



# The social–ecological system framework as a knowledge classificatory system for benthic small-scale fisheries



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## ABSTRACT

Ostrom proposed the underpinnings of a framework for the systematic study of the governance of complex social–ecological systems. Here we hypothesize that Ostrom's social–ecological system framework can be useful to build a classification system for small-scale benthic fisheries, regarding their governance processes and outcomes. The purpose of this paper is to contribute to knowledge accumulation of benthic fisheries. To tailor the framework, we relied on discussions among experts and a systematic literature review of benthic fisheries from 1980 to 2010. This literature review helped us refine variable definitions and provide readers with illustrative reference papers. We then illustrate the approach and its potential contributions through two studies of the emergence of self-organization in Mexico and Chile. We highlight synthetic lessons from the cases and the overall approach as well as reflect on remaining challenges to the development of a social–ecological system framework as a diagnostic tool for knowledge accumulation and synthesis.

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## 1. Introduction

Small-scale fisheries are increasingly conceptualized as integrated social–ecological complex adaptive systems in part because of the type of problems they exhibit (Berkes, 2006, 2011; Folke et al., 2005; Gelcich et al., 2010; Mahon et al., 2008; McConney and Charles, 2010; Wilson, 2006). These problems, such as avoiding overexploitation, are rarely attributable to a single cause (Andries et al., 2007). As Holling et al. (1998, p. 352) state:

Characteristically, these problems tend to be systems problems, where aspects of behavior are complex and unpredictable and where causes, while at times simple (when finally understood), are always multiple. They are non-linear in nature, cross-scale in time and in space, and have an evolutionary character. This is true for both natural and social systems. In fact, they are one system, with critical feedbacks across temporal and spatial scales.

The role of multiple causes has also been described by Ostrom (2005) when discussing the behavior of social rule systems and the governance outcomes they produce. Sets of rules interact in complex patterns, and the addition or removal of a particular rule may affect the interactions of the rest of the set and thus the governance outcome (Cox, 2011). Scholars studying small-scale fisheries have made great strides toward identifying key processes affecting their governance (Castilla and Defeo, 2001; Cinner et al., 2007; Defeo and Castilla, 2005; Gelcich et al., 2010; Hilborn, 2007; Orensanz et al., 2013; Pault, 2006). However, the role of rule configurations in social–ecological interactions, and how it challenges our ability to establish causal mechanisms linking conditions and governance outcomes, has received considerably less attention. One of the many challenges of understanding what configurations of conditions may lead to particular governance outcomes, consists of devising a tractable way to organize and document them. Ontologies, or systems of classification, can serve these functions. For instance, the Latin alphabet constitutes a relatively simple system of classification, and its dictionary serves as the framework in which empirical configurations of this ontology are expressed for a particular language. In this example, past and future books that have or will be written on diverse topics are expressions of how systems of classification allow knowledge accumulation and future

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innovation. Using the concept of ontologies, the pertinent question for SESs is then: How can the SES research agenda develop an approach that allows for knowledge accumulation that can inform typologies of governance arrangements for particular small-scale fishery outcomes?

In 2007, Ostrom proposed the underpinnings of a framework for the systematic study of the governance of complex SESs. Here we hypothesize that Ostrom's social–ecological system (SES) framework can be useful to build a classification system for small-scale benthic fisheries, regarding their governance processes and outcomes. The first step in this process is to develop a suite of key SES variables or processes potentially relevant to anyone considering conducting a study on benthic small-scale fisheries. This is referred to as an ontology. By analyzing the literature, this paper develops a benthic small-scale fisheries ontology. It then illustrates the use of the SES framework through two short studies concerning Mexican and Chilean benthic fisheries. Both studies focused on teasing out the underlying factors affecting the self-organization capacity of the fisheries to avoid tragedies associated with open access. We conclude with some lessons, cautionary notes, and remaining challenges for the use of the SES approach developed here.

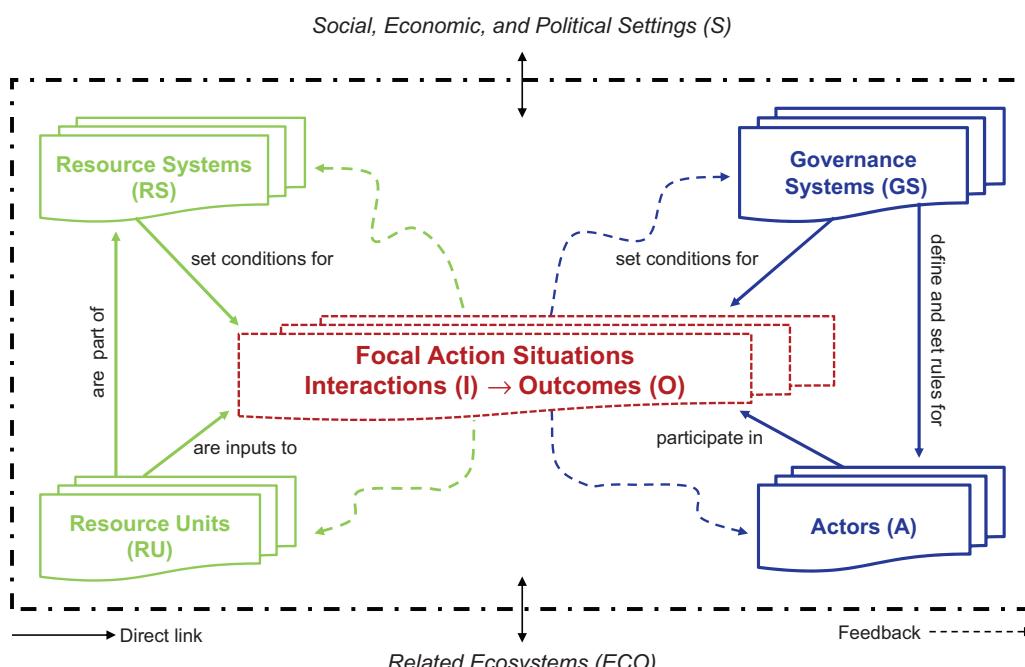
## 2. Theoretical background

Theories of collective action and common-pool resources (CPRs) have contributed to our understanding of processes and conditions facilitating the likelihood of local self-organization (Acheson, 2003; Baland and Platteau, 1996; Berkes, 1989; Bromley et al., 1992; NRC, 1986, 2002; Ostrom, 1990, 2005), but scholars' ability to establish causal linkages among factors and determine their relevance at local contexts, and regardless of context, is still quite limited (Agrawal, 2002). Young (2002) argued for the need to develop an "institutional diagnostic" approach as a way to overcome these challenges. In medicine, doctors usually follow a diagnostic approach toward identifying a solution to a medical problem. A doctor will ask us a number of initial questions and do some regular measurements. In light of that information, the doctor proceeds down a medical ontology to ask further and more

specific questions (or prescribes tests) until a reasonable hypothesis regarding the source of the problem can be found and supported. When we begin to think about a particular SES puzzle, we think about which of the attributes of a particular SES system are likely to have a major impact on particular patterns of interactions and outcomes. While each human being is unique, illnesses can be identified and diagnosed in a similar way to an entire population. A diagnostic approach for SESs should be capable of teasing out what makes each resource use problem unique and what makes each case generalizable and comparable across settings. Here we contend that the SES framework's multilayered organizational structure could be useful to develop a diagnostic approach for the study and governance of SESs (McGinnis and Ostrom, 2013; Ostrom, 2007, 2009).

The point of entry to the SES framework begins with the first-tier variables that a researcher would need to define to determine the particular focal CPR system of interest (Fig. 1): The Resource Units (RU) are part of the Resource Systems (RS), the Governance Systems (GS) define and set rules for Actors (A). All of them influence the resultant Interactions (I) and Outcomes (O) and create feedbacks. These variables (also conceptualized as processes) make up the focal CPR system that links to exogenous factors like other Related Ecosystems (ECO) and Social, Economic, and Political Settings (S).

In this paper, the Resource System (RS) is the small-scale fishery sector and the Resource Units (RU) are the benthic resources harvested by commercial fishers. The Governance System (GS) includes characteristics pertaining to central and local government and factors shaping rules and governance arrangements in Mexico and Chile. These determine incentives and behavior for Actors (A) involved in the fisheries. Such actors include local and non-local fishers, researchers, non-governmental organizations, and government officials. The Social, Economic, and Political Setting (S) is the Gulf of California in northwest Mexico, and the rural central Chilean coast. We aim to diagnose what combinations of SES variables were associated with fishers' ability to self-organize and avoid overexploiting their fisheries, and which interactions led to continued overharvesting.



**Fig. 1.** Revised SES framework with multiple first-tier components. Source. McGinnis and Ostrom (2013).

The SES framework is hierarchical in that it is multilayered. Each of the variables contained in the first tier unpacks to reveal a number of second-tier variables, which could further unpack into a third tier, and so on and so forth. Ostrom's (2009) selection of second-tier variables was based on three decades of empirical work studying CPRs (Acheson, 2003; Baland and Platteeuw, 1996; McKean, 1992, 2000; Ostrom, 1990; Ostrom et al., 1992; Schlager, 1994; Tang, 1992; Wade, 1994). These variables are particularly salient to tease out the likelihood that a local or self-governing association will be constituted by developing rules and norms to limit their harvesting or protect the use of the resource in some manner. However, the use of the SES framework by scholars thus far suggests its versatility to accommodate the investigation of a diversity of governance-related questions (Blanco, 2011; Cinner et al., 2012; Fleischman et al., 2010; Gutiérrez et al., 2011).

### 3. Methods

#### 3.1. Developing a classificatory system for benthic small-scale fisheries

We began by updating the second-tier factors proposed by Ostrom (2009) according to recent modifications suggested by McGinnis and Ostrom (2013). We then reviewed the updated list for relevance to benthic fisheries SESs. This process resulted in the replacement or exclusion of second-tier variables in Ostrom (2009) and the development of new third-, fourth-, and fifth-tier variables presented in Table 1. For the review and development of new

third-, fourth-, and fifth-tier variables, we relied on our own practical experience, the assistance of fisheries ecologists, and on a literature review on benthic small-scale fisheries using the key words "small-scale" or "artisanal." Paper selection was limited to resources harvested through diving and/or intertidal gathering on the marine benthos. Searches were conducted for the time period between 1980 and 2010, encompassing 98% of the indexed literature on the topic. We used ISI Web of Knowledge, a major indexing database aggregate of peer-reviewed literature. For each variable in the framework, a working definition and illustrative citation is provided. Listed citations for each definition are not presented as definitive authoritative sources; they constitute illustrations of how other scholars may have applied the concept in other benthic-related published studies.

#### 3.2. Applying the SES framework to studies of benthic fisheries in Mexico and Chile

We selected two benthic small-scale fishing settings in Mexico and Chile for which peer-reviewed documentation was available and for which the authors had significant first-hand knowledge. The study conducted in Mexico looked at three different fisheries (Puerto Peñasco, Kino, and the Seri) within the Gulf of California. The study conducted in Chile compared the same community in three different time periods. Both studies looked at the combination of factors that could be associated with the fishers' ability to self-organize to control access to other fishers. The main purpose of drawing on these studies was to provide an empirical example of

**Table 1**  
Second to fifth-tier variables of an SES for benthic small-scale fisheries. Factors modified from Ostrom (2009) and specific for benthic small-scale fisheries are noted with color red and italic font. Tiers for Interactions and Outcomes are not included as they were not modified from the original.

Social, Economic, and Political Settings (S)		
S1 – Economic development. S2 – Demographic trends. S3 – Political stability. S4 – Other governance systems. S5 – Markets. S6 – Media organizations. S7 – Technology		
<b>Resource Systems (RS)</b>	<b>Actors (A)</b>	
RS1 – Sector (e.g. water, forests, pasture, fish) <i>RS1.1 Marine benthos</i>	A1 – Number of relevant actors A2 – Socioeconomic attributes A3 – History or past experiences <i>A3.1 Crisis</i> <i>A3.2 Duration</i>	GS5 – Organizations <i>GS5.1 Government organizations</i> <i>GS5.1.1 Support enforcement</i> <i>GS5.1.2 Support funding</i> <i>GS5.1.3 Restoration efforts</i>
RS2 – Clarity of system boundaries	A4 – Location A5 – Leadership/entrepreneurship A6 – Social capital <i>A6.1 Trust and reciprocity</i> A7 – Knowledge of SES/mental models <i>A7.1 Mechanism to share knowledge about the fishery</i>	<i>GS5.2 Non-government organizations</i> <i>GS5.2.1 Capacity building</i> <i>GS5.2.2 Linking</i> <i>GS5.2.3 Bridging</i> <i>GS5.2.3.1 Unions</i> <i>GS5.2.3.2 Cooperatives</i>
RS3 – Size of resource system <i>RS3.1 Carrying capacity</i>	A8 – Importance of resource A9 – Technologies available <i>A9.1 Ownership of technology by fishers</i> <i>A9.2 Homogeneity</i>	GS6 – Rules-in-use <i>GS6.1 Property rights</i> <i>GS6.1.1 Open access</i> <i>GS6.1.2 Moratory and total allowable catch</i> <i>GS6.1.3 Catch shares</i> <i>GS6.1.4 Territorial use privileges</i> <i>GS6.1.4.1 Sea-bed tracts</i> <i>GS6.1.4.2 Individually owned fishing spots</i> <i>GS6.1.4.3 Territorial use communal rights</i>
RS4 – Productivity of system <i>RS4.1 Stock status</i> <i>RS4.2 Biophysical factors</i>		<i>GS6.2 Operational rules</i> <i>GS6.3 Collective-choice rules</i> <i>GS6.4 Constitutional rules</i>
RS5 – Equilibrium properties		GS7 – Norms and strategies
RS6 – Predictability of system dynamics		GS8 – Network structure <i>GS8.1 Horizontal</i> <i>GS8.2 Vertical</i>
RS7 – Storage characteristics <i>RS7.1 Storage in their natural habitat</i> <i>RS7.2 Storage in a human-designed facility</i>		GS9 – Monitoring <i>GS9.1 Social</i> <i>GS9.2 Biophysical</i>
RS8 – Connectivity		GS10 – Sanctions <i>GS10.1 Graduated sanctions</i> <i>GS10.2 Grim trigger strategies</i>
RS9 – Location		
<b>Resource Units (RU)</b>	<b>Governance Systems (GS)</b>	
RU1 – Resource unit mobility	GS1 – Policy area GS1.1 Environment <i>GS1.1.1 Benthic marine</i>	
RU2 – Growth or replacement rate	GS2 – Geographic range GS3 – Population	
RU3 – Interaction among resource units <i>RU3.1 Reproduction</i> <i>RU3.2 Settlement</i>	GS4 – Regime type GS4.1 Democratic GS4.2 Autocratic	
RU4 – Economic value		
RU5 – Number of units		
RU6 – Distinctive characteristics <i>RU6.1 Hatchery</i> <i>RU6.2 Wild</i>		
RU7 – Spatial and temporal distribution <i>RU7.1 Patchy</i> <i>RU7.2 Random</i>		
Related Ecosystems (ECO)		
ECO1 – Climate patterns. ECO2 – Pollution patterns. ECO3 – Flows into and out of focal SES		

how the SES framework can be useful to analyze complex SES interactions, because it makes it feasible to keep track of how different combinations of conditions are associated with similar outcomes.

## 4. Results

### 4.1. Changes to the general SES framework to create a benthic fisheries SES framework

Below we provide a summary of the modifications made to the original SES general list of variables proposed by Ostrom (2009). We used Ostrom (2009) modified by McGinnis and Ostrom (2013) as a template for our benthic fisheries SES framework because their general SES framework is the most up to date. The benthic SES framework is presented in Table 1. The table is organized by: Resource Systems (RS), Resource Units (RU), Actors (A) and Governance Systems (GS). A detailed summary of the modifications is found in Appendix A, followed by Tables A.1–A.4 containing definitions and illustrative examples from the broader literature for each variable presented in Table 1 above.

The Resource System was extended to include second- and third-tier variables/processes. These tiers focus on the heterogeneity of the systems' productivity and connectivity, as these factors can drive resource availability. In addition, differences in resource storage characteristics were added. Resource Unit's characteristics have been described as important in small-scale fisheries governance. In order to acknowledge their role in determining outcomes, we added aspects of species life history traits and spatial distribution as third-tier variables/processes. There is a high diversity of governance arrangements in benthic fisheries. Thus, the development of new tiers for the Governance System was most profound in our adaptation of the SES to benthic fisheries. We added around 37 second-, third-, and fourth-tier variables, mainly to represent the diversity of rules-in-use present in the management of benthic artisanal fisheries. The monitoring and sanctioning diversity was an important addition as new tiers for the governance system. Finally, we added third-tier variables in the Actors' domain. These variables were mainly third-tier aspects related to fishers' history of past experiences, leadership, importance of resources for livelihoods, and access to harvesting technology (Table 1).

### 4.2. Two illustrative applications of the benthic fisheries SES framework

We illustrate how an analyst can use the benthic SES framework depending on their interests by using Table 1 to select different components. The first application shows how factors influenced three Mexican fisheries' capability to avoid the tragedy of open access. Variables related to the Governance System, Resource System, and Actors explained self-organization capabilities among these fisheries. In the Chilean case, the Resource System and Resource Units remained constant over time and therefore did not need to be included in the analysis. Variables within the Governance System and Actors explain changes in self-organization capacity. In the following section, we provide a detailed description of each of the two studies in Chile and Mexico.

#### 4.2.1. An example from three Mexican fisheries on the emergence of local organization capacity to control access

Like many other small-scale fisheries in Mexico, the Seri, Kino, and Peñasco fisheries, and the benthic sessile species that they target, are not actively regulated by government authorities. As a

result, these fisheries enjoy significant levels of autonomy to determine their own operational access and harvesting rules (GS6.2) unless challenged. These fishers harvest sessile species of mollusks (mainly sea pen shells – *Atrina* spp., *Pinna rugosa*, but also rock scallops – *Spondylus calcifer*, and murex snails – *Hexaplex nigritus*). In all cases, fishers use the same technology of exploitation common among small-scale divers in the region (A9.2): a rudimentary underwater breathing apparatus called hookah adapted to a small (~8 m) fiberglass outboard motorboat (Basurto, 2006).

The towns of Puerto Peñasco and Kino Bay were first established as sea bass totoaba (*Totoaba macdonaldi*) fishing camps during the 1930s (Bahre et al., 2000). The Seri – a nomadic group at the time – had an active participation in the highly profitable Totoaba fishery in Kino, which in 1940 would eventually prompt the Seri to establish their own fishing camp and become a sedentary group (Smith, 1954). Since their establishment, Puerto Peñasco and Kino have attracted fishers from all over Mexico, lured to settle by the promise of local booming fisheries and coastal development-related economic activities. Between 1945 and 1950, the population of Puerto Peñasco, Kino, and the Seri was around 2500 (Ives, 1989), 500 (Moreno et al., 2005a), and 300 (Felger and Moser, 1985), respectively. In the early 1970s, fishing of benthic resources with hookah diving equipment began in these villages and all accounts indicate that before the 1980s, they were open-access regimes; that is, no rules had been established to control access to benthic resources (Basurto et al., 2012; Cudney-Bueno and Basurto, 2009).

As the population increased through natural growth and immigration (particularly Puerto Peñasco and Kino), so did the number of fishers and their likely competition for benthic resources. In 2005, the population of Puerto Peñasco, Kino, and the Seri stood at about 40,000, 5000, and 600 inhabitants, respectively (INEGI, 2005). The need to self-organize to control access and use to their benthic resources became evident. Kino's failed attempts to establish local vigilance and enforcement committees to control access to outsiders have been documented by Cinti et al. (2010). Those in control of the committees often found it in their own self-interest to allow outsiders to participate in their fisheries, undermining the committees' legitimacy within the fishing community (Cinti et al., 2010). It is widely perceived that pen shells are less abundant or overexploited in Kino Bay (Basurto et al., 2012; Moreno et al., 2005a). The available official statistical data reported by Moreno et al. (2005b) indicates that in 1992 the production in Kino Bay was almost 170 tones of sea pen shells (*Atrina* spp. and *P. rugosa*). Production has steadily dropped since 1992, and has averaged only 20 tons per year from 1997 to 2003. Local overexploitation of benthic resources has resulted, in turn, in an increased pressure by Kino fishers to attempt to gain access to still other abundant fishing grounds like those used by Peñasco or the Seri, their neighbors to the north.

Since the 1980s, the Seri have found incentives to face the costs of organizing to control access to their resources (Basurto et al., 2012). The number of incentives to organize relies on the Seri's collective knowledge accumulated over thousands of years of inhabiting the area and using benthic resources (A4) (Felger and Moser, 1985). The Seri have developed relevant notions of their resources' spatial boundaries and extent (RS3) and traditional knowledge about aspects of the biology and ecology that allow them to make rough predictions (RS6) about how their actions might affect the future state of their benthic resources (Basurto, 2008). Despite being relative newcomers to the region in comparison to the Seri, Kino Bay and Puerto Peñasco fishers seem to have also developed significant knowledge about the benthic resources they harvest (RS3, RS6) because such knowledge is likely germane to being a successful fisherman.

Of all three fishing communities, only the Seri have formal territorial use of communal property rights (GS6.1.4.3) to their benthic sessile mollusk fishing areas. In 1975, the Mexican federal government granted the Seri with a fishing concession. Only those areas where the Seri most frequently fished, and therefore, developed access controls, became exclusive fishing zones for the Seri community (Basurto, 2005). Over time, these zones were widely recognized by other fishing communities – like Kino Bay or Puerto Peñasco – as of undisputed Seri ownership. All other coastal areas formally granted to the Seri, where they harvest mainly mobile species but not as frequently visited and used, or where they could not find cost-effective ways to develop access controls, have been claimed by other communities and are a constant source of contestation and conflict (Bourillón-Moreno, 2002).

The strong present and future economic (A8.1) and cultural dependence (A8.2) of the Seri on the resource and its territory has generated incentives to design communally accepted operational rules to access and use (GS6.2) their exclusive fishing zone. Further, they have been able to find ways to monitor each other's fishing activities and enforce (GS9) these rules in a cost-effective manner (Basurto, 2005). In contrast, Kino fishers are not as highly dependent on benthic fishing grounds for the maintenance of their livelihoods. Many Kino fishers also participate in other fisheries and are recent immigrants to the region. When confronted with the question of benthic resource scarcity, fishers often state they would harvest something else in the locality or pack up what they own and move elsewhere (Basurto, unpublished data).

It is also important to note that for hundreds of years, the Seri were subject to invasions by other dominant ethnic groups (i.e. Spaniards and, later, Mexican *mestizos*) in attempts to achieve religious and territorial conquest (Sheridan, 1999). Although always internally divided in family groups, the Seri have developed norms of trust and reciprocity (A6.1) toward defending themselves from what they might perceive as new domination attempts. Competition for fishing areas with neighboring communities is just another form in which the Seri perceive outsiders attempting to dominate them. This perception has effectively brought them together despite their internal differences. Indeed, long-term observers have described the Seri as “entrepreneurial” and “resourceful” in their adaptive capacity toward ever-changing external threats (A5) (Felger and Moser, 1985; Wilder, 2000). In contrast, Kino fishers have not been able to build strong trust and reciprocity relationships among fishing community members. Cinti et al. (2010) describe how heterogeneous preferences among different stakeholders in the fishing process create barriers for collective action.

Similar to Kino, Puerto Peñasco is a very dynamic and socially heterogeneous community. Here, a group of family-related fishers formed a fishing cooperative in the 1970s, *Sociedad Cooperativa Buzos de Puerto Punta Peñasco*, and in effect transferred much of their previously built trust and reciprocity into the fishing arena. For roughly the same amount of time as Kino and the Seri (~30 years), Peñasco co-op divers have been commercially diving rocky reefs and adjacent coastal sandy areas, and are locally recognized as the established harvesters of benthic resources in Peñasco.

Peñasco divers' specialization on sessile benthic resources makes them very aware of the fact that they would be the first to suffer the consequences of overexploiting them. In 2000, they began to experiment with the rotation of benthic mollusk beds, in the hopes that this would enable them to avoid overexploitation scenarios. That same year, facing increased competition with fishers and other stakeholders using the same coastal resources, divers approached researchers and a non-governmental organization (NGO) for support to quantify changes in one of their most important fishing areas. The diving co-op received significant

support and leadership (A5) from university researchers and funding organizations that enabled it to afford the costs of self-organizing into a common-property regime. They implemented a local network of marine reserves designed to protect and enhance stocks of the benthic resources on which the co-op depended to maintain their livelihood (A8.1).

Researchers and the NGOs trained divers on safe diving procedures, provided arenas for the discussion and exchange of ideas, and took on some of the financial, logistic, scientific, and implementation burdens related to the establishment of the network of marine reserves. This helped to build important linkages with environmental and local government fisheries management agencies and led to the informal recognition among local stakeholders that the fishing co-op had *de facto* property rights (GS6.1.4.3) over the benthic resources being protected at the reserves. In addition, local divers were fully engaged in biological monitoring (GS9.2) and scientific knowledge development (A7). Within the above setting, co-op divers were able to design and successfully establish monitoring and enforcement rules-in-use for the benthic resources held within the reserves. After two years of limiting fishing in these areas, biological monitoring confirmed minimal harvesting activity (Cudney-Bueno and Basurto, 2009). Further, the biological monitoring generated strong evidence for a sharp increase in the density of benthic resources inside the marine reserves, as compared to before their establishment. Early positive results allowed divers to link their monitoring and enforcement efforts with an increase in the stock of their benthic resource units (Cudney-Bueno and Basurto, 2009).

In sum, the Seri and Peñasco fishers developed positive incentives to change from an open access to a common property-rights regime. These two groups of fishers found that developing a new set of operational rules (GS6.2) to control access and use to their fishing grounds would bring them more benefits than the status quo of open access (GS6.1.1). Furthermore, in their ability to implement institutional change successfully, they also needed to be able to surpass the perceived costs of changing their rules (see Basurto and Ostrom, 2009 for the theoretical model underpinning these statements). As we described above, their ability to do so was likely a function of the combination of specific third-, fourth-, and fifth-tier variables related to the Actors (A), and their Governance System (GS), while these same variables were mostly absent in the Kino Bay case. More specifically, Table 2 shows that the Peñasco and the Seri fisheries had developed shared local knowledge/mental models of their resource, found or developed local leadership (A5) conducive to controlling access and use of their fishing areas, shared high levels of trust and reciprocity (A6.1), and were highly economically dependent on their benthic fisheries (A8.1). All these elements were absent or lacking in the Kino Bay case. Regarding their Governance System (GS), the Seri and Peñasco fishers had formal or informal property rights and had developed social monitoring mechanisms (GS9.1) and graduated sanctioning systems (GS10.1) to maintain their operational rules. In the Kino case, this system was mostly absent. In sum, the absence of these factors at Kino Bay likely elevated the costs of organizing to the extent that surpassed the likely expected benefits of organizing into a common-property regime. Thus, Kino fishers were not able to find enough incentives to move away from the open access status quo. As a consequence – just as Hardin had predicted for open-access fisheries – their benthic resources were eventually overharvested.

#### 4.2.2. An over-time example from a Chilean bull-kelp fishery on the loss and recovery of local organization capacity

Through our case study from Chile, we illustrate how the SES framework can be used to study the unintended effects of particular policy interventions so that dangerous combinations

**Table 2**

Comparison of key variables for three coastal fisheries in the Gulf of California.

Successfully self-organized	Working definition	Kino No	Peñasco Yes	The Seri Yes
<b>Actors (A)</b>				
Number of actors (A1)	Number of actors affecting decision-making processes related to harvesting in the fishery	Rapid growth	Rapid growth	Slow growth
Local leadership (A5)	Actors who have skills useful to organize collective action and are followed by their peers	Absent	Present	Present
Trust and reciprocity (A6.1)	Trust is a measure of the extent to which members of a community feel confident that other members will live up to their agreements even if doing so may not be in their immediate interest. Reciprocity is a symmetrical response to a previous cooperative or defective action by a member of the community	Lacking	High levels	High levels
Shared local knowledge/mental models (A7)	Degree to which stakeholders understand and make sense of the characteristics and/or dynamics of the SES	Low	High	High
Economic dependence (A8.1)	The resource constitutes a source of monetary income and plays a major role in fishers' ability to sustain their livelihoods	Low	High	High
Cultural dependence (A8.2)	The resource constitutes a source of cultural values, practices, and services, and plays a major role in the fishers' ability to sustain their livelihoods	Low	Low	High
<b>Governance Systems (GS)</b>				
Formal or informal territorial use communal property rights (GS6.1.4.3)	Agreed-upon areas for which permanent or limited property rights are granted to all members of a formal organization created for purposes other than fishing	Absent	Present	Present
Operational rules (GS6.2)	Implementation of practical decisions by individuals authorized (or allowed) to take these actions	Present	Present	Present
Social monitoring (GS9.1)	Local actors, or outsiders legitimized by them, observe that other actors comply with agreed-upon behavior in the use of the resource system and units	Mostly absent	Mostly present	Mostly present
Biological monitoring (GS9.2)	Local actors, or outsiders legitimized by them, observe the condition of the resource system and units	Absent	Present	Mostly present
Graduated sanctions (GS10.1)	Actors who violate operational rules are given a sanction coherent with its seriousness and the times the offense has been committed	Mostly absent	Mostly present	Mostly present
<b>Resource Systems (RS)</b>				
Resource size (RS3)	Absolute or relative descriptions of the spatial extent of a resource system	Large	Small	Small
Predictability (RS6)	Degree to which actors are able to forecast or identify patterns in environmentally driven variability on recruitment	Least predictable	Moderately predictable	Moderately predictable

Source. Adapted from Basurto and Ostrom (2009, p. 50).

of policies devised at diverse tiers or attributable to particular aspects of a Resource System (RS) and Resource Units (RU) can be avoided in the future. These lessons are of particular importance to avoid the implementation of panacea-type policy interventions by governments and donor agencies around the world with little regard for existing management arrangements. Common-pool resource scholars identified this problem more than twenty years ago (NRC, 2002). The case study from Puertecillo, Chile, in which a territorial use rights fisheries (TURFs) policy was implemented over an existing traditional management system, constitutes a strong case in point (Gelcich et al., 2006). We conceptualize this study as a comparison of the same fishing community in three different consecutive points in time: (1) the ecosystem was exclusively managed through a traditional management system developed by the local fishers; (2) the system was governed exclusively by an official, biologically driven, national-level TURFs policy; and (3) the system was governed through a new regime that integrated the previous governance approaches.

Puertecillo (34° 17' S; 71° 58' W) is a rural area located in region VI of Chile. There are 49 households in Puertecillo and a total population of 195 (SECLAC, 2005). Puertecillo fishers' income is largely dependent on the sale of the brown bull-kelp (*Durvillaea antarctica*), which is dried for human consumption. Fishers from Puertecillo have been harvesting bull-kelp for generations (A3.2). Bull-kelp is harvested and sold during the summer months (November–March), and its income is used to buy basic food

supplies for the winter (Gelcich et al., 2006). Fishers in Puertecillo historically enjoyed a significant level of autonomy to determine their own operational access and harvesting rules (GS6.2), which led to the creation of a traditional management system held in place for more than 100 years until challenged by a national TURFs policy adopted in Puertecillo in 2003. During this TURFs-based management period, local management practices were eroded and the sustainability of the whole social–ecological system threatened for around four years. Following the implementation of the TURFs period, a process of cross-scale institutional learning provided the foundation for modifying rules. By this process, we mean a multiscale process by which collaboration takes place between parties within a specific network or community of practice. As such, it is a system-wide learning process between and across organizations and agencies. The process of cross-scale institutional learning took nearly a decade to develop as an alternative management pathway. The process eventually allowed Puertecillo fishers and the local fisheries agencies to rise to the resource management challenge of adapting their traditional practices to fit contemporary circumstances. We highlight the changes and key aspects determining fishers' ability to engage in collective learning for successful self-organization (or not) during each time period by using the SES framework (Table 3).

4.2.2.1. Time period 1: The informal traditional governance regime. The traditional governance regime system in Puertecillo gives

**Table 3**

Comparison of key SES variables for three distinct governance time periods in Puertecillo, Chile.

Variable (code)	Working definition	Puertecillo Time 1 Yes	Puertecillo Time 2 No	Puertecillo Time 3 Yes
Successfully self-organized				
<b>Actors (A)</b>				
Number of actors (A1)	Number of actors affecting decision-making processes related to harvesting in the fishery	Stable	Stable	Stable
Local leadership (A5)	Actors who have skills useful to organize collective action and are followed by their peers	Present	Present	Present
Trust and reciprocity (A6.1)	Trust is a measure of the extent to which members of a community feel confident that other members will live up to their agreements even if doing so may not be in their immediate interest. Reciprocity is a symmetrical response to a previous cooperative or defective action by a member of the community	High levels	Low levels	Moderate levels
Shared local knowledge/mental models (A7)	Degree to which stakeholders understand and make sense of the characteristics and/or dynamics of the SES	High levels	Low levels	High levels
Economic dependence (A8.1)	The resource constitutes a source of monetary income and plays a major role in fishers' ability to sustain their livelihoods	High	High	High
Cultural dependence (A8.2)	The resource constitutes a source of cultural values, practices, and services, and plays a major role in the fishers' ability to sustain their livelihoods	High	High	High
<b>Governance Systems (GS)</b>				
Vertical governance network structure (GS8.2)	Link actors with other organizations or the state across levels	Low	High	High
Horizontal governance network structure (GS8.1)	Link actors with each other to act collectively for a common purpose	High	Low	High
Formal recognition property/use rights (GS6.1)	Particular types of rules determining which actors have been authorized to carry out which actions with respect to a specified good or service	Absent	Present	Present
Presence of traditional use privileges: individually owned fishing spots (GS6.1.4.2)	Human-constructed or agreed-upon areas for which permanent or limited property rights are granted to individual fishers	Present	Absent	Present
Operational rules (GS6.2)	Implementation of practical decisions by individuals authorized (or allowed) to take these actions	Present	Present	Present
Biological monitoring (GS9.2)	Local actors, or outsiders legitimized by them, observe the condition of the resource system and units	Mostly present	Mostly present	Mostly present
Graduated sanctions (GS10.1)	Actors who violate operational rules are given a sanction coherent with its seriousness and the times the offense has been committed	Mostly present	Mostly present	Mostly present

Sources. Adapted from [Gelcich et al. \(2006, 2009\)](#).

access rights to eligible members of the community to undertake harvesting activities in designated grounds (known locally as "parcela"). In essence, use privileges are granted to individually owned harvesting spots through a lottery system (GS6.1.4.2). These use privileges are customary access rights legitimized by social norms and codes of behavior that have been in place for at least 100 years. In addition, through the traditional management practices, fishers have gained and shared effective knowledge about the resource system and resource units they are using (A7.1), developing norms of trust and reciprocity with those with whom they have close interactions (A6.1). For instance, the community has a process called "mingaco" in which the owner of a parcela gives food and drink in return for a day's assistance in harvesting. Through a different set of rules, the fisher community allows widows, who do not have the physical capability to extract algae, to collect what is washed ashore naturally by waves. The washed-ashore algae would normally be collected by parcela owners; however, this local rule allows widows to continue harvesting bull-kelp when they reach an age where they cannot afford assistance for extraction ([Gelcich et al., 2006](#)).

Parcelas are granted to each individual fisher through a lottery system that takes place once a year. Once a parcela is granted, the fisher has the right to decide how the parcela is to be managed for a one-year period. Nevertheless, bull-kelp extraction is not permitted between April 1 and September 30. This is a voluntary measure related to the biology of the algae that emerged through local knowledge of the system (A7). It is well fitted to scientific knowledge ([Santelices et al., 1980](#)) that suggests that the period

outside the closed season is when the algae grows faster, and therefore one or two harvests can be attained. This harvesting and governance strategy is only possible because the bull-kelp (RU) has a fast yearly growth rate (RU2: [Castilla and Bustamante, 1989](#)) and is a small distance disperser (RU3.2: [Castilla et al., 2007](#)); thus, the conservation of adult populations has important seeding effects for nearby areas, and seeds do not migrate to distant harbors.

Under the traditional system in Puertecillo, the fishers had considerable autonomy to develop and experiment with their own de facto operational rules related to who fishes, when the fishing season opens or closes, size limits, access areas, and other local rules. However, the lack of legal recognition of the system made it extremely fragile to poaching from outsiders coming from other towns ([Gelcich et al., 2006, 2009](#)).

**4.2.2.2. Time period 2: TURFs policy enacted.** In Puertecillo, conditions related to autonomy in making rules were already present when the national-level TURFs policy began operating in 2003. Under the TURFs policy, the Chilean Undersecretary of Fisheries is authorized to assign formal user rights to artisanal fisher unions in defined geographical coastal areas ([San Martin et al., 2010](#)). In order to be granted a TURF, Chilean artisanal fisher organizations have to comply with a series of regulations (details in [Gelcich et al., 2007](#)) that include establishing a baseline study and a five-year management plan, for which they have to contract technical assistance from specialized biological consultants. Although the policy has been quite successful in regions of Chile where no

traditional management practices existed, unfortunately, in Puertecillo, one year after the formal TURF had been granted and implemented, signs of bulk-kelp overexploitation and associated fishers' social unrest began to become evident (Gelcich et al., 2006). In essence, once the TURFs policy was implemented, fishers no longer depended on shared norms of trust and reciprocity (A6.1), or practices associated with the generation of local knowledge for harvesting strategies (A7). A few members of the community lost incentives to maintain operational community rules and rapidly exploited the stocks before enforcement officials (GS5.1.1) took much note of what was happening (Gelcich et al., 2006).

The TURFs policy eroded local institutions mainly affecting Actors (A) and the Governance System (GS). For instance, TURFs did provide legal recognition of a portion of the coast to the fishers of Puertecillo (GS6.1.4.3), but had negative effects mainly over congruence of rules to local conditions and over levels of participation on collective-choice arrangements, such as how to enforce and harvest. This strongly affected the equity and social cohesion of the system, particularly as it related to trust and reciprocity among fishers (A6.1). The harvesting derogations for widows were banned, and "mingacos" were replaced by the legal requirement for all fishers to participate in a collective harvest (Gelcich et al., 2006).

In addition, the mechanism to sell resources changed from individual bargaining with middlemen to collective bargaining. This changed the power relations in the union, as some members have the power to make crucial bargaining decisions, creating new vertical social relations among a few fishers, consultants, and middlemen (GS8.2). These vertical relationships were potentially positive to access new markets and gain support for enforcement. However, they were mainly used to serve individual interests, making the fisher organization become susceptible to the influence of key and powerful leaders (A5) and affecting trust, bonding relations (A6.1), and knowledge sharing about their SES within the union (A7.1). Indeed, duties associated with obeying TURFs rules discouraged fishers from maintaining an adaptive capacity and effectively using their knowledge for the management of coastal resources (A7.1). The TURFs policy implicitly established that the fisheries undersecretary set and control the management objectives (GS5.1.1). It also determined that research-based biological knowledge is the basic knowledge to include in the TURFs monitoring and evaluation (GS9). Thus, monitoring of the system was still in place, but it changed from a local continually adaptive monitoring system to the use of a formal biological indicator (GS9.2). The irony is that the TURFs policy, which was quite successful in other areas of Chile (Gelcich et al., 2010), was not devised to fit the social–ecological system of Puertecillo, generating more costs than benefits for the ecosystem and the fishers who depended on it.

**4.2.2.3. Time period 3: Merging of the traditional and formal TURFs governance regimes.** After a few years governing bull-kelp exclusively under the national TURFs regime, fishers evidenced that the social–ecological system was reaching a biological and social crisis. A process that included cross-scale institutional learning and the consolidation of horizontal relations between fishers and local fisheries agencies – which had been latent (GS8.1) – provided the foundation for an attempt to modify operational rules once again. This process has taken nearly a decade to develop a new management pathway, but is now allowing Puertecillo fishers and the local fisheries agencies to rise to the challenge of adapting traditional practices and nationally developed TURF rules to fit local circumstances. This new resultant system is still informal, but the authorities and fishers are determined to make it work (Gelcich, unpublished data).

At Puertecillo, mechanisms not directly related to fishing helped to maintain social capital (A6) within the community and

counterbalance the effects of fragmentation within the fisher union. Social capital provided a social cohesion that remained latent until the TURFs system became untenable, calling for new collective-action strategies. This latent social capital was maintained through other community-level interactions and activities that had no relation with fishing, such as the local assembly, a commission created to obtain support to build access roads to Puertecillo, and the rural water committee (Gelcich, unpublished data). All of these relations are embedded in the day-to-day interactions of Puertecillo's small and active community (A1). In addition, the presence of keystone linking agents between the local fisheries service and the fisher union was important in navigating the shift from TURFs to a new set of regulations. These agents included a well-respected fisher union leader (A5) and the local fisheries service officials who began trusting fishers.

The resulting governance regime in Puertecillo is still changing. It currently includes recognition of territorial use rights (GS6.1.4.3) and the reestablishment of individually owned parcelas under lottery assignation (GS6.1.4.2), the "mingaco" and the harvesting alternatives for widows. All of these rules are helping to rebuild trust and reciprocity (A6.1) and shared local knowledge of the system (A7). Resource monitoring systems also include rules by which local knowledge can be integrated with the formal monitoring (GS9.2) in a process that is developing both bonding and linking relationships for the first time in the history of Puertecillo (GS8.1 and GS8.2).

An examination of the SES of parcelas through time has enabled us to identify the specific variables that might be hampering or facilitating successful collective action for resource use sustainability in Puertecillo. It is interesting to note how the characteristics and dynamics of the Governance System (GS) and Actors (A) have been instrumental in regenerating the parcela system for it to operate in a new, complementary way to the official TURFs regime. The importance of trust and reciprocity (A6.1), positive leadership (A5), shared local knowledge (A7), and a combination of both horizontal and vertical governance network structures (GS8.1 and GS8.2) all appear to have an important contribution in establishing more desirable collective-action arrangements for the management of common-pool resources (Table 3). Using the SES framework by including new tiers within these variables can shed important insights on its application for policy analysis of small-scale fisheries in the context of existing traditional management practices.

## 5. Discussion

Most understanding of key factors affecting governance of benthic small-scale fisheries has been derived from case studies (but see Cinner et al., 2012; Gutiérrez et al., 2011 for large-n approaches). Here we have used this existing scientific literature to adapt Ostrom's SES framework as a way to build a classification system for knowledge accumulation or an ontology of benthic fishing SESs. In the process of adapting the general SES framework, it became clear that new tiers were necessary to represent the particularities of benthic small-scale fisheries. Although other studies are adapting the framework to irrigation (Ostrom and Cox, 2010; Villamayor-Tomas, 2012) and federal river systems (Garrick et al., 2013), none of them have yet explored what the addition of fourth- and fifth-tier variables might look like. Our approach was especially important to visualize and represent the heterogeneity in governance and rules-in-use within the benthic fisheries SES. Depending on the purposes of analysis, a scholar could take into account variables/processes at different levels of aggregation or develop further tiers according to the needs generated in specific comparative studies. The cases on self-governance presented from Mexico and Chile illustrate how in-depth studies can be organized

using the SES framework as a classificatory system of benthic fisheries. Here we discuss the potential of this approach to enable the documentation of combinations of conditions, at specific levels of aggregation, associated with certain types of outcomes of interest.

Organizing the Mexico study using the benthic SES framework illustrates what combinations of conditions allowed Puerto Peñasco and the Seri to self-organize to control access to their fisheries, while Kino failed to move away from an open-access regime ([Table 2](#)). Note that Peñasco and the Seri communities arrived at local self-organization through two different combinations of conditions or paths, illustrating the importance that conjunctural or multiple causation can play in understanding interactions and outcomes in complex SESs. The importance of looking at combinations of social–ecological variables/processes to understand interactions is similarly illustrated in the Chile study, although it is structured very differently by comparing the fishing community of Puertecillo in three different time periods ([Table 3](#)). The framework allowed the identification of the different conditions that affected fishers' ability to self-organize in different time periods. For instance, using the framework allowed fairly easily the summarization of the unintended consequences of a national-level designed TURFs governance regime, which resulted in the loss of Puertecillo's self-organization capacity in time-two. In time-three, however, Puertecillo recovered its self-organization capacity through a process of institutional learning, among other factors. In summary, the Mexico and Chile studies show how versatile a benthic small-scale fisheries ontology can be to focus on different case studies or different time periods. In addition, it shows how different fisheries (i.e. the Seri, Peñasco, Puertecillo) arrived at local or self-governance through different combinations of conditions or pathways.

For analysts interested in exploring which social–ecological factors were associated with self-governance among the Seri, Peñasco, and Puertecillo fisheries, we saw that: All cases had presence of local leadership (A5), moderate to high levels of trust and reciprocity (A6.1), high levels of shared local knowledge (A7), high economic or cultural dependence on the resource to sustain their livelihoods (A8.1 or A8.2), presence of social or biological monitoring (GS9.1 or GS9.2), and presence of formal or informal property rights (GS6.1) expressed in diverse forms of territorial use privileges (GS6.1.4). In this example, factors A5, and A7 are located at the second tier, while A6.1, A8.1, A8.2, GS9.1, and GS9.2 are third-tier factors, and GS6.1.4 are fourth-tier factors. The Chile–Mexico comparison relied on variables aggregated at different tiers to find similarities between the cases. Another study, however, could have focused only on examining the fifth-tier variables related to the different forms of territorial use privileges (GS6.1.4) that contributed to successful self-organization in Mexico and Chile. In Chile, territorial use rights were organized through individually owned fishing spots (GS6.1.4.2), while in Mexico the Seri did so through territorial use communal rights (GS6.1.4.3). Learning how these differences emerged at each place could be the entire focus of an in-depth case study. These two examples, while focused on different tiers, are operating within the same framework and thus can make it easier to link studies favoring different levels of generality and specificity into more coherent bodies of knowledge about a subject of interest.

When dealing with complex systems, it might not be possible to determine the role of a particular variable in generating the outcome observed. But it seems possible to identify which combination of variables can be associated with certain outcomes. Thus, tracking such configurations of conditions and their associated outcomes might constitute a first step toward developing systematic approaches to the study of complex systems governance ([Cox, 2011](#)).

Being able to recognize how the same phenomena can be characterized by multiple causality has policy implications because it increases the range of options available toward developing policy prescriptions that avoid panaceas.

Having described some of the potential ways the SES framework can be used in small-scale benthic fisheries, we would like to point out some remaining weaknesses that need to be addressed for its continued development. For instance, establishing second- and third-tier attributes for some conditions, such as learning and leadership, is not straightforward. This was particularly relevant from the Chilean case study, where learning (i.e. individual, social, and institutional) is hypothesized to have played an important role in the emergence of self-organization through time. [McGinnis and Ostrom \(2013\)](#) also point out that the framework does not allow an easy way of incorporating learning as a second-tier attribute. In the Puertecillo example, much of the learning processes from the traditional management system were latent for nearly five years due to the complex process of adaptation to new circumstances. It is a challenge to determine where these important learning processes should be located within the SES framework. Another challenge relates to conceptualizing the role of leaders. Although present in the framework, it needs to be further developed. The experience in Chile showed that leaders can play multiple roles, and that they must understand the ways in which others are viewing their lives. Leaders are also expected to see possibilities and to discern and develop paths of action that might otherwise go unexplored ([Gelcich et al., 2010](#)). In addition, leaders are expected to exercise high-order interpersonal communication capacities ([Graen and Uhl-Bien, 1995](#)). However, all of these characteristics can be used to enhance or weaken collective action. In this sense, the role of power, and how discourses are constructed by leaders regarding benthic fisheries SESs ([Gelcich et al., 2005](#)), is something that we feel needs to be strongly developed within third- or fourth-tier variables in the future.

## 6. Conclusion

In closing, we note some common misunderstandings and remaining challenges to the implementation of the approach presented here.

First, it is often misunderstood that all variables in the SES framework are needed for one particular analysis. It is unlikely that anyone can keep track of all of the variables listed in [Table 1](#). One can, however, hold some variables constant while focusing on some others, as we did in our studies in Mexico and Chile. Second, we view the analysis we conducted as broadly applicable to the analysis of general problems involving human-environmental interactions outside of the purview of the self-organization, common-pool resources literature, and its academic tradition. Researchers working under other traditions can also find this classificatory system useful in organizing and exploring other types of questions or issues related to social–ecological systems.

Third, in using the SES framework, we cannot overemphasize that it is a starting, not an ending, point for inquiry on governance of SESs. Using it as a checklist tablet is unlikely to be very productive. Careful assessment of the meaning of the variables depicted, and understanding of the local context to which the analysis applies, is irreplaceable. The use of a variety of tools in empirical field research, such as grounded theory, among others, will be key to avoid blind spots and make progress in the development of a tiered ontology. As we gain a better understanding of how concepts are embedded and related to each other, it might be easier to elucidate the third-, fourth-, and fifth-tiers of the framework.

Finally, we view classificatory frameworks as basic heuristic tools used by humans since time immemorial (e.g. alphabets or

ethno-classifications) to organize information about a particular phenomena or system of interest (Madin et al., 2008; Salafsky et al., 2008). They are analytical tools to work through complexity, not a statement about the world we live in, which is necessarily much more complex (Basurto and Nenadovic, 2012). Classificatory frameworks, however, can also slow down knowledge accumulation and be misused as checklists for problem analysis, and because they necessarily embed a certain worldview and the normative values held within such worldview, they can create blind spots toward other potential relevant processes and variables, or different worldviews. These issues are often less a function of any particular framework, and more an indication of poor scholarship practice and understanding of the complexity entailed by the social processes described in the framework. In this paper, we take the position that exploration, debate, and design of a classificatory framework like the SES framework constitutes an important enterprise because it offers the promise to make headway toward building diagnostic theories for policy analysis (McGinnis and Ostrom, 2013; Ostrom, 2007, 2009; Young, 2002; Young et al., 2008).

Diagnostic theories for policy analysis are a promising approach to bridge the divide between, on the one hand, policy lessons derived from generalizable models that have been applied across the board as “panaceas” (e.g. the tragedy of the commons) and, on the other hand, from policy analysis that presumes that all individual settings are so different from one another that all we can do is describe the intricate detail of particular settings (Wagner and Talakai, 2007). We welcome feedback from other scholars working with benthic fisheries on future modifications tailored to improve the SES framework potential for the accumulation of knowledge related to benthic small-scale fisheries.

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## Appendix A

A summary of the modifications made to the SES framework (Ostrom, 2009), to tailor it for small-scale benthic resource fisheries, is organized by first-tier variables:

**Table A.1**

Resource Systems (RS).<sup>a</sup>

Attribute	Working definition	Reference
RS1 – Sector	Characteristic(s) of a resource system that distinguishes it from other resource systems	Ostrom (2007) <sup>b</sup>
RS1.1 Marine benthos	Sessile or mobile shellfish or mollusks harvested by humans through diving or gathering in shallow areas	Cox et al. (2010) <sup>b</sup>
RS2 – Clarity of system boundaries	Biophysical characteristics that make feasible for actors to determine where the resource system starts or ends	Castilla and Jerez (1986)
RS3 – Size of resource system	Absolute or relative descriptions of the spatial extent of a resource system	Foale (1998)
RS3.1 Carrying capacity	The maximum number of resource units that the biophysical setting can sustain indefinitely	Castilla et al. (1998)
RS4 – Productivity of system	Rate of generation of units of biomass determined by production-consumption rates per unit of time, surface, or volume	Daw (2008)
		Cabrera and Defeo (2001)
		Moses et al. (2002) <sup>b</sup>

### Modifications to Resource Systems (RS):

- Eliminated “Human-constructed facilities” (RS4) because it is now captured by “Storage in a human-designed facility” (RS7.2).
- Added one second-tier variable: “Connectivity” (RS8) (Table 1).
- Added five third-tier variables: RS1.1, RS4.1, RS4.2, RS7.1, RS7.2 (Table 1).

### Modifications to Resource Units (RU):

- Added four third-tier variables: RU3.1, RU3.2, RU6.1, RU6.2 (Table 1).

### Modifications to Governance Systems (GS):

- Following updates suggested by McGinnis and Ostrom (2013), five new second-tier variables were added: Policy area (GS1), Geographic range (GS2), Population (GS3), Regime type (GS4), Norms and strategies (GS7).
- Following updates suggested by McGinnis and Ostrom (2013), three original second-tier variables were moved to a third-tier: Operational rules (GS6.2), Collective-choice rules (GS6.3), Constitutional rules (GS6.4). All of them are now under “Rules-in-use” (GS6). Substitutes for original second-tier variables (moved to third-tiers) are: “Organizations” (GS5) substituted “Non-government organizations,” which became a third-tier variable (GS5.2). “Rules-in-use” (GS6) substituted “Property-rights systems,” which became a third-tier variable (GS6.1).
- Added fifteen third-tier variables (some of which are mentioned above): GS1.1, GS4.1, GS4.2, GS5.1, GS5.2, GS6.1, GS6.2, GS6.3, GS6.4, GS8.1, GS8.2, GS9.1, GS9.2, GS10.1, GS10.2.
- Added eleven fourth-tier variables: GS1.1.1, GS5.1.1, GS5.1.2, GS5.1.3, GS5.2.1, GS5.2.2, GS5.2.3, GS6.1.1, GS6.1.2, GS6.1.3, GS6.1.4.
- Added three fifth-tier variables: GS6.1.4.1, GS6.1.4.2, GS6.1.4.3.

### Modifications to Actors (A):

- Renamed first-tier variables from Users (U) to Actors (A).
- Renamed second-tier variables from “History of use” to “History or past experiences,” from “Norms/social capital” to “social capital,” from “Dependence on resource” to “Importance of resource,” and from “Technology used” to “Technologies available.”
- Added eight third-tier variables: A3.1, A3.2, A6.1, A7.1, A8.1, A8.2, A9.1, A9.2.

See Tables A.1–A.4.

**Table A.1** (Continued)

Attribute	Working definition	Reference
RS4.1 Stock status	Rate of generation of units of biomass as determined by production in a given year	Froese and Kesner-Reyes (2002)
RS4.2 Biophysical factors	Upwelling, biogeographic or geomorphological factors affecting the generation of units of biomass	Diele et al. (2005) Johnson et al. (2012)
RS5 – Equilibrium properties	Characterization of the type of attractor of a resource system along a range from one to multiple (chaotic) attractors	Holling and Meffe (1996) <sup>b</sup> Scheffer et al. (2003) <sup>b</sup>
RS6 – Predictability of system dynamics	Degree to which actors are able to forecast or identify patterns in environmentally driven variability on recruitment	Dennis et al. (1992) Defeo and Castilla (1998) Foale (1998)
RS7 – Storage characteristics	Degree to which the resource units can be held captive until harvested	N/A
RS7.1 Storage in their natural habitat	Degree to which actors can leave resource units in their natural habitat, assuring a later harvest	Gelcich et al. (2007) Cudney-Bueno and Basurto (2009)
RS7.2 Storage in a human-designed facility	Degree to which actors can store (e.g. artificial enclosure in land or cold storage) resource units outside of their natural habitat for later harvesting	N/A
RS8 – Connectivity	Gene flow between different populations of resource units	Seijo (2007)
RS9 – Location	Spatial and temporal extent where resource units are found by actors	Urban (1998)

<sup>a</sup> Defined as the biophysical system from which resource units are extracted and through which natural dynamic processes regenerate the levels of the focal resource.

<sup>b</sup> Citation is not a benthic fisheries-specific paper but generally applicable and relevant to illustrate the concept and definition.

**Table A.2**

Resource Units (RU).<sup>a</sup>

Attribute	Working definition	Reference
RU1 – Resource unit mobility	Sessile or slow moving for all or parts of benthic resources' life cycle when interactions with fishers can take place	Johnson et al. (2012)
RU2 – Growth or replacement rate	Absolute or relative descriptions of changes in quantities ( $x$ ) of resource units over time ( $t$ )	Dennis et al. (1992) Foale (1998) Correia et al. (1999) Dietz et al. (2002) <sup>b</sup> Metaxatos (2004)
RU3 – Interaction among resource units	Interactions among resource units during different life stages affecting the future structure of the population	Guzmán and Tewfik (2004)
RU3.1 Reproduction	Chemical or biophysical signals cue resource units for gamete release	Guillou and Michel (1993)
RU3.2 Settlement	Chemical or biophysical signals cue larvae to move out of the water column and into the benthos	Manriquez and Castilla (2007)
RU4 – Economic value	Value of resource units in relation to the portfolio of resources available to actors	Gelcich et al. (2009)
RU5 – Number of units	Number of resource units harvested or that could be potentially harvested	Dennis et al. (1992)
RU6 – Distinctive characteristics	Markings and/or behavioral patterns that can be identified in resource units and affect actors' behavior toward them	Acheson and Wilson (1996) <sup>b</sup>
RU6.1 Hatchery	Actors can identify markings linking resource units to particular production areas	N/A
RU6.2 Wild	Actors can identify markings linking resource units to their wild origin	N/A
RU7 – Spatial and temporal distribution	Allocation patterns of resource units across a geographic area in a particular time period	Cudney-Bueno and Basurto (2009)
RU7.1 Patchy	Non-homogeneous spatial and temporal distribution of the resource units	Prescott and Cudney-Bueno (2008)
RU7.2 Random	Homogeneous spatial and temporal distribution of the resource units	Morsan (2007)

<sup>a</sup> Defined as the characteristics of the units extracted from a resource system that can then be consumed or used as an input in production or exchanged for other goods or services.

<sup>b</sup> Citation is not a benthic fisheries-specific paper but generally applicable and relevant to illustrate the concept and definition.

**Table A.3**

Governance Systems (GS).<sup>a</sup>

Attribute	Working definition	Reference
GS1 – Policy area	Rule systems tailored for a particular area of knowledge, geography, or time	Castilla and Fernandez (1998) McGinnis and Ostrom (2013) <sup>b</sup>
GS1.1 Environment	Rule systems tailored to managing and governing human and biophysical interactions usually around common-pool resources	Castilla and Fernandez (1998) McGinnis and Ostrom (2013) <sup>b</sup>
GS1.1.1 Benthic marine	Rule systems tailored to managing and governing human and biophysical interactions of common-pool resources in the marine benthos	Castilla and Fernandez (1998) Abarca and Stotz (2013) McGinnis and Ostrom (2013) <sup>b</sup>
GS2 – Geographic range	Spatial area where the rule system has effect or jurisdiction	Castilla and Fernandez (1998) McGinnis and Ostrom (2013) <sup>b</sup>
GS3 – Population	Population of actors on which the rule system has effect or jurisdiction	Castilla and Fernandez (1998) McGinnis and Ostrom (2013) <sup>b</sup>
GS4 – Regime type	Actors with authority to make decisions on behalf of the entire group of stakeholders and elected to these positions through free voting processes	Gelcich et al. (2008) McGinnis and Ostrom (2013) <sup>b</sup>
GS4.1 Democratic	Actors with authority to make decisions on behalf of the entire group of stakeholders are not elected by them	Gelcich et al. (2010) Basurto (2005) McGinnis and Ostrom (2013) <sup>b</sup>
GS4.2 Autocratic		

**Table A.3** (Continued)

Attribute	Working definition	Reference
GS5 – Organizations	Types of institutions recognized by external actors and/or authorities that facilitate formal structured interactions among actors affected by these institutions	McGinnis and Ostrom (2013) <sup>b</sup>
GS5.1 Government organizations	Institutions with governmental authority mandated to protect the public trust	N/A
GS5.1.1 Support enforcement	Institutions with a mandate for monitoring and enforcement of rules to access and use the resource	Tan-Mullins (2007) Hauck (2008) <sup>b</sup> Naschon and Charles (2010) <sup>b</sup>
GS5.1.2 Support funding	Institutions with a mandate to provide subsidies or credit	N/A
GS5.1.3 Restoration efforts	Institutions with a mandate to address provision problems such as the restocking of natural populations	Carranza et al. (2009)
GS5.2 Non-government organizations	Institutions without governmental authority mandated to protect the public trust	N/A
GS5.2.1 Capacity building	Institutions with a mandate to increase the ability of resource users to govern their resource units (e.g. govern access and use)	Mensah and Antwi (2002) <sup>b</sup>
GS5.2.2 Linking	Institutions with a mandate for providing actors with access to resources or other actors operating across governance scales	Reis and D'Incao (2000) Mahon et al. (2003) Marin et al. (2012) Marin et al. (2012)
GS5.2.3 Bridging	Institutions with a mandate to provide actors with access to resources or other actors operating within the same governance level	Castilla et al. (1998) Gelcich et al. (2010) Baticados et al. (1998) Ponce-Díaz et al. (1998) Ostrom (1990) <sup>b</sup> Basurto (2005) McGinnis (2011) <sup>b</sup>
GS5.2.3.1 Unions	An institution that establishes collective rights and responsibilities related to fishing process, production, and social support	
GS5.2.3.2 Cooperatives	An institution that establishes collective rights and responsibilities related to fishing process and means of production	
GS6 – Rules-in-use	Formal and informal rules in practice shaping human behavior and governing social interactions. Usually there is a formal sanctioning mechanism if not followed	
GS6.1 Property rights	Particular types of rules determining which actors have been authorized to carry out which actions with respect to a specified good or service	
GS6.1.1 Open access	No effective restrictions on use of resources	McGinnis (2011) <sup>b</sup>
GS6.1.2 Moratory and total allowable catch	Access is restricted by size of the fleet, amount of total allowable catch, and/or participating fishers	Ramade-Villanueva et al. (1998) Baine et al. (2007) Hearn (2008) Orensanz et al. (2013) Shivlani and Milon (2000) González et al. (2006) Orensanz et al. (2013) Orensanz et al. (2013)
GS6.1.3 Catch shares	Access granted to communities, boat owners, or individual actors with clear entry and exit rules	
GS6.1.4 Territorial use privileges	Area-based permanent or limited property rights granted to a formally or informally organized group of fishers	Defeo and Castilla (2005) González et al. (2006) Ponce-Díaz et al. (2009) Cudney-Bueno et al. (2009) Orensanz et al. (2013)
GS6.1.4.1 Sea-bed tracts	Sea-bed areas for which permanent or limited property rights are granted to fishers' organizations and individuals	
GS6.1.4.2 Individually owned fishing spots	Human-constructed or agreed-upon areas for which permanent or limited property rights are granted to individual fishers	Seijo (1993) Gelcich et al. (2006) Orensanz et al. (2013)
GS6.1.4.3 Territorial use communal rights	Agreed-upon areas for which permanent or limited property rights are granted to all members of a formal organization created for purposes other than fishing	Glaser and da Silva Oliveira (2004) Basurto (2005) Beitl (2011) Orensanz et al. (2013)
GS6.2 Operational rules	Implementation of practical decisions by individuals authorized (or allowed) to take these actions	Basurto (2005) McGinnis (2011) <sup>b</sup>
GS6.3 Collective-choice rules	The processes through which institutions are constructed and policy decisions made by actors authorized (or allowed) to do so	Cinti et al. (2010) McGinnis (2011) <sup>b</sup>
GS6.4 Constitutional rules	The process through which collective-choice procedures are defined and legitimized. The process usually results in a state or federal fisheries guideline or law	Gelcich et al. (2010) McGinnis (2011) <sup>b</sup>
GS7 – Norms and strategies	The process through which collective-choice procedures are defined and legitimized. The process usually results in a state or federal fisheries guideline or law	McGinnis (2011) <sup>b</sup> McGinnis and Ostrom (2013) <sup>b</sup>
GS8 – Network structure	Human behavior shaped by beliefs, perceptions, and the biophysical setting. It governs social interactions, but it is distinguished from rules in that there is no formal sanctioning in place	McGinnis and Ostrom (2013) <sup>b</sup>
GS8.1 Horizontal	The connections among the rule-making organizations and the population subject to these rules	
GS8.2 Vertical	Link actors with each other to act collectively for a common purpose	Marin et al. (2012)
GS9 – Monitoring	Link actors with other organizations or the state across levels	Marin et al. (2012) Cox et al. (2010) <sup>b</sup>
GS9.1 Social	Local actors or those legitimized by them are responsible to observe and report changes in the SES	
GS9.2 Biophysical	Local actors, or outsiders legitimized by them, observe that other actors comply with agreed-upon behavior in the use of the resource system and units	Basurto (2005) Cox et al. (2010) <sup>b</sup> Fernandez and Castilla (1998) Lunn and Dearden (2006) González et al. (2006) Vasconcelos et al. (2008) Cox et al. (2010) <sup>b</sup> Basurto (2005) Gelcich et al. (2007) Cudney-Bueno and Basurto (2009)
GS10.1 Graduated sanctions	Local actors, or outsiders legitimized by them, observe the condition of the resource system and units	
GS10.2 Grim trigger strategies	Actors who violate operational rules are given a sanction coherent with its seriousness and the times the offense has been committed	N/A
	Drastic sanctions that might withdraw all forms of cooperation with rule breaker	

<sup>a</sup> Defined as the prevailing set of processes or institutions through which the rules shaping the behavior of the actors are set and revised.<sup>b</sup> Citation is not a benthic fisheries-specific paper but generally applicable and relevant to illustrate the concept and definition.

**Table A.4**Actors (A).<sup>a</sup>

Attribute	Working definition	Reference
A1 – Number of relevant actors	Number of actors affecting decision-making processes related to harvesting in the fishery	Mahon et al. (2003)
A2 – Socioeconomic attributes	Characteristics of actors related to social and economic dimensions affecting fishing dynamics	Tzanatos et al. (2006) Cinner and McClanahan (2006) <sup>b</sup> Aburto et al. (2009) Kronen et al. (2010) Únal and Franquesa (2010)
A3 – History or past experiences	Past interactions that affect current actor's behavior and fisheries dynamics	N/A
A3.1 Crisis	Current use patterns triggered by a human or biophysically caused off-patterned event	Gelcich et al. (2010)
A3.2 Duration	Determined as the length of time the resource has been in use	MacDonald (1982) Leiva and Castilla (2001)
A4 – Location	Physical place where the actors are in relation to the resource itself and the market	Agrawal (2001) <sup>b</sup> Agrawal and Chhatri (2006) <sup>b</sup> Cudney-Bueno and Basurto (2009)
A5 – Leadership/entrepreneurship	Actors who have skills useful to organize collective action and are followed by their peers	Gutiérrez et al. (2011) Gelcich et al. (2006) McGinnis (2011) <sup>b</sup> Gelcich et al. (2006) Chapman et al. (2008) <sup>b</sup> Schumann (2010)
A6 – Social capital	Degree by which one or several individuals can draw upon or rely on others for support or assistance in times of need	Gelcich et al. (2008)
A6.1 Trust and reciprocity	Trust is a measure of the extent to which members of a community feel confident that other members will live up to their agreements even if doing so may not be in their immediate interest. Reciprocity is a symmetrical response to a previous cooperative or defective action by a member of the community	Foale (1998) Mahon et al. (2003) Hall and Close (2007)
A7 – Knowledge of SES/mental models	Degree to which stakeholders understand and make sense of the characteristics and/or dynamics of the SES	Zúñiga et al. (2008)
A7.1 Mechanism to share knowledge about the fishery	Actors' fishing practices allow them to learn characteristics of the resource at sufficiently rapid rates leading to behaviors affecting the state of the resource	Basurto (2005)
A8 – Importance of resource	The resource constitutes a source of monetary income and plays a major role in fishers' ability to sustain their livelihoods	Halafo et al. (2004) <sup>b</sup> Basurto (2006)
A8.1 Economic dependence	The resource constitutes a source of cultural values, practices, and services, and plays a major role in the fishers' ability to sustain their livelihoods	Eggert and Lokina (2007) <sup>b</sup> Defeo and Castilla (1998) Foale (1998) Basurto (2006) Narvarte et al. (2007)
A8.2 Cultural dependence	Degree of fishing gear used by fishers owned by those same fishers	
A9 – Technologies available	Degree by which fishers use the same harvesting technology	
A9.1 Ownership of technology by fishers		
A9.2 Homogeneity		

<sup>a</sup> Defined as the characteristics of the individual or corporate users of the common-pool resource.<sup>b</sup> Citation is not a benthic fisheries-specific paper but generally applicable and relevant to illustrate the concept and definition.

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