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Keeping the 'Great' in the Great Barrier Reef: large-scale governance of the Great Barrier Reef Marine Park

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Abstract: As part of an international collaboration to compare large-scale commons, we used the *Social-Ecological Systems Meta-Analysis Database* (SESMAD) to systematically map out attributes of and changes in the Great Barrier Reef Marine Park (GBRMP) in Australia. We focus on eight design principles from common-pool resource (CPR) theory and other key social-ecological systems governance variables, and explore to what extent they help explain the social and ecological outcomes of park management through time. Our analysis showed that commercial fisheries management and the re-zoning of the GBRMP in 2004 led to improvements in ecological condition of the reef, particularly fisheries. These boundary and rights changes were supported by effective monitoring, sanctioning and conflict resolution. Moderate biophysical connectivity was also important for improved outcomes. However, our analysis also highlighted that continued challenges to improved ecological health in terms of coral cover and biodiversity can be explained by fuzzy boundaries between land and sea, and the significance of external drivers to even large-scale social-ecological systems (SES). While ecological and institutional fit in the marine SES was high, this was not the case when considering the coastal SES. Nested governance arrangements become even more important at this larger scale. To our knowledge, our paper provides the first analysis linking the re-zoning of the GBRMP to CPR and SES theory. We discuss important challenges to coding large-scale systems for meta-analysis.

Keywords: Coral reefs, fisheries, Great Barrier Reef, large-scale, marine, social-ecological system

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1. Introduction

Large-scale environmental problems are common but difficult to resolve – and study – due to their complexity. A number of theories and frameworks have been developed to understand environmental change and management and, from these, variables or conditions associated with success or failure in governance have been identified. Common-pool resource (CPR) theory, which aims to explain how collective action emerges and is maintained, was built from empirical and experimental work in natural resource management (Ostrom 1990). One of the first meta-analyses of community-based resource management systems identified eight broad conditions – the design principles – that were more likely than other factors to be associated with collective action and durable local institutions (Ostrom 1990). While the number of enabling conditions for the sustainability of the commons expanded as studies became more numerous and diversified across various resource systems (Agrawal 2003), the design principles remain a foundation of CPR theory.

The eight design principles include (Ostrom 1990): *clearly-defined boundaries* (explicit delineation of the boundaries of the resource system and the resource user group to ensure clarity on who has rights to use and manage what); *congruence between appropriation and provision rules and local conditions* (appropriateness of both sets of rules to their local context and proportionality or congruence with each other); *collective-choice arrangements* (existence of arrangements where most of those affected by operational rules are involved in their formulation); *monitoring* (presence of monitors, who are accountable to resource users or who are resource users themselves and are in charge of auditing both resource status and the behaviour (compliance) of resource users); *graduated sanctions* (existence of penalties that differentially punish those who violate resource-use rules according to the seriousness and frequency of their violations); *conflict resolution mechanisms* (availability of low-cost conflict management arrangements to those who use and manage a resource system); *minimum recognition of rights to organise* (respect of resource-users' rights to devise their own institutions by external government authorities); and *nested enterprises* (organization of various governance activities such as appropriation, provision, monitoring, enforcement, and conflict resolution across multiple levels or scales).

Recent quantitative review of 91 studies pertaining to the design principles finds that they continue to be well supported empirically (Cox et al. 2010). However, most of these studies have focused on relatively small-scale systems, comprising a single resource and one or two user groups such as single catchments or single-jurisdiction fisheries, forests or irrigation systems (Agrawal 2001). Increasingly, awareness of the cross-scale and dynamic nature of environmental problems has led to new concepts and frameworks that aim to account for the complexity of human-environment interactions (Berkes and Folke 2000; Ostrom 2007). Literature on social-ecological systems (SES) explicitly frames environmental problems and solutions in terms of the linkages and feedbacks between coupled social and ecological systems, thereby encouraging consideration of multiple drivers of change, actors and interests, institutional arrangements, and outcomes. An important research gap in CPR and other environmental governance theories is the extent to which their findings apply to SES at larger scales.

The Social-Ecological Systems Meta-Analysis Database (SESMAD) project is an international collaboration to help address this research gap. We have developed a database to comparatively analyse large SES, which is structured around the SES framework. The framework is a multi-tiered classificatory system that organizes a large number of social and ecological variables across four main components: resource systems, resource units, actors, and governance systems (Ostrom 2007, 2009). Together they produce interactions and outcomes, which comprise a central component of the framework. Each of the components can be unpacked into more specific types and sub-types, where a final list of relevant variables would depend on the characteristics of the system being examined (Basurto and Ostrom 2009).

To date, the SESMAD project has used five core case-studies of large-scale systems with sufficient published literature to enable coding of cases into the database across an extensive range of variables. Until more cases are coded we cannot utilize the database for a quantitative comparative study. However, the discipline of coding such a large number of social, ecological and governance variables, plus interactions between variables, enabled us to produce an insightful qualitative analysis of each of the five cases. This paper focuses on the Great Barrier Reef Marine Park (GBRMP), Australia.

We ask: how do the key changes in management through time relate to social and ecological outcomes? And, do principles derived from governance research in small-scale systems apply to the GBRMP? To answer these questions we systematically examine how the CPR design principles apply to the GBRMP as a large system, and then we identify other key variables from the SES framework, as well as the case-specific literature, that stand out as important in understanding and explaining the governance outcomes in the GBRMP.

The GBRMP is large and complex. It covers about 345,000 km^2, contains many types of ecosystems (e.g. islands, coral reefs, seagrass, deep ocean), and provides a variety of ecosystem services to people (GBRMPA 2009; Stoeckl et al. 2011). The GBRMP was established in 1975 and re-zoned in 2004 to improve biodiversity conservation. Governance of the GBRMP is commonly portrayed as a marine conservation success story (Fernandes et al. 2005; Olsson et al. 2008; McCook et al. 2010), but despite the park's history of adaptive management (Hughes et al. 2007a), concerns continue today about human impacts, primarily from land-based and climate change related influences. There is a wealth of literature on the GBRMP but relatively few analyses relate the outcomes of zoning, re-zoning, and adaptive management to established governance theories or frameworks, as we aim to do here. By viewing the GBRMP as a linked SES and considering the CPR design principles in full, our analysis highlights key dimensions of success and failure in the GBRMP. The case therefore provides some important insights for large-scale environmental management.

2. Methods

The methods used here were developed collaboratively as part of the SESMAD project (Cox 2014). SESMAD facilitates systematic collection of information on the social and ecological attributes of large-scale SES, the basic unit of analysis, through content analysis of published studies. In the GBRMP case, we examined relevant peer-reviewed and grey literature to develop an understanding of the GBRMP's adaptive management processes, successes and challenges through time. We focused on peer-reviewed studies, and reports and other documentation (policy, legislation, management plans) published by agencies involved in the management of the GBRMP. Multiple coders then analyzed the case. Each coder attended multiple training sessions and project coordination meetings to ensure consistency in coding approaches and variable definitions to ensure inter-coder reliability, as discussed in the introductory article.

Analysis of available literature on the GBRMP was used to enter data into the SESMAD database, a relational database hosted at Dartmouth College (see Cox 2014). This database contains information on approximately 200 variables of relevance to the study of SES. Variables are organised in tables describing the SES itself, its components, and the interactions among these components (see Figure 1). The SES is defined as a system containing at least one resource system or unit, here referred to as environmental common, at least one governance system, and one or more actor groups. These represent the components that are coded. The governance system table captures information on institutional arrangements, such as rules, policies, and governance activities. The actor table contains characteristics of individuals, organizations, and/or nations who use, manage or otherwise interact with an environmental common. The environmental commons table identifies and categorizes an environmental common, such as an ecosystem, resource, or pollutant. As a relational database, information on relationships between these components is stored in the interaction tables. Typically, the interaction tables describe interactions between the governance system, actors and environmental commons. Different governance regimes or time-periods in the management of an environmental common are reflected in different interactions between the components.

In the GBRMP case, we defined key components as those for which there is evidence of important interactions with social and ecological parts of the system *at the scale of the whole GBRMP.* To capture changes through time in the management of the GBRMP, we examined two time-periods: before (1975–1999) and after (2004–2012) a re-zoning effort. Within each time-period the governance system, environmental commons and actor variables, and their interactions are

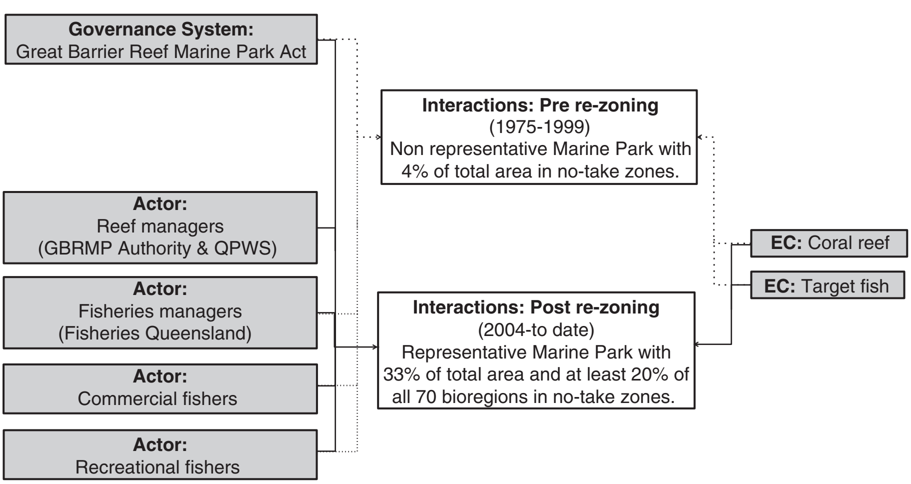

Figure 1: Schematic of the Great Barrier Reef Marine Park as a Social-Ecological System. Two time-periods – pre and post a marine park re-zoning program – are captured through two sets of interactions. Under the Environmental Commons (EC), 'Target fish' are species targeted by commercial and recreational fishers.

considered to be relatively fixed. Yet, some variables have different values across the two time-periods. By comparing the two time-periods we capture changes in GBRMP management characteristics and outcomes, and we identify key variables that are associated with altered outcomes. These changes relate to the re-zoning and to other management adaptations that occurred within the two time-periods. We exclude the transitional time period of the re-zoning (1999–2004) because the SES was experiencing rapid change, which precludes accurate recording of variables. Next, we outline the major events characterising management of the GBRMP, before further detailing how this particular case was structured and coded.

3. Case Background: Timeline of The Great Barrier Reef Marine Park

Table 1 lists the major events characterising the management of the Great Barrier Reef Marine Park. Ecological disturbance events are in *italics*.

3.1. Initial zoning plan for the Great Barrier Reef (1975–1999)

A Royal Commission on drilling for petroleum (1974) and broader concerns about cumulative impacts and the lack of a dedicated regulatory authority for the Great Barrier Reef led to the passing of the Great Barrier Reef Act in 1975 (GBRMPA 2009). The Act established the GBR Region and a new federal agency as the park's authority (Great Barrier Reef Marine Park Authority, GBRMPA). The Act prohibited mining in the GBR Region and enabled planning and implementation of zones. These included no-entry, no-take, and different multiple-use zones, which were gradually implemented between 1981 and 1992 (Great Barrier Reef Marine Park Act 1975). The GBRMP is co-managed by the Federal government and Queensland's state government. These institutional arrangements reflect what Kittinger et al. (2010) refer to as co-trusteeship, describing joint management by government agencies, as distinct from co-management, which typically describes joint management by resource users and government (Pomeroy and Berkes 1997). This co-trusteeship arrangement uses a plethora of management tools to regulate fisheries, tourism, traditional use, research and shipping in the Region.

Almost 20 years after its establishment, the GBRMP Authority initiated a strategic planning process to *Keep the Great Barrier Reef 'Great'* (GBRMPA 1994). This involved an independent review of the Authority (Brown 1997), and culminated in a 25-year strategic plan for the Great Barrier Reef World Heritage Area (established in 1981) (Nursey-Bray and Rist 2009). The GBRMP Authority itself was restructured around core strategic goals and principles (GBRMPA 1994), and a large-scale analysis of the effectiveness of the current zoning plan was undertaken. The result by 1997–1998 was broad scientific and management consensus around the need to increase the extent of no-take zones to improve

Table 1: Major events in GBR Region managements.

	Date	Event
Initial zoning system 1975–1999	1975	Great Barrier Reef Marine Park Act passed
	1979	Offshore Constitutional Settlement signed
		Great Barrier Reef Intergovernmental Agreement signed between Federal and State government
	1981	Great Barrier Reef World Heritage Area established
	1992/1993	Aboriginal native title recognised
	1994	Fisheries Act passed
	1997	Dugong Protection Areas agreed
		AU$2.8 million license buyback in East Coast Inshore FinFish Fishery (net fisheries) as part of Dugong Protection Area Restructuring Package
		Tropical Cyclone Justin
	1998	National Representative System of Marine Protected Areas policy
		El Niño Southern Oscillation coral bleaching
Transition period 1999–2004	1999	Representative Areas Program commences
		Environment Protection and Biodiversity Conservation Act (EPBC) passed
	2000	Queensland East Coast Trawl Fisheries Management Plan published
		AU$20 million license buyback in East Coast Trawl Fishery removing 11% of effort
	2001	Croker Decision extending Indigenous Australian's rights to Sea Country
	2002	*Coral bleaching event*
	2003	Reef Water Quality Plan introduced
Re-zoned system 2004 – to date	2004	New Zoning Plan for the GBRMP passed and implemented
		Queensland Coral Reef FinFish Fishery Management Plan implemented
		Structural Adjustment Package framework to buy out or re-structure fishing businesses developed
		Queensland's Marine Parks Act passed and Great Barrier Reef Coast Marine Park established
	2006	*Coral bleaching event in southern Great Barrier Reef*
	2006/2007	Amendment to the GBRMP Act of 1975
	2008	Reef Water Quality Partnership and Reef Rescue program initiated
	2009	*Tropical Cyclone Hamish*
	2009	Guidelines for commercial operators in the Queensland East Coast Inshore Finfish Fishery published
	2009	Great Barrier Reef Outlook Report published
	2009	Great Barrier Reef Intergovernmental Agreement revised
	2010	Queensland East Coast Trawl Fisheries Management Plan updated
	2011	*Tropical Cyclone Yasi and coastal floods*
	2012	UNESCO report on the Great Barrier Reef World Heritage Area
	2013	AU$9 million license buyback in East Coast Inshore FinFish Fishery (net fisheries)

biodiversity conservation and resilience of the Reef to wide-scale disturbances. The re-zoning process was initiated in 1999.

3.2. Transition period (1999–2004)

A systematic conservation planning approach – the Representative Areas Program (RAP) – was undertaken to identify and implement a larger system of no-take zones that represented the diversity of bioregions and habitats encompassed in the GBRMP. The approach included compilation of more than 40 datasets on biological and physical diversity, two rounds of community consultation (May 2002 and June 2003) resulting in consideration of over 30,000 written submissions, and extensive public communication and awareness campaigns (Olsson et al. 2008; McCook et al. 2010). A new zoning plan was passed into law in July 2004 (Olsson et al. 2008). The new zoning plan designated seven marine zones ranging from 'most reasonable use' to 'no-entry' areas reserved for research purposes only. The biggest changes were an increase in the area covered by no-take zones from about 4% to 33% and inclusion of 20% of each bioregion in a no-take zone. Financial support was provided to fishing-related businesses impacted by the re-zoning. By 2006 the Federal government had provided an estimated AU$250 million for structural adjustment of more than 1700 businesses affected by the rezoning (Gunn et al. 2010). A separate process of significant reform to the fisheries sector also took place because of a concern about their sustainability [e.g. 40% reduction in effort and capacity of the East Coast Trawl Fishery (ECOTF 2011), and; introduction of Total Allowable Commercial Catch (TACC) and Individual Transferable Quotas (ITQ) for the Coral Reef FinFish Fishery (CRFFF 2011)]. In November 2004, Queensland's state government implemented the GBR Region Coast Marine Park, which provided complementary zoning within adjacent state marine waters (Day 2002).

3.3. Re-zoned system (2004-to date)

Consistent monitoring and research has shown that no-take areas are effective at increasing fish biomass, thus supporting the scientific argument for increasing the area of no-take zones to improve biodiversity and resilience of the Reef (McCook et al. 2010). Since the re-zoning, reform of the fisheries sector has continued, for instance more stringent controls have been legislated in the East Coast Inshore Finfish Fishery (gillnet and line fishery) through a TACC allowance, new size and bag limits, and annual seasonal closures for some species (Tobin et al. 2010; ECIFF 2011). But the focus of management concern has largely shifted to land-based impacts and climate change. While the GBRMP Authority does not have the authority to directly manage activities on land, they are mandated to act on impacts to the Reef and are working with other management agencies to try to reduce land-based impacts (Brodie and Waterhouse 2012), including those from new port developments along the Queensland coast (Brodie 2013).

4. Coding and analyzing the GBRMP as a large-scale SES

4.1. Structure of the GBRMP case

In order to code and analyse the GBRMP as a large-scale SES, we deconstructed the system into its simplest component parts. We aimed to capture components and interactions that might explain governance outcomes, but which did not over-complicate coding. We considered the following components to be integral because of the extent of their interaction within the SES at the scale of the Great Barrier Reef: The GBRMP Act is an over-arching piece of legislation that has endured for over 38 years, which sets up the governance system for the marine park. We use a single Act to represent the governance system in the SES database, although in our analysis we recognise and account for the contribution of other GBRMP institutions as outlined in Table 1. Four actor groups emerged because of their influence on managing and extracting from the system: two that implement the Act (reef managers and fisheries managers), and two user groups (commercial and recreational fishers). Reef managers are comprised of two government agencies from two levels of government – the GBRMP Authority and Queensland Parks and Wildlife Service (QPWS) – who are jointly responsible for management of the Reef. Reef managers are then distinguished from Fisheries Queensland – the management authority responsible for commercial and recreational fisheries in the state – because of their different mandates and responsibilities. Commercial fishers comprising distinct fishing sectors that act at a regional scale, for example the Trawl, Line and Net fisheries, were taken as one actor group because the same authorities manage them using similar management tools. Recreational fishers were taken as a separate actor group and were considered as individuals acting at a local scale because participation in representative organisations is limited (Taylor et al. 2012). This selection of actors clearly simplifies the complex social-ecological system interactions taking place in the GBRMP for the purposes of analysis. We acknowledge that there are many other actor groups interacting with the Reef (Figure 1). Reef tourism, for instance, is a major income generator for the Region (Stoeckl et al. 2011). However tourism impact is concentrated and considered to be minor (GBRMPA 2009; Day and Dobbs 2013). Our analysis has focused on the significant impacts directly addressed by the re-zoning process. For practical purposes, we coded two aspects of the environmental common: coral reef, and; species targeted by commercial and recreational fishers (hereafter "target fish"). We chose these because relatively good information exists about their change through time with management, and because they serve as proxies for different aspects of the health of the Reef.

We coded the GBRMP case for two time periods: from establishment to the initiation of the re-zoning process (1975–1999), and from implementation of the new zoning plans to date (2004–2012). We omitted coding the transition period from 1999 to 2004 because many changes were taking place during that time, and our main interest was in assessing differences between the early management of the reef, and the period after all the re-zoning changes had been implemented.

4.2. Social and ecological outcomes

The GBRMP is commonly held up as an example of successful marine management (Fernandes et al. 2005; Olsson et al. 2008; McCook et al. 2010), yet the social and ecological outcomes were mixed when comparing the pre- and post- re-zoning periods (Table 2). Ecologically, strong evidence exists that the no-take zones are effective at increasing biomass of targeted species within their boundaries (McCook et al. 2010), and that they provide some ecological benefits (spillover) beyond their borders (Harrison et al. 2012). Adaptive management of commercial fisheries in combination with the re-zoning of the park means that many commercially targeted fish populations are now considered to be sustainably fished (Fisheries Queensland 2011) or stable (GBRMPA 2009). However, data are limited: many species cannot be properly assessed (e.g. undefined species in Figure 2) and ecosystem effects of fishing are unknown (GBRMPA 2009; Day and Dobbs 2013, although see Grech and Coles 2011). Uncertainty also remains around recreationally important species due to the relative lack of systematic monitoring of recreational fishing effort. In the most recent stock assessment report "a number of recreationally important species remained either 'uncertain' or 'undefined' due to the lack of recent statewide recreational fishing estimates" (Fisheries Queensland 2011, 6). A recently published survey of Queensland's recreational fishery does not clarify the stock status of target fish but does report some key findings since 2000: i) the number of recreational fishers has declined;

Table 2: Social and ecological outcomes of management of the GBRMP as coded in the SESMAD database. (Some changes may be the result of management changes that were initiated separately to the re-zoning process but which occurred within the two different time periods.).

Outcome	Pre-re-zoning (1975–1999)	Post-re-zoning (2004–2012)	References
Resource outcomes			
Change in fish stocks	Decreased slightly	Increased slightly	(Kerrigan et al. 2004; Mapstone et al. 2004; Fisheries Queensland 2011)
Change in coral cover	Decreased slightly	Decreased slightly	(GBRMPA 2009)
Effect of management on fish stock status	Little effect	Effective	DAFF 2011
Effect of management on coral cover	No effect	Little effect	(Hughes et al. 2011; Brodie and Waterhouse 2012)
Biodiversity trend	Slight decrease	Mixed effects	(McCook et al. 2010)
Outcomes for users			
Human use of resources (fishing)	Mixed or increased	Slight decline	(Kerrigan et al. 2004; Mapstone et al. 2004; Fisheries Queensland 2011)

Sustainably fished Barramundi; Bream (yellowfin) Coral trout Emperor (red-throat) Flathead (dusky) Mackerel (spanish, spotted) Moreton Bay Bugs; Mullet Prawns (tiger, endeavour, banana, eastern king); Scallops (saucer) Snapper (stripey); Tailor Threadfin (blue); Whiting (sand, stout)	**Over-exploited** Snapper (pink)
Uncertain – data / signal contradictory Emperor (red) Snapper (crimson, goldband, saddletail) Squid (pencil) Threadfin (king)	**Undefined – not enough data to assess stock status** Mackerel (grey, schooling) Prawn (red-spot) Scallop (mud) Squid (tiger) Trevally

Figure 2: Summary of the stock status of fish listed as targeted by the Line, Net and Trawl fisheries of Queensland (Fisheries Queensland 2011; DAFF 2011). Mulloway, Bay prawns and Jobfish are also listed as targeted species but were not included in the stock status report. Many of the species listed above are also targeted by the recreational fishing sector.

ii) catch and effort have declined, with the exception of catch for barramundi, mangrove jack and tropical snapper, which were higher in 2010, iii) catch declined more than effort suggesting fewer fish for similar effort, and; iii) commercial catch for barramundi, whiting and Spanish mackerel were higher than recreational catch but for cobia, pearl perch, snapper, spotted mackerel and tailor recreational catch was higher (Taylor et al. 2012). Currently, the Pink snapper (*Pagrus auratus*), which is targeted by both commercial and recreational fishers, and sharks and rays targeted as commercial species and caught as by-catch in the East Coast Inshore Finfish Fishery are considered most vulnerable to over-exploitation (Fisheries Queensland 2011). Other resources are not doing as well overall. In particular, coral cover (Sweatman 2008; GBRMPA 2009; Hughes et al. 2011; De'ath et al. 2012) and some charismatic species (turtles, dugongs) are declining (GBRMPA 2009). Declines in coral cover are uncertain as noted in the GBR Region Outlook Report (2009). Most recently, De'ath et al. (2012) report a decline in initial coral cover of 50.7%. There is also some scientific debate about the relative contribution of proximate and distal drivers of this coral cover decline, which include extreme events (cyclones), crown-of-thorns starfish, water quality, temperature anomalies and climate change.

Social outcomes of management of the GBRMP are not monitored as thoroughly as ecological outcomes. Only very recently has a long-term monitoring approach for social outcomes been developed and deployed (Marshall et al. 2013). This means changes over time remain difficult to ascertain (Table 2). While the condition of many fish stocks has improved over time, commercial access to fish decreased following changes in fisheries management, license buy-outs, and re-zoning (e.g. Grech and Coles 2011). Marshall and colleagues (2013) found that commercial fishers felt much less optimistic about the future of their business in the GBR Region than about the future of the GBR Region as a whole. In the recreational sector, recreational fishing is still cited as among the top leisure activities for Queenslanders with over 700,000 recreational fishers (Taylor et al. 2012). However, while the coastal population has increased over the past decade, data suggest that participation in the sector has declined by 6% since 2000 (Fisheries Queensland 2010) and that catch and effort have also declined over this period (Taylor et al. 2012). A follow-up survey by Sutton et al. (2009) suggests that recreational fishers' participation in fishing is declining for reasons related to work and family rather than changing regulation within the sector. Other social outcomes are harder to document. Some conflict and discontent persists about the Representative Areas Programme and, in the commercial sector, the administration of the associated Structural Adjustment Package (Sutton and Tobin 2009; McCook et al. 2010; Lédée et al. 2012). Commercial fishers report moderate confidence that the GBR Region is well managed in general (Marshall et al. 2013). Nevertheless, increasingly, commercial resource-users that remained in the fishing sector are becoming more actively engaged in voluntary stewardship of the Reef through programs such as Reef Guardian Fishers (www.gbrmpa.gov.au), suggesting increased commitment to its ecological outcomes.

4.3. Influence of important CPR variables

A number of variables were identified as important in characterising the governance context of the GBRMP and in explaining differential outcomes pre- and post- rezoning in 2004. Here, we focus first on the eight design principles for long-enduring resource management institutions (Ostrom 1990; Cox et al. 2010) before considering other variables of relevance to the GBRMP as a SES (Ostrom 2007) (Table 3).

4.3.1. Design Principles

Boundaries: Here we consider the biophysical and administrative boundaries delineating the resource and the social boundaries defining communities of users. We coded clarity of physical boundaries, and clarity and negotiability of social and administrative boundaries.

The Great Barrier Reef is the world's largest coral reef and can be seen from space. The coral reef structure has clear physical boundaries, which have been mapped in detail. An ongoing review of the maps used to re-zone the reef identified only a few extra reefs or discrepancies in reef boundaries (Day 2013). In contrast, the resource boundaries of targeted fish are considered unclear at the scale of resource use due to their mobility (though technologies such as fishfinders render boundaries more clear). Most GBR Region fisheries target reef-associated (as opposed to reef-dependent) or pelagic species. Spatial distribution of both reef-associated and pelagic fish can be highly variable. Further, while many target fish likely remain within the boundaries of the Great Barrier Reef as a whole, evidence suggests that both adult fish and larvae move within and among reef habitats (Harrison et al. 2012), meaning that target fish cross administrative boundaries and therefore may change in their accessibility to fishers (i.e. if they move into and out of no-take zones). The biophysical boundary characteristics of the resources did not change with the re-zoning, but the interaction between physical and administrative boundaries did as the area of no-take zones increased.

The social boundaries defining resource user groups are clear in the GBRMP but differ in their negotiability for commercial and recreational fishers. Commercial fishers gain membership by buying and displaying a commercial fisher's license and a boat license specific to their fishing sector. Following management changes in the fishing industry, no new licenses or symbols are available for existing fisheries, and thus these boundaries are rigid (non-negotiable). Fishing capacity in the commercial sector is well regulated. In contrast, no membership or licensing requirements exist for recreational fishers. As this 'boundary rule' is well established and widely communicated we consider the boundary to be clear; everyone knows what the rule is. However, as anyone can become a recreational fisher, whether they fish once a year or every day of the year, boundary negotiability is coded as fuzzy, rather than rigid.

The administrative boundary of the GBRMP and its zones are clearly delineated. The Australian Constitution and Offshore Constitutional Settlement (1979) designate ownership rights to coastal waters (high water mark to 3 nm seaward) to state governments. The GBRMP Act (1975) defines the Region as extending from the coastline at low water to six offshore points of latitude and longitude within Australia's Exclusive Economic Zone. The GBRMP covers 99% of the Region and incorporates most coastal waters including that in Queensland government's jurisdiction (Day and Dobbs 2013). Further, the state and federal zoning plans are contiguous and don't distinguish the state-federal marine park boundaries.

In the initial zoning scheme boundaries were defined relative to physical features such as the reef edge. However, these boundary definitions were considered unclear (see Day 2002 for more details on zone designation and lessons learned). Currently the zones of both the federal and state marine parks are defined by latitude and longitude coordinates. Physical and electronic zoning maps show both marine parks without distinction, and identify zones by name, objective, and colour (Day 2002). Zoning maps are available to users free of charge, and boundaries are clearly demarcated and visible. These zoning boundaries are rigid – non-negotiable – for users, and compliance is considered to be moderate (see below under monitoring).

Clearly defining the extensive biophysical and administrative boundaries of the GBRMP as a large-scale SES is facilitated by access to technology (satellite tracking and mapping), scientific expertise and data (identifying and classifying habitat), and management capacity (administering seven marine zones with different uses). The boundary issue that appears to challenge the success of the GBRMP is the negotiability of social boundaries in recreational fishing, which is compounded by the number and distribution of recreational fishers across Queensland.

Ecological and institutional fit, and proportionality: Designation of the GBR Region and Management Authority in the 1975 Act defined a single management area, which aimed to encompass the entire reef ecosystem, and a single management authority. The Great Barrier Reef Intergovernmental Agreement (1979 revised 2009) signed between the Australian Federal Government and the Queensland State Government then enabled the GBRMP Authority to share management rights and responsibilities with state agencies such as the Queensland Parks and Wildlife Service. The GBRMP thus provides an example of purposeful, broad institutional fit within a large-scale SES. It is a single multiple-use MPA but it supports a diversity of uses, including fishing, tourism, traditional use, research, and shipping (GBRMPA 2009). Management therefore comprises a broad range of tools in addition to zoning, such as Special Management Areas, Fisheries Management Plans, Tourism permits, Traditional Use of Marine Resources Agreements, and Designated Shipping Areas. As Day and Dobbs (2013, 8) note "clarity and consistency in defining legal objectives, jurisdictional boundaries, roles and responsibilities of different authorities and organisation has been critical in the management of the GBRMP". The 2004 re-zoning of the GBRMP, and the Marine Parks Act of 2004 designating the GBR Region Coast Marine Park, which was contiguous with the GBRMP, further improved the ecological and institutional fit of this SES (Day 2002). The Representative Areas Program defined 70 different bioregions and the biophysical principles of the Representative Areas Programme process stated that 20% of each bioregion should be represented or protected in a no-take area. The GBRMP is a good example of ecological and institutional fit in a large-scale SES, particularly in terms of improved fisheries outcomes. Yet, there is growing recognition that external drivers of change, including land-use (agriculture and coastal development) and climate change are significant threats to the future condition of the Reef (GBRMPA 2009). Land-based activities are outside of the direct jurisdiction of the GBRMP Authority. Nevertheless, the GBRMP Act 1975 and the Environment Protection and Biodiversity Conservation Act (1999) provide legislative frameworks under which agencies can work collaboratively to address activities that are indirectly harmful to the Marine Park and World Heritage Area (Day and Dobbs 2013).

Congruence between the rights and responsibilities of different actor groups is more uncertain for the GBRMP case. During the re-zoning process there was concern over the costs imposed on commercial fishers and fishing-related businesses, yet the Structural Adjustment Package valued at AU$250 million was considered vastly disproportional to the estimated value of fisheries incorporated in no-take zones (Macintosh et al. 2010). Ongoing, there are a few rules that apply to resource users to ensure they contribute to the sustainable provision of ecosystem services, for instance: commercial vessels are obliged to compile daily fishing logbooks; trawl vessels are required to install vessel location monitoring systems to enhance ecological and compliance monitoring; and commercial and recreational fishers with TACC quota are required to log a fishing trip before going and to report their catch before landing to enable random checks at port. There is also increasing participation in voluntary provisioning activities such as stewardship and education programs (Day and Dobbs 2013). To what extent these are proportional to the rights and benefits of appropriation is difficult to ascertain in this case. Feelings of unfairness about how impacts affect different types of commercial and recreational fisher have been reported, suggesting a perceived lack of proportionality (e.g. Teh-White et al. 2004).

Collective choice arrangements: There are several formal legislative arrangements that characterise management rights for the GBRMP. As mentioned above, the Great Barrier Reef Intergovernmental Agreement (1979 revised 2009) provides the framework for co-trusteeship of the marine park between the GBRMP Authority and Queensland's state agencies. In the 1990s several important events also meant the recognition of indigenous rights (Mabo Decision 1992; Native Title Act 1993; Croker Decision 2001 in Nursey-Bray and Rist 2009), which have been formalised as co-management of the GBRMP (GBRMP Act 1975; Nursey-Bray and Rist 2009). Traditional owners have management rights and can prepare Traditional Use of Marine Resources Agreements for areas of importance in collaboration with the GBRMP Authority.

The GBRMP Act (1975) and the Fisheries Act (1994) set out the collective choice arrangements related to Zoning plans, Plans of Management (related to special areas or species), and Fisheries Management Plans. The former specifies minimum requirements for consultation, including the length of time a draft plan must be available to the public and the need to "consider any comments made in accordance with the notice" (GBRMP Act 1975, 33). The Fisheries Act (1994, S32) simply states that a fisheries agency must "take reasonable steps to engage in consultation" about a draft plan. Extensive consultation was undertaken during the re-zoning process. However, considerable animosity built up at the time between the GBRMP Authority and resource user groups, and there remain some misgivings over the participatory process (Sutton and Tobin 2009; Lédée et al. 2012). Macintosh et al. (2010) explain that while the Representative Areas Programme itself was collaborative, there was minimum consultation over the mechanisms of the Structural Adjustment Package administered by the Queensland Rural Adjustment Authority, which exacerbated concerns over the transparency and inclusiveness of the re-zoning process. Ongoing, Reef management is facilitated by four Reef Advisory Committees (which are thematic and involve scientists) and 12 Local Marine Advisory Committees (based in 12 towns/cities for involvement of community representatives). Management Advisory Committees for each fishery were also established but have since been discontinued. The extent to which fisheries management is consultative is less prescribed but has involved participation from representative organisations such as the Queensland Seafood Industry Association. Fisher groups also lobby government during important decision-making processes (Macintosh et al. 2010).

As co-management requires that responsibility and authority is shared between a resource-user group and a government agency (Pomeroy and Berkes 1997), we suggest that the GBRMP is not co-managed, for the most part (with the exception of Traditional Owners). And because of the scale of the SES, most stakeholders affected by operational rules in the GBRMP are not involved in collective choice decisions. Nevertheless, commercial and recreational fishers are increasingly represented in policy and planning processes and stakeholder groups do engage in lobbying activities. Political participation is relatively high but decision-making power rests with the management actors. Therefore, the political power of the user groups to actually change the operational rules they are governed under is considered to be moderate. Further, while fisher groups can and do organise politically, they do not typically create their own rules. The Marine Aquarium Fish fishery did develop its own stewardship guidelines (Donnelly 2013) but these are above and beyond existing government regulation. The rights to create rules are generally reserved to management actors. Yet, the governance system is durable and has been managing the resources adaptively. This outcome indicates that at large scales or in contexts of relatively high socio-economic security, such as Australia, it might not be necessary (or feasible) for all users to participate directly in creating and adapting rules.

Monitoring: The spatial extent and remoteness of much of the GBRMP pose significant challenges for monitoring. Nevertheless, much emphasis has been placed on environmental monitoring and experimentation. In 1993 the Australian Institute of Marine Science initiated long-term biological monitoring (underwater benthic and fish surveys) to capture the ecological impacts of anthropogenic changes and extreme events on the GBR Region and its different zones (www.aims.gov.au). The re-zoning process was informed by a ten-year seascape-level experiment on 24 reefs conducted to test opening and closure regimes on reefs (Mapstone et al. 2004; Hughes et al. 2007b). Long term biological monitoring of the reef has been a key success and source of knowledge on reef status (decline and improvement), allowing for a re-thinking of the initial zoning plan and adaptive management to date (McCook et al. 2010; Day and Dobbs 2013). Fish catch monitoring is less widespread or effective. Commercial fishing vessels are obliged to complete daily fishing logbooks on effort and retained catch with the data collated in the Commercial Fisheries Information System. However, independent verification of fish catch through on-board fisheries observers is limited (Grech and Coles 2011). Going forward, there is growing interest by

Table 3: List of theoretically important variables and values across two time-periods. Where changes in variables/principles are only associated with the re-zoned time-period they are included in the right-hand column of the table. Where variables did not change with the re-zoning they cut across both time-periods.

Theoretical Variable	Pre Re-zoning (1975–1999)	Post Re-zoning (2004-to date)
Design principles		
Physical boundaries: clarity	Clear for the coral reef; Unclear for target fish	
Administrative boundaries: clarity and visibility	For users and managers the administrative zoning boundaries of the coral reef are very clear, and for target fish are moderately clear.	
Administrative boundaries: extent of no-take zones	4% of 345,000 km: 13,800 km^2	33% of 345,000: 113,850 km^2
Administrative boundaries: compliance	Evidence suggests moderate compliance of user groups	
Administrative boundaries: negotiability	The zoned boundaries of the GBRMP are rigid (non-negotiable)	
Social boundaries: clarity and negotiability	The boundary rules are clear, but for commercial fishers they are rigid, whereas for recreational fishers they are negotiable.	
		The membership allocations for commercial fishers were reduced through buy-out of fishing licenses.
Ecological and institutional fit	The GBRMP Act was designed to 'fit' with the biophysical boundaries of the system, and the resources being managed.	
		The re-zoning process explicitly accounted for 70 representative bioregions.
Collective-choice arrangements	Consultative arrangements exist between government and resource-users. User group representatives participate in some policy and planning activities, and lobby for more rights. However, decision-making power remains with reef and fisheries managers.	
Monitoring: Environmental	Monitoring is challenged by the spatial extent and remoteness of the GBRMP but extensive ecological monitoring is undertaken.	
		The sophistication of research and monitoring is improving over time, facilitating adaptive governance.
Monitoring: Compliance	Sea and air surveillance monitoring is conducted. Extensive education and awareness also aims to promote voluntary compliance. Resultant compliance is considered to be moderate, as suggested by differences in ecological outcomes in no-entry and no-take zones.	
Monitoring: Social	Monitoring of social outcomes has been poor.	
		A socio-economic monitoring protocol is currently under development.
Sanctioning: Graduated sanctions	Financial penalties for user non-compliance are different for sectors (commercial or recreational), individuals and corporations, and the nature of the violation. Local magistrates courts mediate sanctions.	
Conflict resolution	Analysis of the effectiveness of conflict resolution mechanisms is not yet available for the GBRMP.	

Table 3. (Continued)

Theoretical Variable	Pre Re-zoning (1975–1999)	Post Re-zoning (2004-to date)
		Extensive consultation of user groups during the re-zoning process and a seven-year freeze on boundary negotiations post re-zoning aimed to minimize conflict.
Nested governance arrangements	The GBRMP Act is administered by a single authority in what can be characterized as a highly streamlined polycentric system. Efforts to manage external impacts on the Reef through more extensive nested enterprises are yet to demonstrate substantial improvements.	
SES variables		
Resource characteristics: general	Fish are relatively resilient to resource use due to: moderate mobility, productivity and renewability. They are also difficult to monitor and manage as a result. Corals are more vulnerable to degradation despite being highly productive because they are sessile and take decades rather than years to renew populations. Both fish and corals degrade more rapidly than they recover.	
Resource characteristics: connectivity		Improved internal connectivity of the reef facilitates recruitment of fish and coral larvae and spillover of adult fish from no-take zones into adjacent areas.
	External connectivity between GBRMP and adjacent catchments is high making the reef highly vulnerable to land-use change. These external drivers are intensifying over time.	
Actor characteristics: group size	Group size of managers is small, of commercial fishing sectors is small, and of recreational fishers is high	
		Numbers of individual commercial and recreational fishers have declined.
Actor characteristics: heterogeneity	Resource user groups are considered to have low economic, social and political heterogeneity.	
Actor characteristics: Economic and cultural dependence	Commercial fishers are economically and culturally highly dependent on the resource. Recreational fishers consider themselves to be culturally highly dependent on the resource.	

government and partner research institutions on issues of water quality (Brodie and Waterhouse 2012) and climate change (De'ath et al. 2009).

Conformance of users to the zone boundaries and fisheries management rules is monitored relatively effectively through sea and air surveillance operations by the Reef and Fisheries management actors, alongside other state agencies (www.gbrmpa.com.au). Trawlers are also obliged to have vessel monitoring systems installed (Day and Dobbs 2013). These track their location by satellite, but do not provide information on speed, direction or activity (Grech and Coles

2011). Nevertheless, they aid both effort monitoring and compliance monitoring, which is important considering the costs of both in the context of the large-scale, multi-zoned SES. In some cases the zoning scheme itself further complicates surveillance. For example, in the National Park (no-take) Zone boating and diving (access) is allowed but extraction is not, and in the Buffer Zone trolling for pelagic fish is allowed but line fishing for other fish is prohibited. It is therefore difficult to determine in aircraft surveillance whether or not vessels are undertaking illegal activities in some cases (Day 2002). Finally, the GBRMP Authority and partners actively promote education and voluntary compliance. Overall, compliance is considered to be moderate in the GBRMP. In an anonymous survey of recreational fishers, 90% reportedly comply with no-take zones (Arias and Sutton 2013). However, there is evidence that no-entry zones have a higher fish biomass than no-take zones, which have a higher biomass than fished zones (McCook et al. 2010), suggesting that compliance by commercial and recreational fishers is not complete.

Social monitoring to track the costs and benefits to diverse stakeholder groups of management changes has been less systematic across the GBRMP than ecological monitoring, but is increasingly acknowledged as important. In 2012 a project to design a socio-economic monitoring protocol for the GBRMP was initiated to redress this disparity (Marshall et al. 2013).

Sanctioning: In the GBRMP non-conformance of users to zoning plans results in different types of financial penalties. Fines differ for commercial and recreational fishers (e.g. fines can range from ~AU$2000 for illegal recreational fishing to >AU$10,000 for illegal commercial fishing www.gbrmpa.com.au), for individuals compared to corporations, and according to the nature of the violation. For instance, in the GBRMP access to no-take zones is not prohibited, only extraction. As a result, commercial fishing vessels found in no-take zones with dories (small fishing boats) detached are fined considerably less than vessels caught actively harvesting resources. GBRMP inspectors have discretionary power over individual violations (Day and Dobbs 2013). But the GBRMP Act 1975 also legislates for a very high maximum penalty of AU$5.5 million for aggravated violation by a body corporate, should the courts decide to use this sentence (*Ibid.* 2013). Sanctions are adjudicated by local Magistrate Courts. For recreational fishers, a recent study found that fishers' perceptions about sanctions motivated fishers to comply with no-take zones (Arias and Sutton 2013).

Conflict resolution mechanisms: In the GBRMP there are several conflict avoidance mechanisms in place. There is an emphasis on voluntary compliance through education and information facilitated by free zoning maps, online information on management plans and regulation, and regional offices in Cairns, Mackay and Rockhampton (set up after the re-zoning). With respect to daily use of the marine park, Day and Dobbs (2013) suggest that conflict resolution mechanisms are built into the GBRMP Authority's decision-making procedures, including a means to review permit decisions. They also refer to the Administrative Appeals Tribunal and the

Ombudsman as two further avenues for adjudication. There is little research or other information on levels of conflict around day-to-day management of the GBRMP and the use or effectiveness of conflict resolution mechanisms, such as those detailed above. During the re-zoning process, the GBRMP Authority and its partners invested in extensive community consultation, reviewing over 30,000 submissions in response to the proposed zoning plans. Despite this, high levels of conflict characterised the process, particularly among recreational fishers, and there were concerns that this could affect future buy-in and compliance to the new GBRMP zoning plans (Sutton and Tobin 2009; McCook et al. 2010). At the time the GBRMP Authority addressed conflict through increased numbers of smaller consultation meetings and though factsheets that corrected key misconceptions (Olsson et al. 2008). In 2007, an amendment to the GBRMP Act of 1975 legislated for a freeze on negotiations on changing zoning plans for a minimum of seven years from date of establishment under the premise of providing stability to businesses, communities and biological systems. This has to some extent allowed tensions over the re-zoning process to dissipate. Finally, the GBR Region Outlook Report summarizing the status of the Reef every five years helps to increase transparency of management outcomes.

Nested governance arrangements: Nested governance primarily refers to the vertical linkages across jurisdictions connecting local to national scales of management, for instance. Polycentric governance captures vertical, cross-scale linkages as well as horizontal linkages among different management actors (Ostrom 2005; Biggs et al. 2012). In the GBRMP federal and state governments jointly manage the GBRMP; several pieces of legislation formalise co-management arrangements between GBRMP Authority and Indigenous Owner groups; and the GBRMP Authority consult Local Marine Advisory Committees in twelve locations along the GBR Region's coastline. Other federal, state and local agencies are also involved in specific elements of GBRMP management, such as surveillance or protection of its World Heritage Values. There is even overlap in implementation of key pieces of legislation, including the GBRMP Act 1975, EPBC Act 1999, and Marine Parks Act 2004. These constitute a polycentric governance system. However, considering the size of the SES (345,000 km^2) and the diversity of uses managed – fishing, tourism, traditional use, research, shipping, defence training – we suggest that the GBRMP is relatively centralised or at least represents a highly streamlined polycentric governance system. By this we mean that authority is shared among relatively few different actors. In many places, a SES of this size would cross multiple state or provincial boundaries and would involve many sector-based state agencies (conservation, fisheries, tourism, ports and shipping) without the benefit of a unifying agency and over-arching legislation. The success of the GBRMP can be attributed to its clear governance arrangements. As Day and Dobbs (2013, 2) articulate, "today the GBRMP is a large, single, multiple-use MPA".

However, impacts originating from beyond the boundaries of the GBR Region and the current jurisdiction of the GBRMP Authority pose a challenge to the current governance system. The GBRMP Act (1975) and the EPBC Act (1999) both include clauses related to regulating or prohibiting activities that reduce water quality and impact the Reef. The GBRMP Authority has triggered and been involved in developing a strategy to address water quality in the Region, which includes the Reef Water Quality Protection Plan (2003 updated 2009 and 2013), the Reef Water Quality Partnership (2007) involving three Federal agencies (Department of Agriculture, Department of the Environment, and GBRMP Authority), several state agencies, and the regional Natural Resource Management Bodies, and a Reef Rescue package worth AU$ 200 million (2008–2013) and a further AU$ 200–375 (2013 onwards). These actions demonstrate broader nested governance and the potential for improvements in water quality from catchment land use (Brodie and Waterhouse 2012), although coral cover continues to decline (De'ath et al. 2012). More controversially, the GBRMP Authority and Queensland's state government are also involved in assessments and planning with other agencies over coastal development, in particular port development, largely in response to a pending UNESCO ruling that may change the status of the GBR Region World Heritage Area to one listed as 'in danger' (UNESCO 2012). Action on climate change is non-regulatory and is limited to education and voluntary stewardship activities. Brodie and Waterhouse (2012, 2) review multiple stressors, their impacts, and the associated management effectiveness and suggest that overall there is "a lack of integration of research, management and monitoring activities" related to the land-sea interface.

4.3.2. Other important variables

Resource characteristics: The characteristics of CPR systems and their resource units, such as their mobility, productivity and renewability (Ostrom 2007) affect their 'governability' (Jentoft 2007). In the GBRMP the particular characteristics of the two resources coded – target fish and corals – mean they vary in their vulnerability to, and recovery from, resource use. The target fish of the GBR Region have a number of attributes, in aggregate,[1] that make them relatively resilient to resource use but also difficult to monitor and manage. If you consider both horizontal and vertical space, fish are moderately mobile. For example, barramundi migrate from freshwater rivers to the ocean while some pelagic fish travel throughout the Indo-Pacific. Even reef-associated target fish are relatively mobile compared to other resources, such as corals and trees. Target fish also have moderate productivity and renewability. Russ and colleagues (2008) report a significant increase in density of coral trout in no-take zones of the GBRMP within two years of re-zoning but have highlighted elsewhere that full recovery of some long-lived predator species could be between 15–40 years (Russ and Alcala 2004). Corals, on the other hand, while very productive, are arguably more vulnerable to degradation than target fish because they are sessile and take decades rather than years to renew populations (low renewability). Despite some

[1] These differ by species.

inherent resilience to resource use, both fish and corals can potentially be rapidly over-exploited or degraded, as the speed of feedback from use of these resources is higher than the speed of feedback from management, meaning damage is achieved quicker than recovery.

These characteristics of the resource system did not change as a result of management, but do have important implications for management success. Arguably, spatial, precautionary management, which was enhanced through the re-zoning process, is highly suited to resources with higher potential to decline than to recover, although it is challenged by the mobile and cryptic nature of these under-water resources (Toonen et al. 2013).

One resource characteristic important in the GBRMP case but not well considered in the small-scale CPR literature is biophysical connectivity. Connectivity can catalyse degradation or facilitate recovery of reef ecosystems. Target fish and coral reefs are considered to have moderate internal connectivity, referring to linkages within the system such as among fish populations or between reef habitats. Empirical evidence supports the role of no-take areas as sources of recruitment (coral and fish larvae) and spill-over (adult fish) to other areas, although the extent of this varies by species and according to other environmental factors (currents, physical barriers, temperature) (Nyström and Folke 2001; McCook et al. 2010; Harrison et al. 2012; Wen et al. 2013). On the whole, internal connectivity through recruitment and spill-over occurs at a sub-regional scale, not throughout the whole GBRMP, so populations of corals and fish are relatively distinct between the northern and southern reefs and between inshore and offshore reefs. This moderate internal connectivity helps maintain resilience of reefs to disturbance while allowing users to benefit from conservation efforts. However, the difficulty in observing these dynamics and scientifically demonstrating them is one source of tension between users and managers in this system. Further, GBR Region resources have strong external connectivity between the adjacent catchments and the reef ecosystems, resulting in significant impacts on reef ecosystems from land-based sources (Brodie and Waterhouse 2012).

Actor characteristics: The attributes of resource users, such as size, heterogeneity of users and their dependence on a resource are central to CPR theory (Ostrom 2007), though evidence of how these attributes affect government outcomes remains mixed (Poteete and Ostrom 2004). The two primary user groups considered in this analysis are commercial and recreational fishers. Commercial fishing is the largest extractive activity in the GBRMP worth between AU$123–140 million per year depending on the year (GBRMPA 2009; Deloitte Access Economics 2013). Lédée et al. (2012) report that fishing was the sole source of household income for most fishers in the GBRMP with 88–92% of household income derived from commercial fishing for trawl and line fishers, respectively. A comprehensive long-term monitoring programme on the socio-economics of the Reef also finds that commercial fishing contributed around 80% of the household income for most households interviewed, though the average across all fishers was 65% (Marshall et al. 2013). Many commercial fishers also demonstrate strong occupational and place attachment (Marshall and Marshall 2007). These studies suggest that commercial fishers have high economic and cultural dependence on the GBRMP. A socio-economic assessment just prior to the re-zoning process identified 1691 full time equivalent people employed in commercial fishing (representing 0.5% of employment in the GBR Region catchment). The assessment suggested that only 10.5% of the Gross Value of Production would be lost through re-zoning and concluded that the impacts on the commercial fishing sector would be modest (Hand 2003 in Macintosh et al. 2010). Yet, there was concern from government and industry over the impacts of the re-zoning on fishing dependent communities and substantial tension over fishers' perceptions that they were unfairly disadvantaged by the process. The result was a Structural Adjustment Package that purportedly far exceeded the economic costs of the re-zoning (Macintosh et al. 2010).

Almost 200,000 people fish recreationally in the GBRMP (700,000 across the state of Queensland) (Hand 2003 in GBRMPA 2009; Macintosh et al. 2010; Taylor et al. 2012). While participation has declined since 2000, recreational fishing is still cited as among the top leisure activities for Queenslanders suggesting high cultural dependence (Taylor et al. 2012). Indeed, recreational fishers in Queensland coined the slogan "I FISH and I VOTE" to strengthen their voice in political lobbying for their rights. Yet, the majority of fishers are not members of representative organisations, making it more difficult to co-ordinate this large number of resource users.

4.4. Challenges

Entering the GBRMP case into the SES database forced us to make judgments about the most important components of the system, a process that has benefits and drawbacks. A benefit is that it requires an assessment by coders about key components of the SES, in particular for determining key actors and resource components. Narrowing down these components made coding tractable while still allowing for a qualitative analysis of the GBRMP SES and facilitating future comparisons with other cases. However, because the database explicitly accounts for linkages between distinct system components, the amount of coding can increase exponentially with each additional component, which also meant excluding many of the complexities that are inherent in large-scale SES. For example, many additional actor groups are important in the GBRMP, such as tourism operators and aboriginal co-managers, but we limited coding to those for which there is sufficient data and evidence of extractive influence in the system at the scale of the whole reef (i.e. commercial and recreational fishers). Similarly, the resource system could be divided into many additional components, such as functional groups. We limited our assessment to two components – targeted fish and coral cover – that capture broad ecological successes and failures of the park. Analytically, this presents a challenge because the coders decide *a priori* which components are important, and hence any subsequent analyses can only be done on variables associated with those components already deemed important. Thus the coding process forces simplification of complex systems, but makes analyses of coded components of large-scale SES tractable.

One important implication of the approach taken in this paper is that we focused on the GBRMP and changes in governance related to zoning and fisheries management. We have thus accounted for significant land-based, extreme event, and climate change impacts by coding them as external factors. Considering the increasing impetus on managing externalities from coastal development and catchment land-use in the region, a future approach could be to conceptualise the region as a single, larger coastal SES and to include, for example, graziers, the mining industry, and developers as additional actor components that are internal to the system. This would enable analysis of variables capturing key attributes of these actors. Such an approach would be complicated, in particular, in assigning attribution to particular interactions.

Another key drawback of such analysis of large-scale systems is the complexity and detail lost in aggregating components and averaging trends and outcomes. This is necessary for meta-analysis but limits analytical depth. For example, we averaged attributes for target fish across all target species, many of which differ in their biology and ecology. Similarly, individual operators within each of these commercial fishery sectors can differ significantly in terms of dependence, market share, social capital and involvement in management. Yet, when we consider the user groups as made up of sectors as opposed to individuals, the 'members' are relatively homogenous. Social and ecological outcomes for different fish species and individual commercial actors would also differ, but are captured as aggregate trends. This limits the extent to which our analysis can draw inferences about some of the key CPR variables. For example, actor size and heterogeneity do not have consistent units applied across cases but are to some extent an artefact of the categorisations made to code variables, as appropriate to each case (i.e. individuals, sectors, or agencies). This differs from the small-scale literature, where single units (individuals) can be used to describe communities or groups interacting with an ecosystem.

Similarly, the need to compare across cases coded in SESMAD necessitates aggregation of certain 'relative' variables, which loses a level of disaggregated detail that would favour within-case diagnosis. For example, in the GBRMP ecological and institutional fit improved with the Representative Areas Program so is relatively better after re-zoning than before. However, since its establishment the GBRMP demonstrates good ecological and institutional fit compared to other large-scale SES. So, in this case, both time-periods (1975–1999 and 2004–2012) are coded as showing *no governance-resource mis-match*, hence, forfeiting subtle differences between pre- and post- re-zoning.

5. Discussion

The GBRMP case provides some insights into the relevance of design principles at a large scale, although complexity, scale, and data limitations make attribution of outcomes to specific variables challenging. Regardless of these challenges, we were able to assess the impact of eight principles on both social and ecological outcomes within the GBR Region, and to evaluate their applicability to large SES.

In regards to fisheries, many species have experienced improved trends as a result of management activities, most notably the re-zoning of the GBRMP administrative boundaries to extend the area of no-take zones, and their clear communication to potential users. The influence of the re-zoning on coral cover is not as clear-cut as expected. There is some evidence for improved resilience of corals to disturbance events within no-take zones, but overall coral cover continues to decline throughout the GRBMP, particularly in inshore reefs (Sweatman 2008; Hughes et al. 2011; De'ath et al. 2012). Some of the mixed results in coral cover (which also extends to other coastal habitats) can be explained by natural and anthropogenic drivers that originate outside of the GBRMP system. Reduced intervals between multiple disturbance events, including population explosions of crown-of-thorns starfish, temperature anomalies causing coral bleaching and mortality, tropical cyclones, and fresh-water pulses from flooding events, compound chronic stress from nutrient-loaded run-off and siltation. While direct impacts on target fish are not yet clearly evident, long-term degradation of coral, mangrove and seagrass habitats is expected to eventually impact coral-dependent and coral-associated fish species (Hughes et al. 2003; Munday et al. 2008). These findings suggest that external drivers are still important impacts on large-scale systems: while the boundaries of the GBRMP are considered to be clear and there is ecological and institutional fit in the marine social-ecological system, the administrative boundaries are not presently designed to account for external factors. If we consider the broader coastal SES, including the catchments, the GBRMP Act and its implementing actors demonstrate less institutional and ecological fit and a stronger need for more effective nested governance arrangements than are evident to date.

On the other hand, this highly streamlined polycentric governance system has been considered very successful in integrating different state and federal agencies and managing multiple uses within the GBR Region. While a range of agencies, policies and laws are involved in management of the GBRMP, the GBRMP Act 1975 has precedence over all these other laws in the event of any inconsistencies (Day and Dobbs 2013). This contrasts with the degree of polycentricism in coastal governance in the USA, for example, which involves 20 Federal agencies and the conflicting interests that stalled implementation of the Channel Islands National Marine Sanctuary in California (Crowder et al. 2006). Contrasting the GBRMP Authority with the USA experience suggests that burgeoning polycentricity may not be an advantage. In certain circumstances the diversity and redundancy provided by polycentricity may be countered by the efficiency and control of more centralised systems. On the other hand, polycentricity is thought to confer some level of resilience to SES (Biggs et al. 2012). It is, therefore, possible that low polycentricity may leave governance systems, like the GBRMP Act, vulnerable to political interference and de-gazettement, as is being threatened in other parts of Australia, because fewer actors are bound to the institutions.

Contrary to CPR theory, the success of the GBRMP in regards to fish stocks biomass and resilience of corals to disturbance is not underpinned by high influence of users in monitoring activities or collective choice arrangements. Members of the community of resource users undertake little of the ecological, compliance, and social monitoring (although there are some examples of participation in ecological monitoring by users), and monitors are not directly accountable to resource users. Furthermore, the rezoning consultation process was not perceived to be legitimate by many recreational (Sutton and Tobin 2009) and commercial fishers (Lédée et al. 2012). Teh-White et al. (2004) suggest that recreational fishers felt that they were not treated fairly compared to other stakeholders, and their feedback was not clearly incorporated into the re-zoned plans. A majority of commercial fishers also felt that they were not fairly treated or adequately consulted and compensated (Lédée et al. 2012). Macintosh et al. (2010) suggest that some of this discontent was due to the rushed development of the Structural Adjustment Package which was handled separately from the Representative Areas Programme process, but which was seen as part of the Representative Areas Programme by resource users. Nevertheless, in the GBR Region case, scientific integrity, a relative lack of corruption in policing and law enforcement, and a well-established and stable government may substitute for these principles.

Our analysis provides clear examples of how complexity and scale affect the classical interpretation of design principles. In large scale systems, the size of the resource system and interactions between resource units, and the increased number of actor groups and types of use rights seem to be principal drivers that constrain the applicability of design principles, albeit not all of them in equal manner. For example, both collective choice arrangements and minimum recognition of rights to organize are limited given that participation by all or most of resource users in large scale SES is impractical. Similarly, participation of resource users in monitoring activities is reduced due to coordination challenges and bureaucratic/governance arrangements. Furthermore, availability of low-cost conflict resolution mechanisms is challenged by the increasing diversity of conflicts emerging from the expansion of use rights types. The key question going forward is whether other mechanisms, such as higher-level representation or broad trust in science and law, fully compensate for these design principles at larger scales or at least mitigate against governance failures. Even though the current design principles cannot be viewed as a set of necessary conditions for devising robust institutions in the case of large-scale environmental problems such as the conservation of the Great Barrier Reef (Young 2002), they can arguably still be used to inform the process of creating effective and legitimate governance arrangements.

6. Conclusion

This analysis of the GBRMP as a large-scale SES benefitted from a systematic coding effort utilizing the SES framework and the SESMAD coding protocols.

This study highlights the mixed outcomes of the GBRMP, which is typically lauded as a governance success. Success is broadly attributed to significant and clearly defined changes in administrative boundaries of the GBRMP altering usufruct rights, and to changes in fisheries management institutions and social boundaries in commercial fisheries. These boundary and rights changes were supported by effective monitoring, sanctioning, and conflict resolution. We argue further that success is underpinned by other CPR variables, which remained consistent through time but which characterised effective management of the GBRMP. For instance, moderate biophysical connectivity was important for improved outcomes. We attribute continued governance challenges to connectivity and boundary issues between the land-sea interface, external drivers impacting the marine SES, and the current lack of effective polycentric institutions to govern the region at the scale of the larger coastal SES.

In terms of CPR theory, our analysis of the GBRMP as a large-scale SES argued that the governance system is a highly streamlined polycentric system with relatively little opportunity for resource users to directly influence rule making. These facets appear to contradict CPR theory, though we suggest that instead these findings point to the need to better conceptualise the design principles of collective-choice arrangements and nested enterprises (polycentricity) for large-scale systems analysis.

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