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# Making Ostrom's framework applicable to characterise social ecological systems at the local level

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**Abstract:** Ostrom's framework to analyse the sustainability of social-ecological systems has attracted great interest in the last years. It was not conceived to characterise systems, but its nature and structure make it very appealing to be used with this objective. However, its use to characterise three social-ecological systems where common-pool resource management is central created some methodological struggles and difficulties for comparing outcomes. This paper aims to present some adaptations developed for improving the framework's comprehensiveness and practical applicability at local level, such as a transdisciplinary description of the second-level variables, the definition of a set of third-level variables to facilitate and enrich the descriptions and additional guidelines for gathering the information and planning data searching processes at local level. The whole process of adapting and applying the framework was the result of collaboration among scientists, and local researchers and stakeholders. The adapted framework permitted a comprehensive and comparable characterisation of the social-ecological systems analysed and facilitated its use by the local communities.

**Keywords:** Common pool resources, community-based natural resources management, sustainability

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## 1. Introduction

Sustainable management requires a deep understanding of the complexity of the different systems involved (social, biophysical, economic, etc.) and of their interactions (Cumming et al. 2013). The oversimplification of the relations between human beings and natural resources and the one-size-fits-all recommendations made by managers and regulators have produced mismanagement and failures (Wyborn and Bixler 2013). The failures of this pattern of management – good intentions but poor results (Holling and Meffe 1996; Holling 2003) – emphasise the need to improve management policies and strategies through the interlinked analysis of social and ecological systems (Berkes and Folke 1998), and the active integration of local inhabitants' voices, knowledge and expectations (Carpenter et al. 2012). Knowledge and actions to encourage sustainable management of natural resources are more necessary where most people have the weakest incentives to considering the impacts of their actions, for example, when managing open-access common pool resources (CPR) (Ostrom 1990, 2005; Agrawal 2001).

Ostrom (2007, 2009) proposed a framework to analyse the sustainability of Social-Ecological Systems (SES) that integrated the efforts of many scholars over years to develop an integrative and multidisciplinary approach to understand complex interactions within different systems and scales around natural resources governance (Epstein et al. 2013). The framework is based on 8 first-level core sub-systems defining the interactions (I) between four multi-linked subsystems [resource units (RU), resource system (RS), governance system (GS) and users (U)] that deliver outcomes (O) and interacts with the social, economic and political settings (S) and with the related ecosystems (ECO). Based on extensive field research, Ostrom proposed a set of 53 second-level variables to synthesise the main features of each subsystem, but left open the option to chose other second-level variables or add a deeper level of variables according to the particularities of the analysed SES (Ostrom 2009).

The framework is a conceptual model that provides a common language for case comparison, organizing the many variables relevant in SES analysis into a multitier hierarchy that can be unfolded when needed (Binder et al. 2013). Furthermore, it is holistic (analyses social, economics, ecological and policy aspects at external and internal levels, but also their interactions and outcomes), multi-layered (different layers of information can be superposed and researchers or actors can focus their interests) and nested (individual systems and subsystems

are an integrated whole and – at the same time – part of larger *systems*) (Janssen and Anderies 2013).

This framework has attracted great interest (e.g. *Ecology and Society* and the *International Journal of the Commons* recently published special features devoted to it) and has been broadly used to analyse small scale (Basurto and Coleman 2010; Blanco 2011; Madrigal et al. 2011; Perez et al. 2011; Basurto et al. 2013), and large scale SES (Cox 2014a; Fleischman et al. 2014). However, most of the framework applications found in the literature reference the different variables, but focus on a limited number of them that define some aspects, and frequently code the presence or absence of the variables (Epstein et al. 2013), or provide a value about their status (Leslie et al. 2015).

In a research project aiming to identify sustainable community-based governance models in the management of environmental challenges in Latin America, working with civil society organizations and local communities (see www.comet-la.eu for a full description of the project and its results), the first step was a comprehensive understanding of the SES under analysis. We aimed to use similar methods to compare the results and to scale them up and out. An additional target was to involve local communities, developing outcomes adapted to their needs and providing useful and locally-adapted tools.

After reviewing several frameworks (Berkes and Folke 1998; Walker et al. 2002; Anderies et al. 2004; Díaz et al. 2011; Becker 2012) we decided to use the SES framework [the improved version provided by McGinnis and Ostrom (2014)] since it fits to most of our research objectives: (i) it covers social and ecological aspects and their interactions; (ii) it is applicable to CPR; (iii) it includes qualitative and quantitative data; (iv) it proposes a broad and flexible spectrum of sub-variables and allows them to be adapted to different SES; (v) it can be used at different scales; (vi) it puts an emphasis on the governance rules to manage natural resources and on the local stakeholders' roles; (vii) it was designed to analyse the impacts of users' self-organisation rules on sustainability; (viii) it provides the possibility to compare different case studies; and (ix) it helps researchers and policymakers to deliver useful results for knowledge creation and policy planning.

However, when the 53 second-level variables were initially described in the case studies, we got very heterogeneous answers. The results showed important difficulties to use the framework and problems of applicability at local level. The variables were very differently understood in each case study and most of their descriptions were incomplete, included erroneous concepts, mixed ideas or overlapped information in different variables. As Cox (2014a, b) and Leslie et al. (2015), we found difficulties to operationalize and standardise the variables, and to have similar criteria among different research groups.

Our research challenge was to have a method to analyse different SES adapted to work at the local level and that make possible comparisons. However, the SES is an analytical framework (Binder et al. 2013), not a methodological one and operationalization remains elusive (Leslie et al. 2015). Thus, our research

question was how to adjust the framework in order to have a methodological tool useful to do comprehensive characterisations of SES that could be used by local communities as a planning and management tool. The objectives of this paper are (i) to present the adaptations proposed, namely, the elaboration of a common definition of Ostrom's second-level variables, the inclusion of third-level variables when necessary and the guidelines to describe each of the third-level variables and have comparable data; and (ii) to provide methodological guidance for researchers and communities to organise future applications of the framework, identifying the main challenges faced while gathering data.

## 2. Methods

### 2.1. Case studies

The research has been undertaken in 3 cases studies selected to cover a diverse range of scenarios dealing with relevant environmental challenges in Latin America. In Colombia we analysed biodiversity and water management in two afro-Colombian communitarian councils (*Bajo Calima* and *Alto y Medio Dagua*) located in the biogeographic region of Chocó, at the Pacific coast. This area is internationally renowned as a biodiversity hotspot and for its freshwater richness, but it struggles with illegal logging, crops and mining. In Mexico, we addressed forest management and land use in *Santiago de Comaltepec*, a Chinantec indigenous community in Oaxaca with a long tradition of customary practices for natural resource protection. The community owns different highly preserved forest resources, ranging from cloud forests to alpine and tropical forests that provide different ecosystem services, but the lack of income and job opportunities forces migration. In Argentina, marine and coastal management were analysed at *Bahia Blanca's* estuary where, protected areas of high environmental value, such as salt marshes, coexist with economic activities, such as the largest country port. The industrial activities struggle with artisanal fisheries, tourism and coastal protection. These coasts have a high archaeological and paleontological value, such as fossil footprints of *Megatherium*, but are threatened by buildings and sand extraction. See COMET-LA website for a comprehensive description.

The case studies are remarkable examples of environmental complexity and fragility. They combine different collective and private land entitlement and resource access, economic dynamics, market influences and pressures. They exhibit different local institutional frameworks, but economic development relies principally on natural resource extraction. They have different levels of natural resource conservation, and diverse expectations about the asymmetry between their economic situation and the conservation demands coming from external conservationist agencies and discourses. The local communities face the permanent dilemma on CPR's management between generating private incomes or communitarian wellbeing. The countries where the case studies are located also have different development levels, but they share increasing market demands for natural resources at regional and international scales. The variety of contexts, situations

and actors has opened a large spectrum of possibilities to test the applicability of the framework and provided the basis to the future use of the framework in other SES.

### 2.2. Methodological sequence

An interdisciplinary team was responsible for the methodological development, providing conceptual and methodological guidance to the research groups doing the fieldwork in each country. Those research groups included researchers from different disciplines and the so-called co-researchers (local people involved in the research). To offer the local communities the means to take decisions based on a better knowledge of their SES, the tools were adapted and specific training to understand and master them was provided to the co-researchers. Co-researchers also facilitated the work within the communities. The methodological sequence followed the next steps:

1. *Methodological training workshop with representatives of all the research teams, civil society organizations and local communities*. Natural and social scientists analysed the framework and discussed how the 53 second-level variables could be approached from different disciplines.
2. *Initial description of the variables in each case study*. Participatory workshops (2–3) and in-depth interviews were organised in each case study to characterise the SES. The variables were jointly described between the research teams and the local stakeholders and were the result of knowledge-sharing and deliberating processes. This working method fostered not only the participation but also the involvement of the local communities in the project and the adequateness of the outcomes to their needs.
3. *Analysis of the information gathered*. The methodological team did an initial screening of the information collected in each case study and found different problems that made comparisons impossible. The narratives elaborated revealed different and sometimes even wrong understandings of the concepts. Thus, the methodological team analysed the reasons with workshop facilitators and fieldwork researchers in the different countries.
4. *Identification of the gaps in the framework*. The first identified problem was the difficulty to understand the second-level variables. They were differently interpreted or only partially considered in each case study. The descriptions included different aspects (influenced by the background of the researchers and the situation or the problems faced by the communities). This facilitated the identification of the variables that should be divided. Additionally, some of the concepts were too abstract for the communities. As they did not understand them, they did not provide accurate information. A final problem was the lack of a clear distinction between the SES and its settings. Local people were more familiar and tend to provide information about the SES. Thus, most of the information included in the settings was rather SES information.

5. *Adaptations proposed*. The systematic analysis of these problems led to propose adaptations such as to clarify the boundaries between the SES and the settings by defining the borders and units to be analysed in each category. Secondly, we provided a definition of all the second-level variables and renamed some to have a common understanding and increase accuracy. Following Ostrom we used the term variable, but are aware that some refer to concepts or attributes and cannot be strictly considered as variables. For many others, to define categories or value ranges did not present problems. Some definitions were found in the literature and others defined according to our research goals and priorities. The next step was the development of a set of lower level (third-level) variables for a better comprehension of the most diffuse or broad variables. The information provided by the initial descriptions was used to identify the most difficult to understand variables and those that included several aspects. A literature review was used to detect concepts that should be included and to provide examples. We initially proposed 132 third-level variables. As the objective of the paper is to describe the framework's methodological adaptations we do not describe here the variables [they can be consulted in Avendaño et al. (2013) for Colombia, Escalante et al. (2013) for Mexico and in London et al. (2013) for Argentina]. As some of these variables were SES-specific, the methodological team did a final review of the variables that could be of more general application to other case studies and proposed a set of 119 third-level variables (Supplementary Material).
6. *Guidelines to categorise the selected variables*. To support the consistent operationalization of the variables and to facilitate comparisons, the methodological team proposed several parameters to describe each variable: a) data format, differentiating between quantities, descriptions and maps or satellite images; b) analysis scale, ranging from the local (the SES) to the international levels (we considered regional level as the broader geographical or administrative area where the SES is inserted); c) data sources for secondary information, specifying the type of databases for information searching and d) collection strategies for primary information (Table 1). These types are not exclusive and more comprehensive information can be delivered combining several types.
7. *Support for planning the research.* As a final step we reflected on the main problems found when describing the variables. Quite often, these problems could not be solved, but to be aware of them helped the researchers to plan the tasks and supported their work.

Guidance in steps 6 and 7 was provided for the variables included in settings, resource units, resource system, actors and governance system subsystems because the interactions, outcomes and related ecosystems subsystems are described using information from the former.

*Table 1: Categories to describe the variables.*

| Data format | Analysis scale | Data sources | Data collection strategies |
|---|---|---|---|
| Numerical (N) | International (I) | Environmental databases (E) | Workshops (W) |
| Narrative description (D) | National (N) | Socio-economic databases (SE) | Interviews (I) |
| Geographical (G) | Regional (R) | Geospatial databases (GS) | Surveys (S) |
| | Local (L) | Legal databases (L) | Life stories (LS) |
| | | | Observation (O) |
| | | | Media analysis (M) |

## 3. Results

This section presents for each subsystem a table including the definition of the second-level variables, the third-level ones and the methodological guidance for the information gathering. Table 2 summarised and coded the most common problems encountered when describing variables at local level.

### 3.1. Social, economic, and political settings (S)

This subsystem describes how SES are affected and may affect the larger socioeconomic, political, and ecological context in which they are embedded. It informs of the management strategies designed at different levels, from national to local, and describes how aspects managed at larger scales impact on the SES. To

*Table 2: Practical problems identified to describe the variables.*

| Code | Problem | Description |
|---|---|---|
| 1 | Uncertain reliability of statistics | There is reasonable doubts about the consistency and validity of the available statistics |
| 2 | Lack of data at local level | The existing data is generated to upper levels than the local one |
| 3 | No formal register of data | The information needed has not been measured or registered or these registers are not publicly available |
| 4 | Subjective information | The information derives from participants' opinion or perception and thus results can not be extrapolated |
| 5 | Difficulty to access and collect data | There are not easily available mechanisms or procedures to access or collect data (mainly biophysical and ecological) |
| 6 | Unclear or abstract concept for local stakeholders | The meaning of the concepts is not well understood for participants. It can also refer to new concepts or to concepts the participants are not familiar with |
| 7 | Uncertain limits | The variable measured has blurred boundaries |
| 8 | Difficulty to define categories | The concepts struggle to be delimited in categories |
| 9 | Difficulty to measure | Problems to quantify data with traditional research tools or mechanisms or lack of a range of possible descriptive values |
| 10 | Difficulty to integrate and organise information | The variables are not static, values vary with time, space, etc., thus integration and organization can be complex |

clearly differentiate SES and settings is essential, but it can be difficult because the boundaries are not always clear or may depend on the different features at stake. Some information can be similar, while other variables might differ significantly. The attributes proposed in the framework for this subsystem are very broad and were differently interpreted. Hence, we proposed third-level variables for all the aspects included.

To explain economic development (S1) we proposed: *economic sectors* (S1a), *employment per sector* (S1b), *income per capita* (S1c) and *income dispersion* (S1d). Demographic trends (S2) are explored through *number of inhabitants* (S2a), *population density* (S2b), *demographic structure* (S2c), *population growth rate* (S2d), *migration trends* (S2e) and *settlement patterns* (S2f), which provide a more precise overview of the social situation and the threats derived from human pressures. Political stability (S3) is described by *respect for democratic values* (S3a), *norm compliance* and its reinforcement capacity (S3b), *existence of conflicts* (S3c) and *drivers for political change* (S3d). Government resource policies (S4) are described by *governmental regulatory framework* (S4a) for the management and use of natural resources, *environmental policies* (S4b) at different levels and their level of implementation and *compliance with environmental regulatory framework and policies* (S4c). To explore market incentives (S5), the variable was subdivided into: *type of products* (S5a) marketed (commodities and non-commodities), *influence of local/global markets* (S5b) in the area's dynamic, *access to markets* (S5c), *demand for natural resources* (S5d) and *market incentives for conservation* (S5e). To understand media organization (S6) and its role in society and on environmental issues, we proposed: *presence of media* (S6a), *media deterrence capability* (S6b) and *media interest in socio-environmental issues* (S6c) (Table 3).

Most of these variables need to be described at local or regional level, but for some included in S3, S4, S5 and S6, national or international information is also relevant. Most of the information can be found through secondary sources, but we also proposed primary sources for many of them to include the local knowledge and perception. The main problems found were related with the difficulties to have information at local level, either in national systems or local registers, and its reliability. For some variables, the subjectivity of the information provided or the difficulties to access and collect data were also problematic.

### 3.2. Resource system (RS)

This subsystem describes the environmental conditions where the resources are located or produced. Most of the variables (RS1, RS3, RS4, RS5, RS7, RS8 and RS9) were self-explanatory (Table 3), but RS2 and RS6 not. System boundaries (RS2) is a key variable; well-defined boundaries are more effective for successful collective resource management (Ostrom 1990) and for controlling and preventing negative processes. As SES boundaries can be defined naturally or by man we proposed *natural boundaries* (RS2a) and *anthropogenic boundaries* (RS2b) and added *boundaries to extraction access and property* (RS2c). To analyse the

*Table 3. Adaptations of the social, economic and political settings (S) subsystem.*

| Second level variables | Description | Third level variables | Scale | Data sources | Research tools | Data type | Problems |
|---|---|---|---|---|---|---|---|
| Economic development (S1) | Economic situation, including the standard of living and the economic health of the area | S1a. Economic sectors | R, L | SE | I, S, W | D, N | 1 |
| | | S1b. Employment per sector | R, L | SE | | N | 1, 2, 3 |
| | | S1c. Income per capita | R, L | SE | | N | 1, 2, 3 |
| | | S1d. Income dispersion | R, L | SE | I, O, S, W | N | 1, 2, 3 |
| Demographic trends (S2) | Trends, changes and status of the human population | S2a. Number of inhabitants | L | SE | | N | 1 |
| | | S2b. Population density | L | SE | | N | 1 |
| | | S2c. Demographic structure | L | SE | | D, N | 1 |
| | | S2d. Population growth rate | L | SE | | D, N | 1, 2 |
| | | S2e. Migration trends | R, L | SE | I, S, W | D, N | 1, 2 |
| | | S2f. Settlement patterns | L | GS | | D, G | 1 |
| Political stability (S3) | Core regulatory framework for the country or region and regularity in the rules and values of the democratic processes | S3a. Respect for democratic values | R, L | L | I, LS, M, O, S, W | D | 3, 4 |
| | | S3b. Norm compliance | R, L | L | I, LS, M, O, S, W | D | 5 |
| | | S3c. Conflicts | N, L | L | I, LS, M, O, S, W | D | 3, 4 |
| | | S3d. Drivers of political change | N, R, L | | I, M, S, W | D | 4 |
| Government resource policies (S4) | Top-down policies adopted by the national, regional and local governments to manage natural resource | S4a. Governmental regulatory framework for natural resources | N, R | L | | D | |
| | | S4b. Environmental policies | N, R, L | L | | D | |
| | | S4c. Compliance of environmental regulatory and policy frameworks | N, R, L | L | I, M, O, S, W | D | 2 |
| Market incentives (S5) | Markets for natural resources and conservation incentives | S5a. Type of products | R, L | SE | I, S, W | D | |
| | | S5b. Influence of global/local markets | N, R, L | SE | I, S, W | D | |
| | | S5c. Access to markets | R, L | SE | I, S, W | D | |
| | | S5d. Demand for natural resources | I, L | SE | I, S, W | D | |
| | | S5e. Market incentives for conservation | I, L | SE | I, S, W | D | |
| Media organization (S6) | Number, diversity and freedom of private and public media | S6a. Presence of media | R, L | | I, M, O, W | D | 6 |
| | | S6b. Media deterrence capability | I, L | | I, M, O, W | D | |
| | | S6c. Interest of media in socio-environmental issues | N, L | | I, M, O, W | D | |

equilibrium properties (RS6), we suggested describing the *interactions between subsystems* (RS6a), the *external impacts and system responses* (RS6b) and the *history and evidence of impacts in sub-systems and its effects* (RS6c) (Table 4).

These variables should be described at local or regional level. Most of them need primary information sources, even if secondary sources can be useful for additional information or crosschecking. Here we found a different kind of problems such as the uncertain limits of the variables; the difficulties to define categories and to measure or collect data; and the fact that variables are non-static or informant-based data and thus, subjective.

### 3.3. Resource units (RU)

This subsystem describes the natural resource units generated by the resource system. They can be countable/manageable (e.g. fish, water, wood) or need approximations to be measured (e.g. biodiversity). Most of the variables (RU1, RU2, RU3, RU5, RU6 and RU7) were clearly understood. Additional variables were proposed for market value (RU4). The economic value is associated with monetary value, but a complete understanding of the resource value should include other values. We proposed renaming RU4 as *resource value* and divided it into: *market value* (RU4a) (price associated to the resources), *environmental value* (RU4b), even if it is not recognised by the market, and *strategic value* (RU4c), which can be linked to economic, social, geopolitical, cultural or even symbolic considerations (Table 5).

Most of these variables are described at local or regional level (except those included in RU4 where international information is necessary) and should be described using primary sources, even if secondary sources can also be available. Problems are linked to the lack of local information or registers, the difficulties to measure variables, the non-static type of information and the subjectivity.

### 3.4. Actors (A)

This subsystem describes the actors affecting or affected by the resource system. The SES framework initially defined it as 'users'. However, McGinnis and Ostrom (2014) replaced it by 'actors' to expand the framework's potential range of application. These authors proposed nine second-level variables to describe it. A3, A4, A8 and A9 were similarly understood.

Actors (A1) was renamed as *relevant actors* and included two groups: *direct users* (A1a) and *other actors* (A1b), to be described numerically and mentioning its dependence and influence on the SES. Socio-economic attributes of users (A2) include a broad spectrum of information. We subdivide it into: *demographic attributes* (A2a) (number of inhabitants, population density, gender ratio, demographic structure, population growth rate, migration trends and settlement patterns); *economic attributes* (A2b) (sources of income, subsistence activities, non-paid activities for SES management, time allocation to different economic activities and actors' specialisation/dependence on SES resources) and *social*

*Table 4: Adaptations of the resource system (RS) subsystem.*

| Second level variables | Description | Third level variables | Scale | Data sources | Research tools | Data type | Problems |
|---|---|---|---|---|---|---|---|
| Sector(s) (RS1) | Biological production systems (e.g. water, forest, pasture, fish) | RS1. Sectors | R, L | E, SE | I, O, S, W | D, N | |
| Clarity of system boundaries (RS2) | Clarity of the system's geographical, social and legal boundaries | RS2a. Natural boundaries | R, L | E, GS | O, S, W | D, G | 7 |
| | | RS2b. Anthropogenic boundaries | R, L | GS, SE | I, O, S, W | D, G | 8 |
| | | RS2c. Extraction access and property boundaries | L | GS, SE | I, S, W | D, N | 7 |
| Size (RS3) | Size of the different types of resources | RS3. Size | L | E, GS, SE | | N | 9 |
| Human constructed facilities (RS4) | Anthropogenic structures facilitating resource management (e.g. boundaries, access ways, storage or transformation facilities) | RS4. Human constructed facilities | L | E, GS, SE | I, O, S, W | D | |
| Productivity of system (RS5) | Estimation of the resource system productivity (qualitative if necessary) | RS5. Productivity of the resource system | L | E, SE | I, S, W | N, D | 2, 5, 9 |
| Equilibrium properties (RS6) | Influences (positive and negative) on the equilibrium of the resource system (interaction between species, or between biological and anthropological systems) | RS6a. Interactions between subsystems | R, L | | I, O, S, W | D | 9 |
| | | RS6b. External impacts and system responses | R, L | E | I, S, W | D | 6, 9 |
| | | RS6c. History and evidence of impacts in sub-systems and its effects | R, L | E | I, M, S, W | D | 2, 6, 8, 9 |
| Predictability of dynamics (RS7) | Capacity to estimate the evolution and dynamics of the resource system and the impact of interventions or external influences | RS7. Predictability of system dynamics | R, L | | I, S, W | D | 4, 6, 9 |
| Storage characteristics (RS8) | Retention of information about the system dynamics | RS8. Storage (memory) of the effects of disturbances | R, L | | I, S, W | D | 4, 6, 9 |
| Location (RS9) | Geographic location | RS9. Location | L | GS | | G | |

*Table 5: Adaptations of the resource units (RU) subsystem.*

| Second level variables | Description | Third level variables | Scale | Data sources | Research tools | Data type | Problems |
|---|---|---|---|---|---|---|---|
| Resource unit mobility (RU1) | Mobility or not of the resource (e.g. fish and water are mobile, while trees are static) | RU1. Resource unit mobility | R, L | E | I, S, W | D | |
| Growth or replacement rate (RU2) | Estimations based upon the resource unit's life cycle (e.g. reproductive age, harvesting age, growth rate) | RU2. Growth or replacement rate | L | E | I, W | D, N | 2 |
| Interaction among resource units (RU3) | Identification of the relation patterns between resources (e.g. competition, collaboration) | RU3. Interaction among resource units | L | | I, S, W | D, N | 9 |
| Resource value (RU4) | Value of the resources, including the values non recognised by the markets | RU4a. Market value | I, L | SE | I, S, W | D, N | 3 |
| | | RU4b. Environmental value | I, L | E, SE | I, S, W | D | 4, 9 |
| | | RU4c. Strategic value | I, L | SE | I, S, W | D, N | 4, 9 |
| Number of units (RU5) | Total volume or amount of resource (e.g. wood volume, agriculture production volume, number of fish) | RU5. Number of resource units/ amount of resource | L | E | I, S | N | 2 |
| Distinctive characteristics (RU6) | Natural or artificial markings to distinguish categories in the resource | RU6. Distinctive characteristics | R, L | E | I, S, W | D | 9 |
| Spatial and temporal distribution (RU7) | Availability of the resource in space and time | RU7. Spatial and temporal distribution | R, L | E, GS | I, S, W | D, G, N | 10 |

*attributes* (A2c) (access to health assistance, formal education and basic services, poverty and vulnerability levels, local consumption patterns, women's rights in relation to natural resources access and cultural identity). For those described in the settings, here, we asked to highlight the differences.

Leadership/entrepreneurship (A5) has a high impact on management decisions. We proposed to include: *leadership patterns* (A5a) to explain the type of leadership existing and the acceptance of and respect for leaders and *entrepreneurship patterns* (A5b) to define the entrepreneurial skills of actors and leaders. Norms/social capital (A6) is also critical for understanding the SES functioning, but included unclear concepts for the communities. We subdivided into: *traditional forms of collaboration* (A6a), *social capital* (A6b), including aspects such as trust and reciprocity, *attitude toward corruption* (A6c) and *traditions and community values related to natural resource use* (A6d). To better understand knowledge of SES/mental models (A7) we suggested: *local knowledge of SES* (A7a), *knowledge of the effect of over-harvesting* (A7b), *knowledge of social attitudes toward resource management* (A7c), *knowledge of the effect of biological shocks* (A7d) and *mental models related to SES management* (A7e) (e.g. conservation, exploitation, human-nature relationships) (Table 6).

All these variables need to be described at local level (in some the regional level can also be relevant) and using primary sources (only for A1, A2 and A4 secondary sources can be used). This is the subsystem where most problems were found and almost all the problem's categories occurred. The most common problems were the subjectivity of the information and the difficulties to measure the concepts included. However, other problems like the lack of formal registers and the non-static information also happened.

### 3.5. Governance system (GS)

This subsystem looks into the processes through which decisions on SES management are made, implemented, reformed and reinforced. The framework proposed eight variables to describe it. For GS2, GS5, GS6 and GS7 no additional variables were necessary. Government organizations (GS1) was subdivided into *state organisations* (GS1a) and *communitarian organisations* (GS1b), to distinguish between the role played by the government in the SES management and the existing community-based governance structures. Network structure (GS3) was divided to identify the most important networks affecting the SES: *social networks* (GS3a), *community networks* (GS3b), *environmental networks* (GS3c) and *market networks* (GS3d). To better describe the property-right system (GS4), we introduced *property-rights system* (GS4a), *excludability* (GS4b) options and *subtractability* (GS4c). Monitoring and sanctioning (GS8) was divided in *monitoring processes* (GS8a) and *sanctioning processes* (GS8b) to underline the importance of both and the fact that they are not necessarily linked (Table 7).

*Table 6: Adaptations of the actors (A) subsystem.*

| Second level variables | Description | Third level variables | Scale | Data sources | Research tools | Data type | Problems |
|---|---|---|---|---|---|---|---|
| Relevant actors (A1) | Actors with a direct influence on the SES | A1a. Direct users of natural resources | L | SE | S, W, I | N, D | 2, 9 |
| | | A1b. Other actors | R, L | SE | S, W, I | N, D | 9, 10 |
| Socio-economic attributes of users (A2) | Socio-economic characteristic of the resource system users | A2a. Demographic attributes | L | SE | S, W, I | D, N | 2, 3 |
| | | A2b. Economic attributes | L | SE | I, S, W | D | 3, 9 |
| | | A2c. Social attributes | L | SE | I, O, S, W | D | 2, 3 |
| History or past experiences (U3) | Chronological description of the main events related to the resources and its management | A3. History or past experience | R, L | | I, LS, O, S, W | D | 4 |
| Location (A4) | Geographical location of resource system's users (e.g. settlements, villages, dispersed) | A4. Location | L | GS, SE | I, S, W | D, G | |
| Leadership/entrepreneurship (A5) | Existence of, and attitude towards leadership and entrepreneurship among users | A5a. Leadership patterns | L | | I, LS, O, S, W | D | 4, 10 |
| | | A5b. Entrepreneurship patterns | L | | I, LS, O, S, W | D | 4, 9 |
| Norms/social capital (A6) | Levels of social and institutional interactions among users, including aspects like reciprocity and trust | A6a. Traditional forms of collaboration | L | | I, LS, O, S, W | D | 4, 9 |
| | | A6b. Social capital | L | | I, LS, O, S, W | D | 4, 6 |
| | | A6c. Attitude toward corruption | L | | I, LS, O, S, W | D | 4, 10 |
| | | A6d. Traditions and community values related to natural resource use | L | | I, LS, O, S, W | D | |
| Knowledge of SES/mental models (A7) | Level of knowledge among the users of the SES conditions, the potential and real disturbance patterns and its possible effects | A7a. Local knowledge on SES | L | | I, LS, O, S, W | D | 4, 9 |
| | | A7b. Knowledge of the effect of over-harvesting | L | | I, O, S, W | D | 4 |
| | | A7c. Knowledge of the effect of social attitudes toward resource management | L | | I, O, S, W | D | 4, 8, 9 |
| | | A7d. Knowledge of the effect of biological shocks on the SES | L | | I, O, S, W | D | 4 |
| | | A7e. Mental models related to SES management (e.g. conservation, exploitation, human-nature relationships) | L | | I, LS, O, S, W | D | 4, 8 |

*Table 6: (continued)*

| Second level variables | Description | Third level variables | Scale | Data sources | Research tools | Data type | Problems |
|---|---|---|---|---|---|---|---|
| Importance of resources (A8) | Users dependence on resources for livelihood | A8. Importance of resources | L | | I, O, S, W | D | 2, 3 |
| Technologies available (A9) | Type of technologies used to extract, harvest and manage the resource, and access of users to different technologies | A9. Technologies available | L | SE | I, LS, O, S, W | D | 3 |

*Table 7: Adaptations of the governance system (GS) subsystem.*

| Second level variables | Description | Third level variables | Scale | Data sources | Research tools | Data type | Problems |
|---|---|---|---|---|---|---|---|
| Government organizations (GS1) | Presence or absence of different organizations at local level | GS1a. State organizations | N, R, L | L, SE | I, S, W | D | |
| | | GS1b. Communitarian organizations | L | L | I, S, W, LS | D | |
| NGOs (GS2) | Presence of NGOs | GS2. NGOs | R, L | L | I, S, W | D | 3 |
| Network structure (GS3) | Network configuration at local level and their interactions | GS3a. Social networks | R, L | | I, LS, S, W | D | 3, 4, 10 |
| | | GS3b. Community networks | L | | I, LS, S, W | D | |
| | | GS3c. Environmental networks | R, L | | I, LS, M, S, W | D | |
| | | GS3d. Market networks | N, L | | I, LS, M, S, W | D | |
| Property-rights systems (GS4) | Local property-rights systems and their relation to resource management | GS4a. Property-rights system | R, L | L, SE | I, O, S, W | D | |
| | | GS4b. Excludability | L | | I, O, S, W | D | 4, 9 |
| | | GS4c. Subtractability | L | | I, O, S, W | D | 4, 9 |
| Operational rules (GS5) | Local rules for defining Who, How, Where, When, and Why have access to local natural resources | GS5. Operational rules | L | SE | I, O, S, W | D | |
| Collective-choice rules (GS6) | Rules set defined by involved actors according to local environment and political and economic conditions | GS6. Collective-choice rules | L | SE | I, S, W | D | |
| Constitutional rules (GS7) | Legal framework defined by regional and national governments | GS7. Constitutional rules | R–L | L, DB | I, S, W | D | |
| Monitoring and sanctioning processes (GS8) | Locally adapted processes to monitor and sanction natural resource use and management strategies | GS8a. Monitoring processes | L | SE | I, O, S, W | D | |
| | | GS8b. Sanctioning processes | L | SE | I, O, S, W | D | |

These variables need to be described at local or regional levels (with the exception of GS1a and GS3d that are also affected by the national scale). Primary and secondary sources can be combined to describe them, even if the primary ones predominate. Many variables were easily described. The main problems were lack of formal registers, difficulties to measure or subjectivity of the information.

### 3.6. Interactions (I)

Several variables informing the Interactions among sub-systems (I4, I5, I6, I7, I9 and I10) were easily understood, only examples or additional information were added. Harvesting levels (I1) was divided into *harvesting levels of different users and its effects on the SES* (I1a) and *free-riding* activities (I1b). Information sharing (I2) should be more specific, unfolding the processes and their effects on the SES dynamics by describing the *knowledge transmission* of the cumulative ecological body (I2a), the *information/knowhow sharing about SES variations* (I2b) and the presence or absence of *learning processes* (I2c). Deliberation processes (I3) was better understood by adding *knowledge about participation mechanisms and rights* among the users (I3a) and *trust building processes* (I3b). For networking activities (I8), *internal networking activities* (I8a), *external networking activities* (I8b), *partnership and cooperation activities* (I8c) and *external communication processes* (I8d) were proposed (Table 8).

### 3.7. Outcomes (O)

This subsystem describes the results of the interactions among the aforementioned variables. It explains and evaluates the results of the dynamic interaction processes among different sub-systems and the interrelations and influences on the SES. The three variables that describe them required additional variables to capture the richness of outcomes and nuances in the SES.

O1 would be better named as *socio-economic performance measures* because it includes social and economic processes. Seven third-level variables are proposed: *efficiency* (O1a), *social sustainability* (O1b), *economic sustainability* (O1c), *equity* (O1d) to explain the distribution of benefits among SES users, *accountability* (O1e), *effects of deliberation processes on the SES* (O1f), *empowerment* (O1g) (including a gender analysis) and *adaptation strategies* (O1h) to environmental or man-made changes.

O2 should comprise: *environmental sustainability* (O2a); *pressures on resources* (O2b), including aspects such as the increasing demand of resources, the presence of new actors and resource uses, the uncontrolled harvesting, etc.; *natural habitat conditions* (O2c), including information on biodiversity indexes, species richness, connectivity, and situation of the habitat (conserved/degraded/fragmented); *effect of SES management on natural hazard impacts* (O2d) to describe whether changes in type, frequency or patterns are happening; *environmental quality* (O2e) to describe the condition of the resources, including information on its quality and availability; *resilience* (O2f) and *vulnerability*

*Table 8: Third level variables defined for the Interactions (I) subsystem.*

| Second level variables | Description | Third level variables |
|---|---|---|
| Harvesting levels (I1) | Quantity of resource(s) harvested by different users | I1a. Harvesting levels and effects on SES<br>I1b. Free-Riding |
| Information sharing (I2) | Methods for information sharing among users | I2a. Knowledge transmission<br>I2b. Information/knowhow sharing about SES variations<br>I2c. Learning processes |
| Deliberation processes (I3) | Deliberation processes used among users | I3a. Deliberation processes<br>I3b. Knowledge about participation mechanisms and rights<br>I3c. Trust building processes |
| Conflicts (I4) | Existing conflicts among users | I4a. Conflicts |
| Investment activities (I5) | Investments for improving and managing the resources (investor, amount invested and destination of investment) | I5a. Investment activities |
| Lobbying activities (I6) | Internal and external influence capacity of the users | I6a. Lobbying activities |
| Self-organizing activities (I7) | Internal rules for the extraction and management of resources among users | I7a. Self-organizing activities |
| Networking activities (I8) | Networking and partnership activities of the users within and outside the community | I8a. Internal networking<br>I8b. External networking<br>I8c. Partnership and cooperation<br>I8d. External communication processes |
| Monitoring activities (I9) | Monitoring activities on the use and management of resources (e.g. locally-defined by users, controlled by the government) and their performance | I9a. Monitoring activities |
| Evaluation activities (I10) | Processes of evaluation of the resource situation and of the effects of management initiatives | I10a. Evaluation activities |

*Table 9: Third level variables defined for outcomes (O) subsystem.*

| Second level variables | Description | Third level variables |
|---|---|---|
| Socio-economic performance measures (O1) | Evolution and impacts of the socio-economic concepts included | O1a. Efficiency<br>O1b. Socio-economical sustainability<br>O1c. Equity<br>O1d. Accountability<br>O1e. Effects of deliberation processes in the SES<br>O1f. Empowerment<br>O1g. Adaptation strategies |
| Ecological performance measures (O2) | Evolution and impacts of the ecological concepts included | O2a. Environmental sustainability<br>O2b. Pressure on resources<br>O2c. Natural habitat condition<br>O2d. Effect of SES management on natural hazards potential impacts<br>O2e. Environmental quality<br>O2f. Resilience<br>O2g. Vulnerability |
| Externalities to other SES (O3) | Non desired effects (positive and negative) that occur as results of processes | O3a. Positive externalities<br>O3b. Negative externalities |

(O2g). The two last variables are not easy to measure, but a qualitative approach can be selected to understand the views of stakeholders on them. Basurto et al. (2013) used this approach assigning a low, medium, or high measure to some variables. Finally, O3 have been subdivided into *positive externalities* (O3a) and *negative externalities* (O3b) (Table 9).

### 3.8. Related ecosystems (ECO)

The last core subsystem describes the connection between the considered SES and the surrounding using three second-level variables: climate patterns (ECO1), pollution patterns (ECO2) and flows into and out of the focal SES (ECO3). No additional variable was proposed because our SES have limited capacity to influence these parameters. Additionally, it was not easy to collect information or data at local level to describe the influence of the SES management on other ecosystems. However, the attributes gathered in this subsystem are relevant enough to pose a challenge for future research in environmental sustainability on the issue of integrated scale management.

## 4. Discussion of results

The adaptation process has been a tough task that needed several iterations and where researchers from different disciplines and local co-researchers made an effort to identify and operationalize the main aspects included in the framework's concepts or attributes. The research teams appreciated the methodological

adaptations and valued the guidance offered in the definition of what to describe, the inclusion of third-level variables and the information about the scale of analysis, the databases and strategies for information searching and the expected format of information delivery. This guidance helped channelling the participatory and deliberation processes on the different aspects included in the subsystems and the variables, and facilitated the methodological and fieldwork design of the following phases of COMET-LA project. Additionally, the identification of problems associated to the variables supported the research planning and the variables description, and comforted the researchers when they faced difficulties to have precise descriptions. The adapted framework led to more homogeneous variable descriptions and facilitated comparisons (see Avendaño et al. 2013; Escalante et al. 2013; London et al. 2013).

The local communities appreciated the benefits of the original framework to have a comprehensive understanding of their SES, but realised the difficulties of using it. Thus, they acknowledged the interest of the adapted framework to make easier the complete characterisation of their SES and its usefulness as a planning and management tool. All of them are now in a process of designing strategic management plans for the territories and recognised that this wide-ranging characterisation will assist them in these processes. Furthermore, they feel confident to use the tool in the future to update the information when necessary.

## 5. Conclusions

The SES framework is a well-rooted conceptual framework, but was not conceived for comprehensive characterisation. Its nature and structure make it very appealing to be used with this objective, but is operationalization was complicated when applied to a place-based research.

Communities managing CPR need adapted tools that combine local and scientific knowledge. The adaptations proposed proved to be useful for both researchers and communities. It helped the communities to have a broader and inclusive understanding of their SES. For researchers, this tested set enriched the framework, facilitated comparisons and helped avoiding common misleading situations, such as dissimilar interpretations based on disciplinary borders, competition between scientific and local knowledge, biased interpretations and over-valuation of some sort of data over others.

The differences and the diversity of actors and components in the three SES allowed identifying several difficulties and supported the usefulness of the adapted framework in different contexts. We acknowledge that the proposed variables generated enough information to characterise SES but might not necessarily be the only ones to analyse other SES.

Furthermore, its application set in motion an interesting transdisciplinary methodological learning process, gathering researchers and local stakeholders in the search for tools that facilitate a common understanding of CPR sustainable

management. The experience showed that the complexity of the framework limits the possibility to be used by local communities without external guidance. However, the training of local inhabitants and the methodological guidelines helped them to master and use the framework. The process fostered community empowerment and the elaboration of context-specific information to drive decision-making processes.

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