2016) Mitra Insani Foundation: canal blocking (2012)	World Resources Institute: research and investigation (2014) Eyes on the Forest: hotspot monitoring and investigation (2015) Perkumpulan Elang in partnership with the Riau Natural Resources Conservation Centre: canal blocking and peat re-wetting (2016) People's Movement to Stop Haze Singapore (PM.Haze): peatland restoration (2014)

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Supplementary Table A: List of experts consulted

Institution	**Interview date**
World Resource Institute Indonesia	February 1, 2017
APRIL Group	February 3, 2017
Institut Pertanian Bogor, World Bank, and REDD+ Task Force	February 14, 2017
Jikalahari	May 2, 2017

Supplementary Table B: Fire management interventions and their institutional characteristics

Lead actor / decision-making	**Monocentric**	**Multilevel**
Government	Directorate General of Forest Protection and Nature Conservation 21/KTPS/DJ-IV/2002 on guidelines for the establishment of forest fire control brigades Ministry of Agriculture Regulation no. 14/Permentan/PL.110/2/2009 on guidelines for the utilisation of peatland areas for oil palm cultivation Government Regulation 71/2014 on the protection and management of peatland United Nations Development Program (UNDP): canal blocking in peatlands (2015) Ministry of Environment Instruction S.494MENLHK-PHPL2015 prohibiting peatland development Ministry of Environment Regulation 10/2010 on the mechanisms of environmental pollution and damage prevention related to forest and land fires Governor Regulation 11/2014 on the Forest and Land Fire Control Center of Riau Province Indonesian National Board for Disaster Management Rapid Response Brigade (2009)	Indonesia-Malaysia Collaboration in Rokan Hilir under the ASEAN Peatland Management Project: air quality monitoring and education in zero-burn farming techniques (2008) Fire Care Communities based on Regulation of The General Director Forest Protection and Natural Conservation No.P. 2IV-SET2014 REDD+ Management Agency: auditing compliance of agroforestry corporations with fire and peat management rules (2014) Ministry of Forestry Regulation P.12/Menhut-II/2009 on forest fire control Presidential Instruction 16/2011 on the improvement of Land and Forest Fire Control

	Government of Indonesia Regulation 4/2001 on environmental damage and pollution control in relation to forest and land fires Government of Indonesia Regulation 45/2004 on forest protection Ministry of Agriculture Regulation no. 26/Permentan/OT.140/2/2007 on the guidelines for estate crop licensing Presidential Instruction 10/2011 establishing a moratorium on developing peatlands Presidential Instruction 6/2013 establishing a moratorium on developing peatlands Ministry of Agriculture Regulation no. 47/Permentan/OT.140/4/2014 on the establishment of fire brigade and the guidelines for the prevention and control of forest and land fires Ministry of Environment Regulation 7/2014 on environmental loss due to pollution and environmental damages Presidential Instruction 11/2015 on the improvement of forest and land fire control Presidential Instruction 8/2015 establishing a moratorium on developing peatlands Ministry of Agriculture Regulation no. 11/Permentan/OT.140/3/2015 on Indonesian Sustainable Palm Oil (ISPO) Presidential Instruction 1/2016 on Peat Restoration Agency Riau Provincial Regulation 8/2014 on Environmental Management and Environmental Law Compliance Riau Province Ministry of Agriculture Regulation No. 98 of 2013	ASEAN Agreement on Transboundary Haze Pollution (2002) ASEAN Peatland Forests Project: institutional change, conserving peatlands, and encouraging sustainable management (2009) ASEAN Panel of Experts on Fire and Haze Assessment and Coordination (2005) SEApeat project: institutional change, fire monitoring, and incentives and education for sustainable peatland management (2011) Southeast Asia Fire Danger Rating System project (1999) Indofire System under the Indonesia-Australia Forest Carbon Partnership: hotspot monitoring (2009) Perdes 7/2009 Sepahat/Bengkalis ASEAN Agreement on Transboundary Haze Pollution: Guidelines for the Implementation of the ASEAN Policy on Zero Burning (2003) ASEAN Agreement on Transboundary Haze Pollution: Guidelines for the Implementation of Controlled Burning Practices (2004)

	Minister of Agriculture No.19/Permentan/OT.140/3/2011 creating the Indonesian Sustainable Palm Oil certification Government Regulation No. 57/2016 Riau Governor Regulation No. 5/2015	
Industry	Riau Ecosystem Restoration Project (APRIL Group in partnership with Flora and Fauna International and Bidara): support and incentives for community-based conservation on the Kampar Peninsula (2013) Integrated Forestry and Farming System Project (Asia Pulp and Paper in partnership with Desa Makmur Peduli Api) (2016): support and incentives for community-based forest conservation APRIL Group Fire Free Village program: fire management incentives and education for communities (2014) Asian Agri Fire Free Village program: fire management incentives and education for communities (2016) Musim Mas Fire Free Village program: fire management incentives and education for communities (2016) Minamas/Sime Darby: fire response and monitoring and fire management education for communities (2015)	Roundtable on Sustainable Palm Oil (RSPO): principles and criteria (2013) Asosiasi Amanah: oil palm smallholders collective providing support for RSPO and ISPO certification (2011) Forest Stewardship Council (FSC): deforestation monitoring (2014) Indonesian Palm Oil Pledge (IPOP): evaluation and audit licensing of peat (2015) Giam Siak Kecil Bukit Batu Biosphere Reserve (Sinar Mas in partnership with civil society and government) (2009) Roundtable on Sustainable Palm Oil (RSPO): principles and criteria (2007) Roundtable on Sustainable Palm Oil (RSPO) (2005)
Civil society	Wetlands International: peatland mapping in consultation with Deltares (2015) Greenpeace: research and investigation (2013) Indonesian Women's Union (Seruni): gender-based community empowerment (2015)	World Resources Institute: research and investigation (2014) Eyes on the Forest: hotspot monitoring and investigation (2015)

	Riau Forest Rescue Network (Jikalahari): hotspot monitoring and watchdog activities (2016) Mitra Insani Foundation: canal blocking (2012)	Perkumpulan Elang in partnership with the Riau Natural Resources Conservation Centre: canal blocking and peat re-wetting (2016) People's Movement to Stop Haze Singapore (PM.Haze): peatland restoration (2014)