

Governing large-scale social-ecological systems: Lessons from a comparison of five cases

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Abstract:

This paper compares five case studies of large scale governance of common-pool resources: management of forests in Indonesia, the Great Barrier Reef in Australia, the Rhine River in western Europe, the Ozone layer (i.e. the Montreal Protocol), and the Atlantic Bluefin Tuna (i.e. the International Convention on the Conservation of Atlantic Tuna). The goal is to assess the applicability of Ostrom's design principles for sustainable resource governance to large scale systems, as well as to examine other important variables that may determine success in large scale systems. While we find support for some of Ostrom's design principles (boundaries, monitoring, sanctions, fit to conditions, and conflict resolution mechanisms are all supported), other principles have only moderate to weak support. In particular, recognition of rights to organize and the accountability of monitors to resource users were not supported. We argue that these differences are the result of differences between small and large scale systems. At large scales, other kinds of political dynamics, including the role of scientists and civil society organizations, appear to play key roles. Other variables emphasized in common-pool resource studies, such as levels of dependence on resources, group size, heterogeneity, disturbances, and resource characteristics also receive mixed support, pointing to the need to reinterpret the meaning of common-pool resource theories in order for them to be applicable at larger scales.

Keywords: Common-pool resource theory, design principles, scale, forests, fisheries, marine protected areas, pollution.

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INTRODUCTION

Common pool resource (CPR) theory emerged in response to arguments that collective action for mutually beneficial goals, including resource management, is unfeasible in large groups (Olson, 1965) or without coercion (Hardin, 1968) or private property rights (Gordon, 1954). CPR theory explores a wider set of conditions that can foster collective action. Ostrom (1990) identified eight “design principles” which are key conditions that facilitate successful collective action for resource governance. These principles have received strong support from subsequent research on local resource management, yet it remains unclear whether they apply to larger-scale environmental governance dilemmas (Cox, Arnold, and Villamayor Tomás 2010).

The articles in this special issue examine governance of large-scale social-ecological systems to explore whether the design principles and other key factors emphasized in the governance literature remain relevant at large scales. The five preceding articles consider: global regulation of ozone-depleting substances in the Montreal Protocol (Epstein, Meek, Perez-Ibarra and Schoon, this issue); management of Atlantic Bluefin tuna, an open ocean fishery (Epstein, Nenadovic, Cox, Boustany, this issue); mitigation of trans-boundary water pollution in the Rhine region (Villamayor-Tomas, Fleischman, Perez-Ibarra, Thiel, van Laerhoven); national forest management in Indonesia (Fleischman, Garcia-Lopez, Loken, Villamyaor-Tomas this issue), and; a regional marine protected area network, the Great Barrier Reef, Australia (Evans, Ban, Schoon, Nenadovic, this issue). In this paper, we synthesize and compare the insights across the five cases to gain a deeper understanding of the applicability of CPR theory to large-scale systems. In doing so we focus on the well-known design principles, as well as a few other key factors from the case studies, which we argue provide interesting insight into CPR theory in large-scale systems. We do not systematically compare all the variables identified in the case studies. Thus our comparative study should be seen as a limited comparison to highlight some early lessons. A more rigorous comparison across a larger number of cases will be possible in the future as Social Ecological Systems Meta-Analysis Database grows.

CPR theory focuses on social outcomes such as enduring institutions and actor organization, with limited attention to ecological outcomes. In contrast, the cases in this special issue focus on both ecological and social outcomes. Hence, our analysis reveals that in large-scale systems success is often partial or mixed. For instance, three of these cases present well-known success stories: management of the Great Barrier Reef, pollution control in the Rhine River, and international regulation of ozone depleting substances via the Montreal Protocol. Yet, we find that these successes are incomplete: the Great Barrier Reef Marine Park has demonstrated significant improvements in fisheries management and reef resilience but faces considerable threats from land-based pollution and climate change; the governance regime of the Rhine River has successfully alleviated point-source pollution but is less successful in resolving non-point source pollution and cleanup of river sediments; the Montreal Protocol has reduced the emissions of ozone depleting substances, but the residence time of these chemicals means that the ozone-related response remains to be seen. In all three cases, successful management dates back only 20-30 years, far shorter than most of the long-enduring institutional arrangements studied by Ostrom (1990) and others.

The two remaining cases are less successful overall, although neither is an abject failure. Indonesia has some of the highest global deforestation rates and continues to be a center for illegal logging, but deforestation rates have fallen significantly since a new governance regime emerged post-1998. Similarly, the International Convention for the Conservation of Atlantic Tunas (ICCAT) has been widely criticized for its failure to restore tuna populations, yet the dramatic decline in Western stocks pre-dates the convention, which has subsequently managed to maintain that stock at stable, albeit low levels. In our comparison we focus on the relative improvements made (or not) by the focal governance system itself, contrasted through temporal snapshots, even where ‘sustainability’ itself may not be achieved.

METHODS

Variables for this study were selected in two ways. First, we focused on Ostrom’s (1990) design principles, as modified by Cox et al (2010). This focus was chosen because these principles are supported by solid theory and abundant empirical evidence (Ostrom 1990; Agrawal 2001; Cox et al. 2010). The principles, discussed in greater detail below, include: *clearly defined boundaries*; *congruence between appropriation and provision rules and local conditions*; *collective-choice arrangements*; *monitoring*; *graduated sanctions*; *conflict-resolution mechanisms*; *minimal recognition of rights to organize*; *nested enterprises*. Second, we selected six other variables for the insight they give to understanding how CPR theory translates to larger-scale systems. Two variables are considered important in the small-scale CPR literature but fall outside of the design principles – *dependence on the resources* and *group size / heterogeneity*. Two sets of factors have also emerged as important variables since the initial design principles were created – *external disturbances* and *resource characteristics*. Finally, an additional two factors appear to replace or augment important design principles – *political power and civil society*, and *scientific knowledge*.

In the case papers, the authors explore characteristics of governance, actor groups, and resources and their correlation with resource conditions over time through distinct snap-shots. Here, we synthesize the inferences made by these authors for each variable of interest. As illustrated in the introduction, ‘success’ in these large-scale cases is often not clear-cut. Hence, we focus on the contribution of individual factors to the relative success or failure of the current governance system in each case. If the overall outcomes are poor but a factor contributed to improving the outcome, we rate that factor as a relative success. Relative success is taken as an improvement in the conditions of the resource when this is at least partially driven by an improvement in cooperation levels within and/or between actor groups. This approach thus differs from a strictly correlational approach to inference, as we analyze the contributions of individual factors to the outcome in addition to correlating the presence or absence of factors with the outcomes. In addition to synthesizing insights from the papers, we compared across cases to identify insights not captured in the individual analyses. Coauthors from all five case studies contributed to this comparison paper, thereby ensuring in-depth understanding of each individual case.

RESULTS AND DISCUSSION

This section first summarizes the extent to which the design principles were found to be important explanatory variables across the five cases, before considering six other important variables that have attracted the interest of CPR scholars.

DESIGN PRINCIPLES

1A. Clearly defined boundaries: Actors who have rights to withdraw resource units from the resource system must be clearly defined.

The presence of clear boundaries has consistently been identified as an important design principle for successful collective action (Ostrom 2011, 1999). Ciriacy-Wantrup and Bishop (1975) suggested that the existence of boundaries was the fundamental distinction between open access and common-property regimes. We follow Cox et al. (2010) in subdividing the boundary principle to distinguish between the social boundaries of users and the physical boundary of the CPR itself.

The importance of clear social boundaries is moderately supported by the five cases. In the Rhine River, the Great Barrier Reef and the Montreal Protocol, clear identification of stakeholders and the assignment of rights and responsibilities were facilitated by well-defined institutional or administrative boundaries, which appear to have contributed to sustainable management. In the Great Barrier Reef Marine Park even the early governance system clearly defined who had withdrawal and other access rights. In the pollution cases, while early open access periods characterized by the absence of social boundaries were correlated with high levels of pollution, the new governance systems provided greater clarity regarding emission rights, subsequently leading to lower emissions. Similarly, Indonesian forests initially lacked clearly-defined withdrawal rights, but a change in governance meant boundaries were better defined. Nevertheless, improvements in outcomes were less pronounced than in the pollution cases, perhaps due to the incomplete and contested nature of those boundaries. Finally, while membership in ICCAT clearly defines the right to trade with other members, the convention does not define withdrawal rights in non-member states and is at times poorly enforced within member states. Most case papers conclude that this principle is important primarily through its interactions with clear resource boundaries (principle 1B) and is dependent on other variables, notably monitoring & enforcement - principles 4 and 5.

1B. Clearly defined boundaries: The boundaries of the CPR must be well defined.

Clear biophysical limits of (e.g. physical boundaries that delimit one resource system from another) and spatial boundaries defined by the governance regime (e.g. socially-constructed geographic regions) are both considered necessary preconditions to avoid open-access situations.

This principle is moderately supported by the cases. With the exception of Atlantic Bluefin tuna, all the resource systems studied have clear biophysical boundaries. The Rhine River, Great Barrier Reef, and Montreal Protocol cases also have clear governance-defined boundaries. In combination this boundary clarity has contributed to development of effective monitoring and governance in the Rhine and Great Barrier Reef cases; the effect is less clear for the Montreal Protocol where the boundaries are global in nature, encompassing the entire atmosphere. While

biophysical boundaries are clear in the Indonesian forest case, governance-defined spatial boundaries are less so. In contrast, the biophysical boundaries of Atlantic Bluefin tuna stocks remain unclear and ICCAT has failed to define boundaries that correspond to the actual distribution of stocks. The effects of unclear boundaries on the general failure of ICCAT and Indonesian forest governance are difficult to disentangle from other attributes of these cases. Interestingly, however, both of these cases demonstrated a general mismatch between the physical and governance-defined boundaries of the CPR. Thus it may be that these two dimensions of CPR boundaries may jointly influence successful governance, and may explain why they have been conflated in previous research.

2A. Congruence between appropriation and provision rules and local conditions

(congruence): Rules restricting where, when, how and how many resource units can be appropriated must relate to local conditions.

The ‘fit’ or ‘congruence’ principle specifies the importance of matching rules to the characteristics of resources and resource users (Folke et al. 2007). The principle ensures that the governance response is appropriate to the magnitude and scale of impacts on the CPR system (Bohensky and Lynam, 2004). While the original design principle focused on “local,” a term that is inherently difficult to interpret at large scales, the concept of fit between rules and characteristics is not scale dependent, and thus we focused on the concept of congruence.

This principle is supported in four of the five cases, but seems to have the greatest importance in the fisheries cases. Fish are often highly mobile, exhibit chaotic population dynamics (Acheson and Wilson 1996), and are distributed across a large spatial area. The ‘fit’ between the governance system and this dynamic resource unit is therefore particularly challenging. The expansion of no-take zones in the Great Barrier Reef Marine Park to improve protection of important fish stocks and habitats provides a good example of improving congruence between governance institutions and local conditions. In stark contrast, the governance of eastern and western Atlantic Bluefin tuna stocks is not congruent with current knowledge of their respective population dynamics, and may be contributing to overexploitation. In the pollution cases, widespread coordination matched governance actions to the scale of the environmental problem. This contributed to more efficient environmental and social monitoring and, in turn, to the relative success of pollution abatement efforts. Finally, the importance of this principle for the Indonesian forest case is inconclusive. The decentralization process aimed to align decision-making on appropriation rules with the scales at which harvesting was occurring, yet while deforestation rates did improve during that period they remain high.

2B. Congruence between appropriation and provision rules and local conditions

(proportionality): The benefits obtained by users from a CPR, as determined by appropriation rules, are proportional to the amount of inputs required in the form of labor, material, or money, as determined by provision rules.

Another dimension to this principle of ‘fit’ refers to how the costs and benefits of environmental governance are distributed within a group of resource users. It is often defined as the proportionality principle, as it invokes concepts of fairness and equity that match benefits to

contributions. Again, while originally defined in local terms, similar logic applies at larger scales.

The proportionality principle is supported in three of the five cases. However, the logic of proportionality differs between these cases. In international settings, such as the Rhine River and Montreal protocol, proportionality fostered rule formation and implementation: in both cases stalemates between perceived winners and losers were broken through agreements to re-distribute some of the costs and benefits, between upstream to downstream users in the Rhine River and between developed and developing countries in the Montreal protocol. By contrast, in Indonesia a lack of proportionality contributed to increasing deforestation. Because of the tax structure, timber taxes disproportionately benefit the central government, giving local governments an incentive to encourage conversion to agriculture or oil palm plantations, which have benefits proportioned more equally between central and local governments. The role of the proportionality principle in the Great Barrier Reef and ICCAT cases is uncertain. In the Great Barrier Reef, the existence of some discontent by commercial and recreational fishers points to issues related to the distribution of costs and benefits of the re-zoning plan. However, the discontent did not prevent approval of the plan and has not hindered its implementation. In the case of ICCAT, the influence of political bargains and lobbying on fishing quotas points to the interest of parties in minimizing differences between winners and losers of fish restrictions. In a context of strong scientific uncertainty, however, those efforts did not lead to improved fish populations.

3. Collective-choice arrangements: Most individuals affected by the operational rules can participate in modifying those rules.

Ostrom (1990) argued that the ability of individuals affected by the operational rules to participate in modifying those rules was important for two reasons: first, it enhanced the legitimacy of those rules, thereby increasing the likelihood of compliance; and second, it facilitated adapting operational rules in response to changing local conditions.

Support for the collective choice principle in these cases is mixed. The Indonesian forest and Montreal protocol cases directly support the principle. In Indonesia, a strong, centralized dictatorship prevented user participation in governance. Reforms after the collapse of this government in 1998 increased public participation in decision-making, and these changes are associated with improved outcomes. The Montreal Protocol created a framework for decision-making that involved both member states and large industries, and this collaboration is associated with the success of the treaty. By contrast, in the other cases, most affected stakeholders did not participate directly in collective choice situations, yet governance of the Rhine River and Great Barrier Reef has been successful. In both cases collaborative arrangements between interested parties may mitigate the absence of collective-choice arrangements. In the Rhine case countries and large polluting firms have collaborative agreements, and in the Great Barrier Reef national and state government collaborate formally, while user groups are consulted in policy. In ICCAT member states negotiate resource limits, quota share and institutions at the international level on behalf of their industries, but the resource users themselves have limited opportunity to participate. This parallels system failure, but whether it contributes to it directly is inconclusive – in fact, it could be argued that nations

working on behalf of their fishing industries have been major contributors to governance failures. At large-scales, other political dynamics may perform roles similar to direct participation by resource users at small scales – a point that will be discussed below in the section on political dynamics and civil society.

4A. Monitoring: Monitors are present and actively audit CPR conditions and appropriator behavior.

Monitoring is one of the design principles that has received the most support in subsequent literature (Coleman and Steed 2009; Cox, Arnold, and Villamayor Tomás 2010; Tucker 2010). There are two distinct aspects of monitoring – monitoring of resource conditions and user behavior. Monitoring of resource conditions is necessary for the governance system to adapt to new conditions, and monitoring of user behavior is vital for enforcement of rules.

Both types of monitoring are supported in the cases, but to different degrees. Monitoring of resource conditions is strongly tied to outcomes – the three cases that had strong ecological monitoring, the Great Barrier Reef, Montreal Protocol, and Rhine River, display the best outcomes. In each case, information from monitoring has clearly been used to improve the governance system over time. By contrast, the ICCAT and Indonesian forest cases had weaker ecological monitoring systems, and displayed poorer outcomes. Furthermore, recent improvements in ecological monitoring in Indonesia correlate with lower deforestation rates. Monitoring of user behavior, however, was weakly tied to outcomes. For the Indonesian forest and ICCAT cases, weak monitoring of users appears to contribute to poor outcomes, while for the Montreal protocol case, monitoring by the UNEP secretariat appears to contribute to high levels of compliance. However, in the Great Barrier Reef monitoring of users is extremely challenging and there are low levels of self-monitoring. As such there is some evidence of non-compliance in no-take zones but overall improvement in fisheries outcomes (McCook et al., 2010). In the Rhine River case, farmers are not monitored but large firms self-report discharges, and this system is related to improvements in point-source pollution.

4B. Monitoring: Monitors are accountable to or are the appropriators.

Many studies of small scale CPRs emphasize the importance of local monitors who are accountable to or are the appropriators (Persha, Agrawal, and Chhatre 2011; Chhatre and Agrawal 2008). Without this accountability, it is argued that monitors may act in the interest of external actors who favor destruction, rather than sustainability of the resource. It is not clear from the theory how this principle will apply at large scales where accountability relations are complex.

This principle is not clearly supported by any of the five large-scale cases under study. In all cases, monitoring is primarily a function of government agencies that are at best distantly accountable to resource users, yet several cases show that this kind of monitoring has successfully contributed to sustainable resource use. As is the case with the principle on collective-choice arrangements, it appears that other types of actors are able to fill the role played in small scale CPRs by appropriators. For instance, in the Rhine River organized interest groups such as Dutch farmer associations, environmental groups, and waterworks associations, as well

as industrial groups, play an important role in monitoring. In the Great Barrier Reef, the state government is responsible for monitoring and is indirectly accountable to the Marine Park Authority. Within the context of a broader democratic governance framework, these agencies are indirectly accountable to the electorate. In the Montreal protocol, all monitoring is done by international agencies. In Indonesia, improvements in deforestation rates have been associated with three shifts in monitoring: empowerment of local communities, improved government oversight, and an increasing role for international and civil society actors concerned with the environment. Finally, monitoring of Atlantic Bluefin tuna populations and harvesting rates is carried out primarily by national and international government agencies. Yet, in this final case monitoring of resource status and users has not led to improved outcomes primarily because the knowledge generated by monitoring is contested in political arenas. Understanding how political accountability at large scales influence resource outcomes should be a key area for future SESMAD research, since this appears to be an area where large-scale systems differ from small-scale systems in ways that are not well understood.

5. Graduated sanctions: Appropriators who violate operational rules must be sanctioned according to the context, seriousness and frequency of the offense.

Sanctions are another one of the design principles that have received considerable support in subsequent studies (Cox et al. 2010; Coleman and Steed 2009). Sanctions help ensure compliance in a variety of ways including economic deterrence (Becker 1968). Graduated sanctions, which increase with the severity and frequency of violations can ensure flexibility to punish repeat offenders without creating a draconian, and therefore illegitimate, governance system (Ostrom 1990).

Evidence for the importance of sanctions is mixed in the five cases. For ICCAT and the Indonesian forest cases weak or absent sanctioning mechanisms are associated with poor outcomes. Similarly, in the Rhine River case, sanctions are applicable to point-source polluters and not to non-point source polluters, explaining the disparity in their outcomes. In the Great Barrier Reef differential sanctions exist and can be considerable for severe offences, however the extent to which non-compliers are detected and prosecuted and by extension the influence of sanctions on compliance is uncertain. The Montreal protocol contains a trade sanctioning mechanism, although it has never been used and yet, compliance with the Montreal protocol is high. We could not find specific evidence of graduated sanctions in any of the cases. It is not clear if this is because graduated sanctions are less important at larger scales or because analysts of large-scale situations have not been attentive to their existence.

6. Conflict-resolution mechanisms: Appropriators and their officials have rapid access to low-cost arenas to resolve conflicts among appropriators or between appropriators and officials

According to Ostrom (1990) the existence of low cost-conflict resolution mechanisms is essential because they enable appropriators and officials to resolve conflicts that are the result of ambiguity in rules without having to renegotiate or challenge the rules.

Clear evidence in support of this principle was not found in the cases. However, in some of the cases the political contexts and negotiation strategies adopted by actors imply the presence of *de-*

facto mechanisms of conflict avoidance or resolution. For instance, in the Great Barrier Reef sanctions are adjudicated through a well-functioning judicial system. The European Union and member countries may provide similar conflict resolution venues for the Rhine River case. In Indonesia, while the previous Suharto regime broadly suppressed conflict, the developing democratic institutions in the country now provide some measure of conflict resolution, corresponding to moderately better outcomes. Finally, in all three international cases, international negotiations resulted in agreements. In the Rhine River and Montreal Protocol these negotiations helped resolve previous stalemates and essentially led to the emergence of the current governance regime. In contrast, ongoing, annual negotiations within ICCAT over the assignment of fishing quotas are associated with poor governance outcomes.

7. Minimal recognition of rights to organize: The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.

According to Ostrom (1990), resource users must be able to design at least some of their own rules without being undermined by higher-level authorities. This has been found to be particularly important in developing countries, where there is a long history of governments undermining local rights to resources (Bromley 1991). However at large scales it is not always clear how this principle differs from participation in collective choice processes (principle 3).

In only one of the cases we studied do appropriators or polluters have clear recognition of their rights to organize, while in the other four cases, these rights are attenuated. Polluters in the Rhine River case have the right to organize politically and, using market-based instruments, have a measure of autonomy in devising abatement rules and targets. In contrast, while fishers in the Great Barrier Reef can and do organize politically and are consulted in fisheries policy, they do not create their own rules, yet governance is successful. Polluters are not granted autonomy in the Montreal protocol case, although Dupont did play a key role in initial negotiations. In Indonesia, formal rights to organize were not recognized until after the fall of Suharto, and despite enhanced autonomy these rights remain weak with ambiguous effects on forest management. Finally, in the ICCAT case fishers lack the right to design institutions but they do organize to lobby their respective representatives. In all, adherence to this principle does not map well onto resource governance outcomes, and may indicate that it is less important in large-scale cases.

8. Nested enterprises: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities should be organized in multiple layers of nested enterprises.

Ostrom (1990) argued that because of the nature of environmental problems, even local governance systems needed to be nested within higher-level governance structures. In large-scale systems this principle may be expected to be even more critical.

The evidence for this principle is mixed in our five cases. Decentralization of forest management in Indonesia was associated with decreased rates of deforestation, indicating that a movement away from centralized management towards a more nested system favored sustainable management. In the Rhine case, nesting national and international regulatory frameworks also appears to have contributed to success. On the other hand, ICCAT, which, like the Rhine, nests

national regulatory frameworks within an international treaty, is largely a failure. Governance of the Great Barrier Reef is highly centralized but has achieved impressive results. Yet governance of the broader catchment is less successful despite multiple organizational layers. This has led to the recent involvement of the international UNESCO World Heritage Program. In the Montreal protocol case, the presence of nested enterprises was not seen as an important contributor to success. In the Indonesian, Rhine, and Montreal cases, civil society groups appear to offer a kind of horizontal interplay that may have contributed to the improvement of governance regimes.

Table 1: Summary of findings for the Design Principles.

Design Principle	# of supportive cases	Finding
1A. Clearly defined boundaries: (Governance defined social boundaries)	5	Moderately supported across all cases but only in interaction with 1B, 4A, 4B, and 5
1B. Clearly defined boundaries: (spatial/biophysical boundaries)	2	Clearly supported in 2 cases, unclear in remaining cases. Difficult to disentangle from issues with 4A, 4B, and 5.
2A. Congruence between appropriation and provision rules and local conditions: (fit)	4	Supported in four of five cases. Strongest for fisheries cases and weakest for forestry case.
2B. Congruence between appropriation and provision rules and local conditions: (proportionality)	3	Supported in three of five cases. Side payments may lead to greater proportionality, favoring international agreements, while lack of proportionality may contribute to increased deforestation in Indonesia
3. Collective-choice arrangements:	2	Supported in two cases. In other cases, political structures and civil society may play some of the role filled by collective choice structures at local level.
4A. Monitoring: (presence)	5	Supported in all cases, but support is stronger for monitoring of CPR conditions than appropriator behavior.
4B. Monitoring: (Accountability to users)	0	Not clearly supported in any cases
5. Graduated sanctions:	4	Importance of sanctions partially supported in four of five cases, but no clear evidence of graduated sanctions found.
6. Conflict-resolution mechanisms:	4	While explicit conflict resolution arenas are not present, most cases have either some form of national or international forum, which serves this function.

7. Minimal recognition of rights to organize:	1	Only supported in one case. Most appropriators have political rights, but cannot design governance mechanisms for resources. This does not seem to hinder sustainable management.
8. Nested enterprises:	2	Supported strongly in only two cases, partially supported in a third. Civil society may play an important role in addition to formal government.

OTHER IMPORTANT VARIABLES

Dependence on Resource: In many small-scale CPR systems users are dependent on resources for their subsistence and livelihood needs. Analysts argue that this can either tie users into unsustainable patterns of resource, or, where conditions allow (i.e., well defined tenure), can promote stewardship of resources (Ostrom, 1990).

As our cases demonstrate, in large-scale CPR systems the effect of this variable is less straightforward: dependence is manifest in a variety of ways as the types of actors expand and the types of social-ecological interactions diversify. In the Indonesia forest case, both local user groups and state actors are considered to be heavily dependent on forest resources, and it was the economic dependence of state actors that drove higher levels of deforestation in the previous governance regime. Similarly, state members of ICCAT, in representing the interests of their fishing industries, which are not economically dependent on the Atlantic Bluefin tuna resources but which are incentivized by the high economic value, have lobbied strongly to influence extraction limits thereby contributing to governance failure.

In the remaining three cases, positive governance outcomes have been achieved despite high dependence on resources. In the Great Barrier Reef, commercial fishers are economically and culturally highly dependent on reef fisheries, such that finding alternative livelihoods or experiencing reduced access to fisheries resources are considerable challenges. Recreational fishers also claim high cultural dependence. In the Rhine River case, increased appreciation of the river's ecological and cultural values contributed to strong remedial action against polluters. In the Ozone case, economic dependence on ozone depleting substance production was mitigated by breakthroughs in technological substitutes. Resource dependence did not, therefore, explain outcomes. Nevertheless, 'dependence' or interests associated with valuable resources clearly drives some of the high levels of resource appropriation and pollution emissions experienced in these large-scale systems, thereby exacerbating the governance challenge.

Group Size & Heterogeneity: The size and heterogeneity of groups has been a mainstay of the collective action literature since Olson (1965). Empirical studies are far from unanimous but suggest that group size and heterogeneity have both direct and indirect effects on collective action (Agrawal and Yadama 1997; Vedeld 2000; Agrawal and Goyal 2001; Poteete and Ostrom 2004). In general, it is hypothesized that groups are more likely to resolve a collective action problem when they are small, share common interests and identities, but are heterogeneous in terms of wealth and endowments.

In our analysis of large-scale systems, assessing the effects of group characteristics is challenging in that observed effects could be artifacts of the way in which actor groups are defined in each case. For instance, the Montreal protocol case defines Nation States as the governing actors and industry as the ‘users’. They concluded that the small size of both groups (i.e. the relatively small number of states and industries involved) greatly facilitated agreement and implementation of the protocol. However, it is equally plausible to identify sub-groups within nations and polluting industries (e.g. for example “atmosphere users”) which would lead to very different estimates of group size. The ICCAT case, which focused exclusively on the attributes of member nations, suggests that heterogeneity of interests and identities may be contributing to the lack of improvement in Atlantic Bluefin tuna stocks. Heterogeneities include variability in political systems, regulatory regimes, culture, wealth and interests (i.e. consumption vs. production). In fact, Japan as the overwhelmingly dominant market for tuna products begins to approach a *de facto* veto player in negotiations. The other three cases outline more homogenous interests, which align with more successful outcomes. This is particularly evident in the pollution cases, where public awareness and the potential for large-scale impacts served to align the interests of negotiating parties. The result is that the findings for the group-size and heterogeneity variables are difficult to interpret at large scales.

External Disturbances: Contributors to CPR theory have only recently started focusing on the effects of disturbance on local resource governance (Anderies, Janssen, and Ostrom 2004; Cox and Ross 2011; York and Schoon 2011). Some argue that disturbances may increase the salience of cooperation (Plummer and Fitzgibbon 2004).

Two of the five cases support the hypothesis. In the Rhine River case, the emergence of collaboration among national governments was partially triggered by ecological disasters. In the Great Barrier Reef case, commitment to the 1999-2004 re-zoning program was strengthened by the occurrence of a tropical Cyclone and mass coral bleaching events. In contrast, in the Indonesian forest case disturbances exist (e.g., droughts and fires related to El Niño, the fall of Suharto’s government in 1998), but there is no clear link to responses by the governance system. Overall, it appears that the occurrence of external disturbances is not usually sufficient to trigger or sustain cooperation among actors in large-scale systems. Policy entrepreneurs and authorities with a stake in resource conservation seem to be a necessary condition to convert disturbances into opportunities to strengthen governance.

Resource Characteristics (productivity, renewability, and mobility)

Resource characteristics, while not the focus of most CPR theory, are nonetheless an important influence on the effectiveness of management (Agrawal and Goyal 2001; Agrawal 2003). For natural resources, three aspects of resource characteristics and their relationship with sustainable governance have been studied in detail: productivity, renewability, and mobility. Productivity is the rate at which biomass is produced, and is usually considered for ecosystems (rather than resource units). Renewability refers to the doubling time of a resource being managed, and mobility is the extent to which the resource moves.

Evidence for the importance of these resource characteristics is mixed in the five cases. In the cases of Indonesian forests, Great Barrier Reef Marine Park, and Bluefin tuna, renewability of the resource being managed appears more important than productivity of the resource system.

Fish targeted by fishers in the Great Barrier Reef are renewed more quickly than corals, a possible contributing factor to the recovery of fish stocks following expansion of the network of no-take areas. For Bluefin tuna, the western stock has a slower renewal time than the eastern stock, likely contributing to large declines in the stock. Resource mobility affects vulnerability of resources in several seemingly conflicting ways. Resources that are sessile, such as trees and corals, can be more vulnerable to exploitation because appropriators know where to find them, and because persistent external factors can cause degradation (e.g., nutrient runoff and sedimentation for corals). However, being sessile makes monitoring of the resource much easier. On the other hand, highly mobile resources, such as Bluefin tuna, are extremely challenging to monitor. Prior to development of technologies that facilitate exploitation (e.g., GPS, sonar, spotter planes), the mobility of Bluefin tuna might have served as a buffer from overexploitation. Yet with the advent of sophisticated technologies, coupled with the high price of Bluefin tuna, this is no longer the case. Thus, overall, resource characteristics appear to be important, but can be manifest in different ways and interact with other aspects of social-ecological systems.

The pollution cases present an additional layer of complexity as they include both a naturally produced resource (i.e. ozone and water quality); and a pollutant (i.e. ozone depleting substances, organic and inorganic pollutants) that undermines natural processes. Nonetheless given that governance focuses on supporting natural processes via pollution regulation this section focuses on the pollutant. For pollutants, productivity can be interpreted as the rate at which pollutants are released into the environment, renewability as the residence time of a pollutant (i.e., how long it remains in the resource system before coming non-toxic), and mobility as the spatial extent of spread of a pollutant. Ozone depleting substances are highly mobile with long atmospheric residence times which have contributed to the persistence of ozone depletion despite declining production. Organic pollutants in the Rhine case are also mobile and continue to be produced from non-point sources at high levels; but cutbacks in point source production combined with shorter residence times have led to improved water quality. In sum, these large-scale pollutant cases appear to demonstrate that individual attributes of a pollutant explain little in terms of environmental outcomes in the absence of additional attributes.

Political dynamics and civil society: Political dynamics and civil society interactions are not conventionally emphasized in CPR theory but at large scales may perform roles similar to participation in collective-choice situations by resource users at small scales. Rather than emphasizing local organization, as in CPR theory, these variables point to the importance of legal rights for broad classes of actors, levels of political organization within and between actors, and the importance of non-governmental organizations at various levels. At large scales, civil society organizations may act as important mediating forces between the decision-making process and those affected by the operational rules, while participation in decision-making and the legitimacy of those decisions may be mediated by broader political trends – such as the legitimacy of the overall governance system.

Four cases highlighted the importance of these variables. Both the Montreal protocol and Rhine River cases discussed the importance of civil society in putting pressure on international decision-makers to take action. Civil society organizations have also begun to play an important role in the Indonesian case since the fall of Suharto. Both the Indonesian forest and Great Barrier Reef cases also discuss the role of differential levels of political power. Under the centralized Suharto regime, a small group of oligarchs possessed the power to suppress all political

opposition – enabling the regime to effectively exclude all other actors from formal decision-making. This correlated with very high extractive pressure. In contrast, in the Great Barrier Reef case, while users do not have any direct legal participation in the rule-making process, rules are generally complied with. This could be the result of widespread awareness campaigns encouraging stewardship alongside the perception that the governance institutions have broad political and social backing across Australia. Further research is needed to understand how political dynamics encourage – or hinder – successful large-scale governance.

Scientific Knowledge: Studies of small-scale CPRs have emphasized the importance of local or indigenous knowledge for sustainable management (e.g. Gadgil et al., 1993, Berkes 1999, Olsson & Folke 2003). In our large-scale cases, scientific knowledge appears to be important. In two cases, the Great Barrier Reef and Montreal protocol, scientists played crucial roles in discovering problems, galvanizing public awareness, proposing and advocating for solutions, and building consensus. It is not clear what factors enabled scientists to achieve a consensus on the nature of the problem and the actions to be taken. The role of scientific knowledge was less crucial in the Rhine River, although long-term ecological monitoring provided a basis for agreement about the nature of problem. In stark contrast, despite decades of research, scientific knowledge about the relationship between seemingly distinct Atlantic Bluefin tuna stocks remains hotly contested, and scientific advice about fishing levels is routinely ignored and/or manipulated. The role of scientific knowledge in governance of the Indonesian forest case seems relatively minor, as there is little scientific study of the problem of deforestation, and it is not clear how improved scientific understanding may have contributed to better outcomes. It is unclear why scientific advice was followed in the Great Barrier Reef and Montreal cases, while it was not in the ICCAT case. Thus, it is not clear how this variable interacts with other conditions to co-produce outcomes.

Table 2. Summary of other variables.

Variable	Finding
Dependence on resources	Mixed. Dependence on resources manifests in many ways in complex large-scale systems.
Group size and heterogeneity	Mixed. Effect of group size on environmental outcomes largely ambiguous. Cases with more homogeneous interests had more successful outcomes.
External disturbances	Mixed. External disturbances played an important role in some cases, but overall not sufficient for sustained cooperation among actors at large scales and over time.
Resource characteristics	Mixed. Productivity of a system did not appear to influence outcomes, but renewability influences success. Resource mobility is also important, but in conflicting ways (low and high mobility can increase vulnerability).
Political dynamics and civil society	Important. Political dynamics and interactions with civil society may perform roles similar to direct participation by resource users at small scales
Scientific knowledge	Important. Seems to play an important role in underpinning successes in large-scale social-ecological governance

COMPARISONS ACROSS CASES

In this section we first compare the least and most successful cases. Second, we compare the international cases with the others. Third, we consider differences in the outcomes of our fisheries cases, and contrast important variables in the pollution cases.

We find that the least successful cases (ICCAT and Indonesian forests) share the absence of three design principles: clearly defined social boundaries (1A), monitoring (4A), and nested enterprises (8). They also differ on key variables, suggesting multiple pathways to poor outcomes. For instance: the absence of collective-choice mechanisms was strongly associated with deforestation in Indonesia but only weakly linked to outcomes for Atlantic Bluefin tuna; the existence of multi-level governance was immaterial in the ICCAT case, but its emergence in Indonesian forest management was associated with small improvements in deforestation rates, finally; the lack of fit between governance institutions and the resources they are designed to govern explained failures in ICCAT, but had mixed results in Indonesian forests.

The more successful cases share the presence of three design principles: clearly defined social boundaries (1A), monitoring (4A), and fit to local conditions (2A). All three cases also have clearly defined biophysical boundaries (1B), although the implications for outcomes are less clear for the Montreal protocol due its global nature. The absence of collective-choice arrangements was notable in two of the three success cases, contrary to CPR theory. Yet, it is suggested that in both the Rhine River and Great Barrier Reef cases, other political dynamics may have substituted for ‘user’ participation in decision-making. As above, success cases also differ in some key variables reiterating the absence of panacea or one-size-fits-all solutions to environmental governance (Ostrom, 2007). For instance, accountability of monitors to appropriators (4B) and rights to organize (7) were present and influential in the Rhine River case, but were absent with minimal effects on outcomes in the Great Barrier Reef and Montreal protocol cases.

All three international regimes (ICCAT, Montreal protocol and Rhine River) lacked sanctioning mechanisms between countries. Nevertheless, two of them achieved significantly improved outcomes. This finding is consistent with legal scholarship, which suggests that it is difficult to align the principle of national sovereignty and international authority (e.g., Birnie et al., 2009). This design principle may, therefore, need adapting to international settings. By contrast, group heterogeneity seems to be more salient in international scenarios. There are two plausible reasons. First, international cases naturally involve more diversity than national cases, if only because state boundaries tend to reinforce cultural and political differences as well as in-out group dynamics. Second, international cases often require the creation of new communication and cooperation structures, which often involves prolonged bargaining, rendering differences of interests more salient to the actors involved.

In the fisheries cases, as compared to the non-fisheries cases, clear biophysical boundaries and congruence between rules and local conditions emerged as particularly important. Our analysis suggests that these principles strongly influenced the different trajectories of the ICCAT and GBR cases but played a relatively minor role in the other three large-scale CPRs. It is possible

that the mobility of fish in coastal and ocean systems make the definition of biophysical boundaries and the creation of matching governance institutions particularly challenging, but also particularly important for outcomes. This contrasts with the fairly static or bounded biophysical boundaries of forests, rivers, and the earth system.

Finally, in the pollution cases the proportionality between the cost and benefits of cooperation was found to be particularly relevant. In cases of pollution there is often strong asymmetry between polluters and those who bear the negative externalities of pollution. This situation is different from classic appropriation scenarios where all members of a group of users share similar private benefits and costs of over-appropriating the resource. In atmospheric pollution cases like the Ozone, polluters bear the costs of pollution but these are minimal compared to the private benefits they obtain from their emitting activities. In river pollution cases like the Rhine, upstream polluters can avoid bearing any costs of pollution. In these scenarios it is challenging to fully internalize the pollution externality by making polluters pay for its full cost. Thus, the ability to negotiate a fair allocation of said costs can be central to the success of the governance system. Indeed, in both the Montreal protocol and Rhine River cases, the ability of stakeholders to distribute the costs of pollution abatement in a way that satisfied polluters and non-polluters seems to have played a critical role in determining outcomes.

CONCLUSION

Validation of the design principles

Comparing the five cases shows varied support for the eight design principles (see Table 1). Clearly defined social and physical boundaries (principles 1A and 1B) and monitoring of CPR conditions (and to lesser degree user behavior) (principle 4A) were important in all five cases – explaining both relative success and failure. Graduated sanctions (principle 5), fit to local conditions (principle 2A), and (implicit) conflict-resolution mechanisms (principle 6) also received strong support, in four of the five cases. Proportionality (principle 2B), collective choice arrangements (principle 3), and nested enterprises had moderate support (in 2-3 cases each). Whereas, accountability of monitoring to resource users (principle 4B) was not supported in any of the five cases, while minimal recognition of rights to organize (principle 7) was only supported in one case. Overall, the results are somewhat similar to those of Cox et al. (2010), which found strong support for principles 1A, 2A, 2B, 4B, and moderate support for principles 1B, 3, 4A, 5, 6, 7, and 8.

Our results offer support to certain design principles but also highlight differences in their application to small-scale versus large-scale systems. In particular, we suggest that the weak support of principles 4B and 7 could be explained by the scaling up of governance. This is clearest in the case of 4B, which establishes the need for self-monitoring by users or accountability of monitoring to resource users. In large-scale systems, states and international bodies act as monitors thereby altering the direction of accountability. In our cases we found that involvement of other actors, including civil society actors, may substitute for resource users in ensuring an appropriately motivated monitoring system. Further research is needed to clarify how political dynamics and civil society play a role in these accountability relationships.

Interactions between principles

Interactions between principles were also found to be important in several cases. Clearly defined physical and social boundaries were supported across all five cases and interacted closely with ecological and social monitoring (principle 4A), accountability of monitors to resource users (4B), and sanctioning (principle 5). We also found that several of the design principles interacted with other governance variables, like political dynamics and civil society, and resource characteristics. For instance, civil society organizations were found to be crucial in promoting monitoring, sanctioning, and rule-making in several cases (Indonesia, ICCAT, Montreal). Similarly, political dynamics compensated to some extent for the absence of collective-choice arrangements and influenced the proportionality of costs and benefits (Indonesia, GBR). Resource characteristics also mediated the effects of other variables. Both the size and mobility of the resources systems and units influence the ease of monitoring and of matching governance institutions to resource dynamics. These complex interactions among variables make it difficult to identify strong causal relationships between design principles, governance variables and outcomes.

Limitations and future research

One key challenge of comparing the design principles across cases is that Ostrom (1990) presented them as being neither necessary nor sufficient conditions for sustainability, but rather as empirically observed regularities in successful cases. A finding that a design principle is present in an unsuccessful case, or absent in one that is successful, is thus not definitive evidence that the principle is wrong. Instead, we argue that our large-scale cases indicate multiple pathways to both success and failure that, in different contexts, are dependent on different configurations of variables.

Our analysis was based on a relatively small sample of cases, which only allowed for qualitative comparison across different SESs. Many more cases are needed for a quantitative assessment of design principles and other variables. Building a larger compilation of cases of for large-N comparisons is the goal of the SESMAD database. With this database, researchers will be able to develop meta-analyses of many cases. These analyses will permit deeper comparisons of the operation of design principles across different cases, such as between fisheries and forestry resources, as well as the different configurations of variables that influence the sustainability of the governance systems.

More broadly, analysis of large-scale systems is constrained by the relative lack of examples of large-scale governance globally, and a dearth of research on some of the factors considered. For instance, conflict resolution mechanisms have not been directly researched in any of the cases. We found that for many of the variables considered in this issue, more empirical research is needed to understand the mechanisms by which these factors influence governance outcomes, and interact with each other.

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