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The Fortune of the Commons: Participatory Evaluation of Small-Scale Fisheries in the Brazilian Amazon

Antonio F. P. Oviedo[1] · **Marcel Bursztyn**[1]

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Abstract This paper applies a participatory approach in evaluating small-scale fisheries, focusing on the *Arapaima gigas* fishery in the Brazilian Amazon. The evaluation uses the social-ecological system (SES) framework, adopted to explain the conditions needed for sustainability and user cooperation in natural resources management, as a more suitable alternative to the 'blueprint' or 'panaceas' approaches, based only on property rights or governmental intervention. However, managers and users often do not have the necessary information compiled and available for a specific SES while some actions need to be taken immediately. Thus, consensus and negotiation among stakeholders about SES variables may be useful to evaluate system performance and indicate actions to promote sustainability. In the case study, using a consensus-building model, we found that arapaima SES leads to sustainability and is far from being a case of 'tragedy of the commons.' More investments in suitable monitoring and enforcement for adaptive management are recommended. Adopting an SES framework based on stakeholders' prospects may be useful until complete interdisciplinary studies become available so as to seek of sustainability in the long term.

Keywords Participatory evaluation · Social-ecological system · Sustainability assessment · *Arapaima gigas* · Amazon

✉ Antonio F. P. Oviedo
antoniopoviedo@gmail.com

[1] Center for Sustainable Development, University of Brasília, Campus Darcy Ribeiro, Brasília, DF 70910-900, Brazil

Introduction

In recent decades, one of the main scientific challenges in addressing threats to sustainability has been the suitable integration of disciplines that deal with biophysical and human dimensions (Basset 2007; Moran 2010; Sternlieb et al. 2013). Meanwhile, the traditional economic approach to the study of the management of shared resources has predicted that all actors behaving in their self-interest lead to the overuse or overharvesting of shared resource (Hardin 1968). Even worse, there has been a tendency to oversimplify the complexity of human-environment interactions by suggesting 'universal solutions' for the management of natural resources that have very distinct ecological traits and social contexts (Pritchett and Woolcock 2004; Wilson et al. 2013). However, Ostrom (1990) showed that people are, in fact, capable of self-organizing and successfully governing their shared resources. Those findings fostered further conceptual development that led to the social-ecological system (SES) approach (Ostrom 2009) with major implications for policy, helping to explain the ineffectiveness of many governance regimes (Anderies and Janssen 2013).

SES research project and fieldwork has indicated that there are multiple factors that account for success in managing common-pool resources (Frey and Rusch 2013). Institutional settings are very heterogeneous. The effectiveness in applying models has shown limitations and failures (Ostrom et al. 2007; Meinzen-Dick 2007); good solutions are good because they have been tailor-made for specific realities. Ostrom (1999) defined a set of success factors that she called design principles: "an essential element or condition that helps to account for the success of these institutions in sustaining common pool resources and gaining the compliance of generation after generation of appropriators to the rules in use." Subsequently, that work has been further developed in the SES framework (Ostrom 2009).

Since 1990, several studies have used or discussed these design principles and their contributions to the success of cooperation among common resource users (Cox et al. 2010; Agrawal 2001). A study using 25 field projects on Asian fisheries evaluated Ostrom's design principles, and proposed clear boundaries of resources and defined number of users as a highly important principles (Pomeroy et al. 1998). Adding the policy dimension, Garretta et al. (2012) examined the role of stakeholders' fora in encouraging shared understanding among stakeholders. The perception of local users on natural resource use policies offers managers clues for policy design and improved system efficiency. For better policy performance, users and managers need to be involved in the decision-making process (Nunan et al. 2012; Marshall 2007).

A step toward modeling SES is taken by arranging variables into a multilevel framework. Using this framework allows researchers to set up analysis of how attributes of the resource system, resource unit, users, and governance system interact with one another, and the outcomes from this interaction (Ostrom 2007). Also, researchers can use this framework to evaluate the effect and interaction of these attributes on the economic, political, and ecological settings (Ostrom et al. 2007). The framework is intended to allow for a high interaction between local and traditional knowledge and science. This interaction will enable diagnostics to match governance arrangements to specific problems in a social-ecological context (Ostrom 2007).

SES needs quantitative and qualitative data. Multidisciplinary studies must be conducted in order to improve data sets and better evaluate the interaction between government and local users, and to improve policies (Ostrom et al. 2007). SES can be used to evaluate the influence of social factors on land management and policy design. Qualitative data show that stakeholders' attitudes and behavior are potential indicators to assess policy performance for land restoration (Petursdottir et al. 2013; Asah 2008). The study of Petursdottir et al. (2013) also suggests that limitations on governance can impact the outcomes of policies related to resource management. Gutiérrez et al. (2011) examined 130 co-managed fisheries in a wide range of countries with different social, economic, and ecological conditions. Their evaluation considered variables relating co-management attributes under categories suggested by Ostrom (2009). Strong leadership was identified as a key variable contributing to co-management, as well as fishing quotas, social cohesion, and protected areas. The authors concluded that enforcement mechanisms, long-term management policies, and resource information were less important variables.

The SES approach to fishery management presents a huge perspective towards achieving sustainability (Kittinger et al. 2013; Gutiérrez et al. 2011). However, the complex and place-specific nature of SES interactions constrain the identification of the state and trends in SES variables of interest to managers and policy-makers (Olsson et al. 2004; Asah 2008). Due to the perspective presented by the SES approach, there is a demand for simplified and easily interpretable indicators of the state and trends of relevant SES variables (Carpenter et al. 2001). SES knowledge generation integrated with management practices is increasingly proposed, evolving with the institutional framework and the learning-by-doing process (Walker et al. 2002; Olsson et al. 2004), as a mode of reflexive governance (Beck 2006).

Sustainability assessment using indicators and SES variables are being developed as a tool for policy design and performance in fields such as environment, economic, social, or technological improvement (Ostrom 2007; Bauler 2012; Singh et al. 2012). According to Ness et al. (2007), sustainability assessment gives managers an indicator of the nature-society system over time, in order to guide actions to ensure sustainability. Monitoring process and reporting on environmental and social conditions should be integrated or extended to provide useful information to navigate a transition towards sustainability (Bebbington et al. 2007). To move beyond panaceas and build diagnostic methods, we need to identify combinations of variables that affect site-specific SES. Also, we should examine variables of a resource system and the resource unit which affect the performance of users and the governance system (Ostrom 2007). Growing knowledge about the relationship between biodiversity and ecosystems may help here (Pimm 1984; Schwartz et al. 2000; Loreau et al. 2001; Balvanera et al. 2006).

SES variables as indicators of system performance can help build consensus among managers by easing knowledge sharing (Bauler 2012). The process of knowledge generation and specific SES variables might thus gain in importance as governance tools when acknowledging their institutional embeddedness. This approach could continuously adapt the institutional process of sustainability assessment (Connor and Dovers 2004; Ostrom 2007), once it keeps variables embedded within decision-making arenas. Participatory approaches have been used as effective decision-making processes to address sustainable development issues (van den Hove 2000). However, considering the plurality of representation of a given system and predictive uncertainty (Prigogine 1997), the participatory approach should combine the consensus-oriented cooperation with the compromise-oriented negotiation process aiming at the collective agreement of a particular outcome (van den Hove 2006).

There is widespread recognition of the valuable role that local and traditional ecological knowledge can play in the contemporary management of natural resources (Butler et al. 2012). This knowledge consists of the practical skills and wisdom acquired through livelihood activities and the collective knowledge acquired by the community over generations (Berkes et al. 2000; Brook and McLachlan 2008). Local knowledge of species, their life histories, distributions, climate, and environmental characteristics are nested within resource management systems, tools, and measures. In turn, these are embedded within the grassroots institutions, codes, norms, rules, and decision-making procedures required to implement management systems (Weber 2003; Oteros-Rozas et al. 2013). In many cases, the combination of traditional ecological knowledge and scientific knowledge led to the creation of efficient management systems (Folke 2004; Drew 2005; Folke et al. 2005; Berkes 2009; Brondizio et al. 2009; De Freitas and Tagliani 2009; Raymond et al. 2010; Vierros et al. 2010; Terer et al. 2012). Johannes (1998, 2002) and Johannes et al. (2000) suggest that depletion of fishery stocks, limited scientific data, and limited governance capacity are factors that leverage knowledge integration. According to Garibaldi and Turner (2004) and Castello (2004), dealing with “cultural keystone species” such as the arapaima may facilitate this kind of integration.

However, while the SES framework approach can embrace multidimensional and interdisciplinary aspects related to sustainability from a conceptual point of view, an additional synthetic methodological step is needed so as to promote its application in most practical situations. This article aims at proposing a participatory approach to assign values for SES variables having in mind the empirical analysis of the evolution of arapaima management system.

Case Study: Arapaima Fisheries in Acre State

As in many other regions in the world, fisheries managers in the Brazilian Amazon have been experimenting since the early 1990s with participatory management systems (Castro and McGrath 2003). This shift is a response from grassroots in favor of local management schemes, as well as changes in national policies. Fishing agreements (IBAMA 2003) have been a form of the governance system whereby resource users and local institutions work together with government agencies to deal with some aspect of resource management (Castello et al. 2011).

The research took place in the Purus and Envira rivers in the municipalities of Manoel Urbano and Feijó (Fig. 1), state of Acre, Brazil. The study area consists entirely of floodplains (Junk 1997). This type of ecosystem is characterized by floods during part of the year, and during the dry season, part of the main river’s water is naturally dammed in lakes. The area is inhabited by traditional riverine communities (Moran 1984).

The Acre study case began in 2004, involving twelve communities controlling approximately 30 km^2 of floodplains, distributed in 14 lakes. Fishers from Purus and Envira rivers had demonstrated an interest in managing fish resources. Research work started with the mapping of the floodplain lakes resource system and community management practices to learn how resource units were used and to evaluate to what extent the management regime had an impact on fisheries productivity (Oviedo 2006). That work concluded that community management had a significant effect on the productivity of lake fisheries (Martins 2010) but also that in order to do so, it would require a broad-based approach. Fishery policy needed to be modified to provide an adequate legal basis for ecosystem and community management. Local institutions had to be created in order to implement these policies, while central government agencies had to adapt themselves to be able to work within a participatory management model. Finally, community members and government agents needed to learn their new roles within the evolving management system.

Community groups have been working to develop management systems for the *Arapaima gigas*, one of the largest freshwater fish species in the world. Arapaima is an important fishery in the Amazon basin and plays key ecosystem roles (Queiroz 2000). Public policies of harvest season and minimum size, and total moratoria have been established in Acre state. However, monitoring and law enforcement are limited. Castello et al. (2014) highlight that with most of the catch being in violation of management policies in the Amazon basin, fishing of arapaima is now overexploited and declining. Arapaima is listed as endangered species in the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES).

The arapaima has characteristics that make it a promising species for community management: it surfaces regularly to gulp air, is primarily sedentary, spawns in floodplain lakes, and forms couples to care for offspring (Castello 2004). A method for estimating arapaima populations based on wildlife census techniques (visual counting) was developed at the Mamirauá Sustainable Development Reserve, state of Amazonas (Castello 2004). This method takes advantage of biological characteristics of arapaima and the fishers’s skill in distinguishing adults from juveniles when they rise to the surface. A group of arapaima fishers from Acre traveled to the Varzea Project (a pilot initiative on arapaima management) in Santarem, state of Para, to learn this technique. On returning, they formed a management team and improved arapaima management schemes.

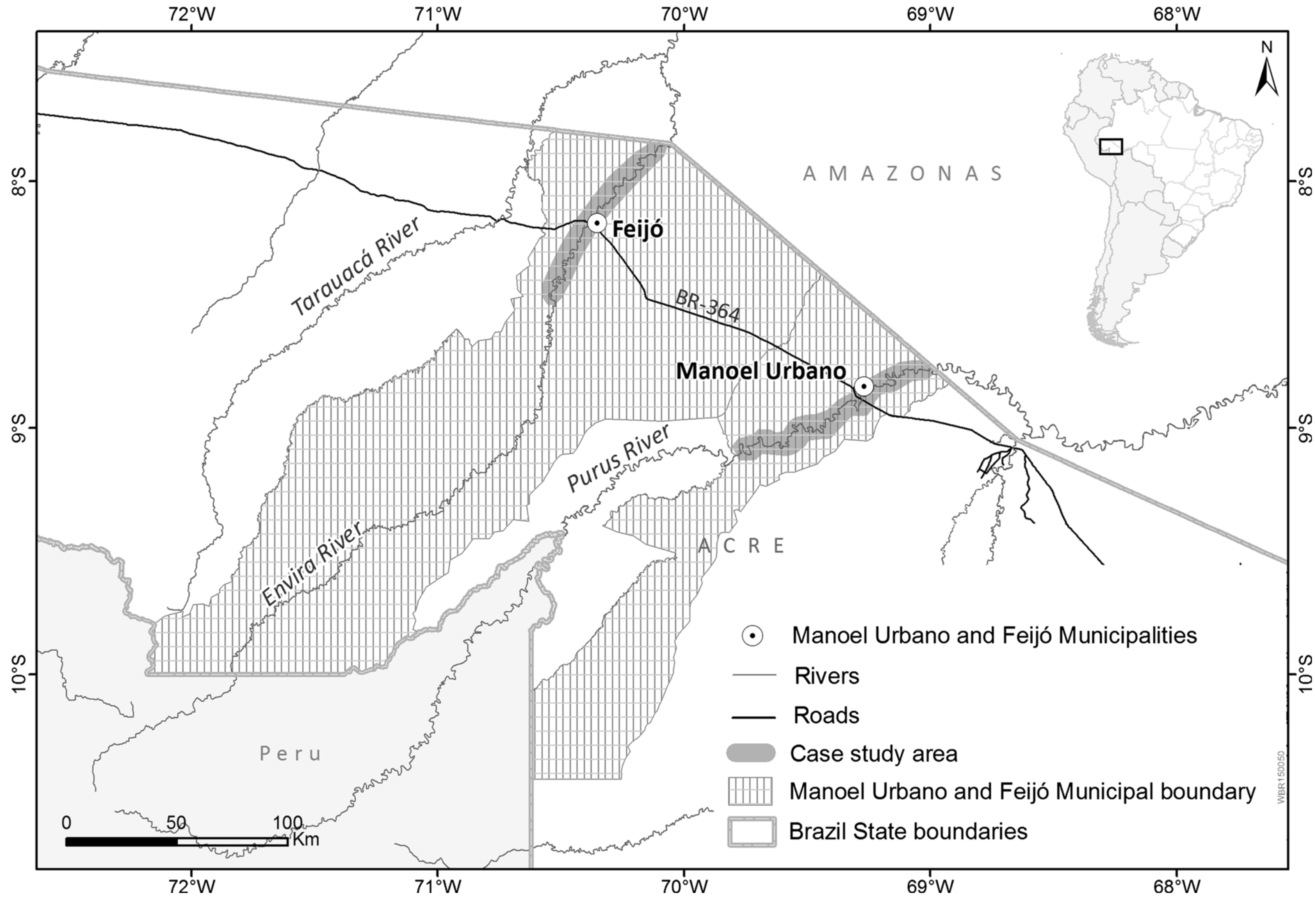

Fig. 1 Case study at the Purus and Envira rivers

Whereas before fishers could only say whether a given lake had more or less arapaima than another, now the management team can make a reliable estimate of the number of adult and juvenile arapaima, the size of the breeding population, and the size distribution of the arapaima catch. Teams can now predict how many arapaima can be caught each year without threatening system sustainability, monitor progress in rebuilding arapaima populations and periodically revise management rules (Oviedo and Crossa 2011).

The most effective method, in terms of harvesting and benefit-sharing is a collective harvest using large nets and harpoons. The management team organizes one or more collective harvests to catch the entire annual quota. Income from the sale of fish is divided among participants according to how much they contributed to collective actions, with a proportion of the total amount going to the municipal Fishers's Union and to community members who patrol the lakes.

This system also reinforces community organizational capacity. It is based on a participatory methodology in which results depend on the ability of group members to work together. Successive annual estimates of arapaima populations enable the group to measure progress in achieving management objectives. The collective harvesting system reinforces the fact that arapaima is a community resource, and the size of total catch provides concrete evidence of the value of the fishery to the community. The contribution to the Fishers's Union and communities underscores the collective benefit provided by the fishery while dividing income among participants ensures that rewards are in proportion to each fisherman's contribution to the management system.

The practice of collective action has brought significant changes at community and government levels. First the users with some level of conflict were mobilized to take management actions together. After a while, fishers understood they had more capacity and power as a group than as individuals. The management team can monitor the management rules and behavioral norms at community level rather than seeking outside assessment. The arapaima harvesting and marketing are supported by government agencies, as well as the civil society organizations (Fishers̓s Union and NGOs). The creation of this multi-institutional arrangement strengthened the decision-making arena and fostered the prospect for a more formalized co-management system.

At the same time, arapaima research efforts and technical assistance helped to improve community organization and eliminate illegal practices. The planned arapaima sale directly to buyers would increase fishing' profits, thus lowering illegal practices. Fishermen created local markets, and the management team was formalized into the municipal Fishers's Union. These formal groups required that users commit formally to obeying fishing regulations. With the prospect that users could control the arapaima stocks, the management team negotiated with the national environmental authority (IBAMA) the possibility of legal harvesting. IBAMA had banned arapaima fishing in the state but had made an exception in management plan cases. The management team carried out annual arapaima assessments. The harvest quota is about 30 % of the estimated number of adult arapaima and is determined through negotiations between fishers and IBAMA.

The vigilance program was considered partly effective. To some, the program was short of volunteers because of the risk involved in overseeing outside fishers. To others, the vigilance program was largely ineffective with respect to locals because local communities have high kinship network densities among families and family members. Vigilant volunteers often faced the problem of having to sanction relatives or close friends. Fishing agreements depend on the irregular patrol of lakes, typically conducted by few volunteers, while the great majority evades this task. While this may work for dealing with the occasional incursions of outsiders, it is insufficient for dealing with "inside" violators, members of the community itself. In this case, informality and the lack of representative patrols and leadership leave those who identify violators vulnerable to charges of partiality. Also, logistical and financial difficulties are exacerbated by problems involving vigilance. Efficient mechanisms for punishing violators and solving conflicts are thus another challenge for such a management scheme. Community volunteers and IBAMA agents have not tackled this challenge. This can partly be attributed to the lack of resources to undertake patrols, but, more importantly, it reflects the fact that IBAMA agents do not easily accept sharing authority with community members.

Methods

We evaluated the extent to which fisherman participation improved the management system by using the design principles proposed by Ostrom (1990). Previous works have demonstrated that they are reliable indicators of the conditions under which user groups can manage natural resources sustainably (Agrawal 2001; Ostrom 1990). These are as follows: Principle 1 assumes the existence of clearly established resource boundaries and of its users. Principle 2 assumes that the resources are exploited sustainably. Principle 3 assumes functional collective action. Principle 4 assumes that the resource and its users are monitored. Principle 5 assumes that rule offenders are sanctioned. Principle 6 assumes the existence of a conflict resolution mechanism. Principle 7 assumes formal central government regulation. And, principle 8 assumes there is institutionally organized multi-level management scheme. Our evaluation of the case study determined the presence or absence of each of Ostrom's (1990) eight principles for the periods before and after the management system was implemented (Table 1).

An SES framework (Ostrom 2009) was used to assemble multidisciplinary knowledge in order to facilitate evaluation and identify combinations of variables that affect interactions and outcomes of this specific management system. The aspects of decomposing complex systems are essential for achieving a better understanding of complex SESs (Ostrom 2007) and crafting ways to improve their performance. The first aspect is the conceptual partition of variables into classes and subclasses. The second aspect is the existence of relatively separable subsystems that are independent of each other in the accomplishment of their many functions and their development but eventually affect each other's performance. This framework (Fig. 2) is based on the relationship among four SES subsystems:

i. Resource Systems (RS): a certain territory containing the natural resource;
ii. Resource Units (RU): the primary resource unit most used for harvest;
iii. Users (U): the sets of individuals who use the territory (resource system) for different purposes; and
iv. Governance System (GS): government and other organizations involved with resource system management, its specifics norms and rules and how they are made.

Each of the subsystems mentioned above is made up of second-tier variables as described by Ostrom et al. (2007) and Ostrom (2009). Some variables have been considered by these authors as key-variables related to creating conditions for cooperation among users (Table 2). Those subsystems are connected by a set of interactions (I) producing a set of outcomes (O) that in turn provide feedback to the subsystems, associated ecosystems (ECO) and social, economic, and political settings (S), as shown in Fig. 2.

Obtaining measurements for SES variables is the first step in analyzing whether the users of the arapaima management system would self-organize. The analysis must

Table 1 Assessment of the arapaima management system compliance with Ostrom's (1990) sustainable governance design principles

Ostrom's design principle	Arapaima SES before management system (2004)	Arapaima SES after management system (2012)
P1—Defined boundaries	Present: zoning system	Present: zoning system improved by collective fishing agreements and user's data base
P2—Resource be exploited sustainably	Absent: overharvesting and arapaima stocks declining	Present: management measures, arapaima stocks increasing
P3—Collective action	Absent: individual management	Present: fishing agreements increased participation
P4—Monitoring	Absent: no monitoring systems	Present: counts of arapaima are made by the fishers themselves and community monitoring of fish landing data
P5—Graduated sanctioning	Absent: illegal fishing and free-rider	Present but weak: sanctioning by fishing quota
P6—Conflict resolution	Absent: no conflict resolution occurs	Present but weak: conflict resolution mechanism exists but not all conflicts are resolved
P7—Formal recognition from central governments	Absent: total moratoria	Present: legal permit to harvest arapaima based on management plan
P8—Nested enterprises	Absent: activities are not organized in multiple layers	Present: institutional arrangement with communities, state government and IBAMA

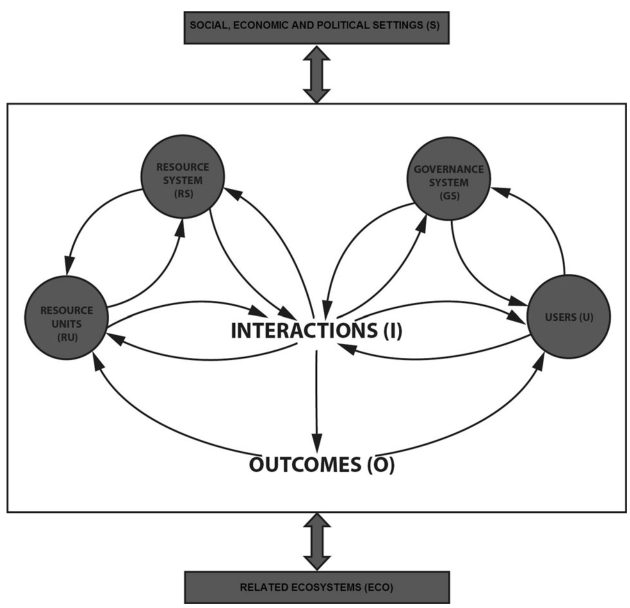

Fig. 2 Framework for social-ecological analysis adapted from Ostrom (2009)

acknowledge the interactions between variables. Furthermore, these interactions occur mainly in a non-linear system (Janssen 2002; Levin 1992). Anderies and Janssen (2013) have developed a didactic approach to applying the SES framework evaluation mechanistically. However, for this paper, a complementary method was suggested to evaluate a given SES along a multidimensional spectrum of sustainability, based on an empirical approach.

In 2010, a 3-day workshop was held involving fifteen fishers (seven fishers from Manuel Urbano and eight fishers from Feijó) and two local government agents to set and assign values for a group of variables for the periods before and after the arapaima management system. All the participants composed a homogeneous group involved from the beginning of the management system. A brainstorming session conducted by the local government agents with the help of the workshop moderator (a scientist involved in the case study) identified a set 29 SES variables as most relevant for arapaima management system: (i) 10 Key-variables suggested by Ostrom et al. (2007) and Ostrom (2009); and (ii) 19 SES second-tier variables (Table 3). Value assignment was performed by group members based on empirical evidence about the management system. To calibrate the range of values, the assumptions made by Hardin (1968) were used as depicted by Ostrom et al. (2007) in order to set the non-sustainability threshold. On the other hand, the best scenario for SES variables was taken to set the other extremity, i.e., the ideal conditions for the sustainable co-management system. We used a set of 25 variables (S4, S5, RS1, RS3, RS5, RS7, RU1, RU4, RU6, GS4, GS6, U1, U5, U6, U7, U8, I1, I2, I4, I7, O1, O2, O3, ECO2, and ECO3) to design Hardin's and sustainable scenarios, and 19 variables (S4, RS2, RS3, RS5, RS7, RU1, RU6, GS4, GS6, GS8, U1, U4, U5, U6, U8, I4, I7, I8, and O2) to evaluate the arapaima management system (Table 3). In order to guarantee study replication of and comparison, rules were established to assign values to all SES variables, attributing greater weight to those considered as key variables. The assigned value range varies from −1 to +1 for key-variables (including variables S5, RU6, GS4, I1, I2, I4, I7, O1, O2, O3, ECO2, and ECO3) and from −0.5 to +0.5 for the other variables.

Table 2 Set of key variables and respective effects as indicated by Ostrom et al. (2007) and Ostrom (2009)

Variable	Effect
RS3—Size of resource system	Moderate territorial size is more conducive to cooperation
RS5—Productivity of resource system	An exhausted or very abundant resource will not incentive its management. Moderate productivity showing possible scarcity, with both risks and opportunities, will elicit interest among users
RS7—Predictability of system dynamic	The system should be predictable enough in order to users may estimate the effects of particular rules
RU1—Resource unity mobility	Resources with high mobility will demand high costs in monitoring great territories
U1—Number of users	Rely mainly on RS3. To manage many users for a relatively small territory may not be cost-effective. On the other hand in large territory a large number of users may be useful for monitoring activities
U5—Leadership/ entrepreneurship	When some user are respected as leaders and have entrepreneurial skills, the cooperation among users is more likely
U6—Norms/social capital	Prior existence of ethical/moral standards which determine ethical/moral norms of reciprocity among users will diminish the transaction costs in reaching agreements
U7—Knowledge of SES/mental models	When users share common knowledge of relevant SES attributes, how their actions affect each other, and rules used in other SESs, they will perceive lower costs of organizing
U8—Importance of resource	The costs in organizing and cooperate is worth only if either the resource plays a major role for the users livelihood or it has another social or cultural value which claims for its sustainability
GS6—Collective-choice rules	If users have the legitimacy and the autonomy to create an to enforce their rules, they will be more motivated into keep engaged in self-organization and protect the resource against outsiders

All qualitative information gathered between 2004 and 2012 has been analyzed as proposed by Dey (1993). In this regard, qualitative information depends on contexts, and the analysis should be based on stakeholder objectives and perceptions. So, results reported in this article related to the arapaima management system are those shared among the stakeholders involved (fishers and government agents). The group members built a formal procedure to reach consensus for each variable assignment. Hence, communication becomes central. The procedure adopted the requirements of Habermas' communicative rationality (Habermas 1996; Enevoldsen 1998) for participatory approaches: (i) Free speech situation, where the speech is devoid of external constraint and of strategic behavior, and in which only the best argument counts; (ii) Consistency between discourse, beliefs and behavior, where each participant should be rationally accountable by offering justifications and reasons; (iii) Transparency, where each participant's references and values should be explicit and open to other's criticism; (iv) Focus on common interest, where participants should strive beyond the mere adjustment of particular interests. Habermas' requirements highlight the negotiation of a compromise in which participants strive to conciliate individual and diverging interests. As divergence occurs during the SES value assignment, the group applied unlimited rounds of negotiation to reach consensus. Representatives of divergent variable's value argue their views of the management system and SES variable values were updated at each round of negotiation.

After the consensus-oriented process, we calculated an average score value (Eq. 1) for the highest-tier variable of SES framework, based on the associated second-tier variables, to produce a subsystem score or value (Table 3). We produced scenarios for the periods before and after the management system implementation, as well as for Hardin's tragedy of the commons and sustainable co-management system. The arapaima management system is described and presented in a web diagram showing visually how each of the subsystems changed over time. Also, the web diagram provides an estimate of where the arapaima management system is on the continuum between an unsustainable SES and a sustainable scenario.

$$\mathrm{SGAs} = \frac{\sum_{v=1}^{Ts} \mathrm{G}v}{Ts} \qquad (1)$$

where SGA is the subsystem score, Gv is the value assigned for variable v effect, and Ts is the total number of variables for the subsystem s.

Results and Discussion

The arapaima management system implementation was based on the setting of Ostrom's (1990) design principles. Only one design principle (P1, defined boundaries) was present in the Acre case study before the arapaima management system started. Nine years after the arapaima management system was implemented, practically all of the eight design principles were in place (Table 1).

Table 3 Subsystem score (SGA) calculations using SES second-tier variables

Variable	Values assignment				Subsystem	Aggregated Values by SES Susbsystem			
	Hardin's tragedy of the commons	Arapaima SES before mgmt (2004)	Arapaima SES after mgmt (2012)	Co-mgmt and sustainable		Hardin's scenario	Arapaima SES before mgmt (2004)	Arapaima SES after mgmt initiative (2012)	Sustainability threshold
S4—Government resource policies	0	0	0.5	1					
S5—Market incentives	0.5	–	–	0	S	0.167	0	0.083	0.167
RS1—Sector	0.5	–	–	0					
RS2—Clarity of system boundaries	–	0	0.5	–					
RS3—Size of resource system[a]	1	1	1	1					
RS5—Productivity of system[a]	0.5	0.5	0.5	1					
RS7—Predictability of system dynamics[a]	0	0	0.5	1	RS	0.222	0.166	0.277	0.333
RU1—Resource unit mobility[a]	1	1	1	1					
RU4—Economic value	0.5	–	–	0					
RU6—Distinctive markings	0	0	0.5	1	RU	0.214	0.142	0.214	0.286
GS4—Property-right system	0	0	0.5	1					
GS6—Collective-choice rules[a]	0	0	0.5	1					
GS8—Monitoring & Sanctioning processes	–	0	0.5	–	GS	0	0	0.187	0.25
U1—Number of users[a]	−1	0	0.25	1					
U4—Location	–	0.5	0.5	–					
U5—Leadership[a]	0	0	0.25	1					
U6—Norms/social capital[a]	0	0.5	1	1					
U7—Knowledge of SES/mental models[a]	−1	–	–	1					

Table 3 continued

Variable	Values assignment				Subsystem	Aggregated Values by SES Susbsystem			
	Hardin's tragedy of the commons	Arapaima SES before mgmt (2004)	Arapaima SES after mgmt (2012)	Co-mgmt and sustainable		Hardin's scenario	Arapaima SES before mgmt (2004)	Arapaima SES after mgmt initiative (2012)	Sustainability threshold
U8—Importance of resource[a]	0	0	1	1	U	−0.222	0.055	0.333	0.555
I1—Harvets levels of diverse users	−1	–	–	0					
I2—Information sharing among users	0	–	–	1					
I4—Conflict among users	0	0	0.5	1					
I7—Self-organizing activities	0	0.5	1	1					
I8—Network activities	–	0	0.5	–	I	−0.125	0.062	0.25	0.375
O1—Social performance	0	–	–	1					
O2—Ecological performance	−1	0	1	1					
O3—Externalities to other SESs	0	–	–	1	O	−0.333	0	0.333	1
ECO2—Pollution Patterns	0	–	–	1					
ECO3—Flows into and out of focal SES	0	–	–	1	ECO	0	0	0	0.667

[a] Key-variables as suggested by Ostrom et al. (2007) and Ostrom (2009)

– No value assigned

The arapaima management system progressed showing significant improvement in regard to Ostrom's principles (Table 1). The collective action (P3) work began in 2004 with the municipal assemblies, when fishers and government agencies agreed to a shared vision for achieving sustainable fisheries (P6) and created rules for fishing agreements in target lakes (P1 and P3). Participatory work began with the closure of the arapaima fishery for stock restoration (P5) and capacity building of community volunteers, in 2005. The integrated ecosystem vision began with the implementation of arapaima management plan (P2) and at the beginning of harvest, in 2007 (P7). The association began in 2009, when the local management teams were created in Manoel Urbano and Feijó for co-management with government agents (P8). Since 2005, these teams have been monitoring arapaima stocks to establish annual fishing quotas and legal harvest permits (P4). In Manoel Urbano, lake productivity had increased by about 44 % since 2004. In Feijó, the arapaima population had increased by about 23 % since 2008 (Oviedo and Crossa 2011).

Three assumptions can explain why arapaima management system led to the establishment of the seven Ostrom's principles not observed before it began : (1) shared knowledge implemented between fishers and government agents supported the decision-making process; (2) monitoring done by local users increased knowledge and management system empowerment; and (3) participatory approach for designing local rules promoted the adaptive management process. Field surveys made by fishers and government agents improved understanding of the arapaima fishery and its related ecosystem, and also enabled the development of fishing agreements. There are five lakes managed under fishing agreements in Manuel Urbano and nine lakes in Feijó with proposals IBAMA-approved fishing agreements. Investing in the knowledge sharing helped to adjust design principles 2, 3 and 8, related to sustainable fishing practices, collective action, and institutional arrangements, respectively. The monitoring process provided government agents with reliable data and facilitated the understanding of local users, who adhered more easily to fishing rules. This was key to setting design principles 4 and 7, which are related to monitoring the resource and the rights of fishers to legal harvest permits. The participatory approach created decision-making arena, involving local users and government agents to share knowledge and understand how to adapt to environmental feedback. This approach was crucial to setting design principles 3, 5, 6 and 8, that are related to collective action, rule offenders, conflict resolution and institutional arrangements. Also, the case study strongly aligns with Garibaldi and Turner's (2004) approach, where the work with an endangered species promotes the rescue of local knowledge and the development of further scientific studies for the management scheme.

Incomplete enforcement suggests the design principles of graduated sanctioning (P5), and conflict resolution (P6) have not yet been fully reached. Cases of illegal fishing were recorded in 2011 and 2012 in Manoel Urbano and Feijó, respectively, where violations and sanctions were not evident. Since 2011 the management teams and government agencies explore a collaborative approach to future management, followed by setting up low-cost arenas for conflict resolution and a graduated sanctioning system.

With the regulations of collective fishing agreements in 2005 and 2008, the community livelihood and institutional settings were improved, thus promoting sustainable measures for the arapaima management system. The challenge faced by any decentralized governance system is clear in the arapaima SES, especially creating conditions for local users to be integrated in design management measures. Approaches used in this case study meet these challenge in three ways. First, participatory fora provide fishers with the opportunity to generate place-specific measures and minimize ad hoc methods based on expert knowledge. Discursive interactions with fishers enable collective learning about SES (Berkes 2009). Second, the SES is a shared framework, as described is integrative, rooted in empirical reality and communicated with field examples (Holling 2001). Third, SES analysis should be applied and improved in other periods of the case study, as well as supporting the adoption of rules and norms (De Vellis 2003).

We applied a consensus-building model to evaluate the arapaima management system. Consensus on the values of SES variables was reached after a few rounds of iteration with group members. We also calculated SES subsystems values resulting from arithmetic means based on the associated second-tier variables. This procedure is suggested by Regan et al. (2006) as more appropriate. If fishers are open to communicate for conciliating individual and diverging interests, and this process is iterated, the group will reach the consensus. The model proposes a change of assignment preferences at each round and formally reflects the heart of the negotiation process. Group decision-making for SES evaluation involves different knowledge areas, and formal methods are unlikely to address all the challenges of group consensus. At some stage, the use of ad hoc methods is recommended. For instance, the brainstorming session that resulted in the set of SES variables. There are interesting questions arising from this case study methodology. We consider this method, based on the participatory approach and communicative rationality is a useful tool to evaluate how group members affect consensus. Future questions are particularly important in assigning values and composing groups. How does the divergence on values across group members affect consensus? How does a heterogeneous group affect consensus? How does group size affect consensus? How do different stakeholders perform in a consensus-oriented process?

In using the SES framework, we estimated both Hardin's and sustainable scenarios based on a particular set of second-tier variables (Table 3). Generating Hardin's scenario requires nine assumptions: (i) The resource system is a floodplain lake system (RS1); (ii) no collective action is present (GS6); (iii) Small-scale fishery is unpredictable (RS7); (iv) Mobile resource units harm self-organization (RU1), and they are not the property of their owners (RU6); (v) There is economic value due to free-rider behavior (S5 and RU4); (vi) Users do not contribute to the management system (U1); (vii) The lack of leadership and local rules negatively affect the establishment of management systems (U5 and U6); (viii) Users which do not share common SES knowledge independently make decisions to maximize their returns (U7); and (ix) Users are dependent on the resource system for their livelihoods (U8).

These assumptions lead to an empirical prediction of overharvesting (I1) and the destruction of the SES (O1 and O2). For the sustainable scenario, we maximized the assumptions set out in Hardin's scenario aiming at a self-organized system. Both scenarios allowed us to evaluate the management system performance on a continuum between an unsustainable SES and a sustainable one (Fig. 3). SES subsystems and its variables can guide a road map for sustainable development. For instance, despite the

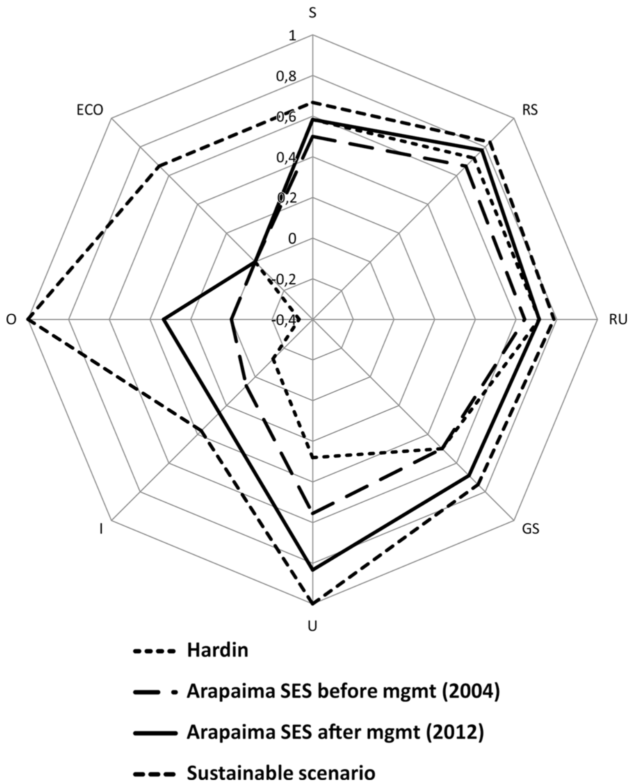

Fig. 3 Subsystem score (SGA) for arapaima SES associated with stages of management system

advances made by the arapaima management system, improvements must be made in resource users and the governance system, enhancing the use of resource system and resource units, and consequently the interactions and outcomes for sustainable development. However, scenarios for Hardin's tragedy of the commons and the period before management were reversed in subsystems S, RS and RU. This may be due to the lack of information about the resource system, resource unit and social economic settings, which impact consensus on SES variable values for each scenario.

The performance of the arapaima SES using a particular set of second-tier variables (Table 3) were evaluated for the periods before and after the management system was implemented. Figure 3 shows how the arapaima management system changed over time with impacts on most first-level core subsystems. The participatory approach for the establishment of fishing agreements (S4) and adaptive management improved the clarity of system boundaries (RS2), collective action (GS6), local rules (U6), and have acquired meaningful knowledge about the resource system and resource units which fishers are using. The knowledge sharing promoted the development of monitoring tools (GS8). Fishers make collective decisions to maximize the recovery of arapaima stocks and sustainable production (U6). The total moratoria of arapaima have enabled IBAMA and the management teams to develop harvesting rules and norms that have supported the recovery of the stock. Given fishers' ability to assess the arapaima population and the formal association of the management teams, resource users negotiated with IBAMA permission to legally harvest arapaima. These assumptions about second-tier variables lead to an empirical prediction of institutional performance supporting work on conflict among users (I4), self-organizing activities (I7) and networking (I8). The outcome of this interaction promoted improvements in ecological performance (O2), enhanced by reduced overharvesting and a legal harvest permit.

The eventual improvement of the arapaima management system is thus attributed to the congruence of multiple factors. Changes in political settings (S) over time affected the capability of resource users (U) and government agents in a governance system (GS), while their interactions also impacted the resource system (RS) and resource units (RU). Knowledge sharing, collective action and the use of norms grew over time. Simply engaging fishers to participate in the decision-making process enables them to approach a sustainable harvesting level (O2), rather than severely overharvesting the arapaima. Fishing agreements use the artificial marking of arapaima (RU6) as a way to identify collective property or resource units needing protection. Conditions related to self-organization (I7) in making norms were also present when arapaima were sustainably exploited, as the number of users (U1) and sharing norms related to harvest levels were known (U6). A major factor in converting free-rider fishers into effectively organized management teams was implementing ways to convert the harvest time scale from short-term to long-term. An established management plan (GS6 and U6) with long-term interest in sustainability was more likely to invest in norms related to technology and harvest level, and in generating useful information about arapaima stocks.

A key factor in restoring arapaima stock has been increased resource control, where better user knowledge on abundance, distribution and production should be highlighted. Future case study prospects involve research programs to collect mark-recapture data, radio telemetry and economics aiming to enhance resource system and resource unit knowledge. Furthermore, local organizational strengthening enables greater adherence to collective agreements. Local group organization and arapaima management work was stimulated by the operational-level rights (GS4, access, withdrawal, and management) devolved with the regulation of fishing agreements. Obtaining at least the management right to the continued use of a resource may stimulate local users to seek long-term goals (Schlager and Ostrom 1992).

Those results indicate a promising future for the sustainability of the arapaima SES, but major monitoring efforts and institutional strengthening support for self-enforcement are still needed. Along this line, it is necessary to pay attention to the fact that long-term sustainability of rules depends on monitoring and enforcement as well as on their not being overruled by central government (Schweitzer et al. 2009). The long-term effectiveness of rules depends on users' willingness to monitor one another's practices (Ostrom et al. 2007). Another factor may be the unbalanced power among local users and government agents, which may impact the degree of power-sharing. Power dynamics is recognized to be highly influential in the co-management process, and the balance among participants can determine the extent of integration and social networking (Wilson et al. 2006; Doubleday 2007; Pinkerton 2009).

Conclusion

Case study results can help develop alternative tools and approaches for small-scale fisheries in the tropics. The evaluation of Ostrom's design principles indicates that small-scale fisheries present challenges on most principles. Principles 1 and 3 usually are diminished by the open-access fishing areas and the lack of knowledge sharing. Principles 2, 4, and 7 usually are diminished by the lack of monitoring processes. Principles 5, 6, and 8 are usually diminished by current top-down management models. We have proposed three ways of enhancing management system effectiveness.

From the methodological viewpoint, we agree with the inadequacy of the blueprints and panaceas approach (Ostrom et al. 2007). Nevertheless, an "expandable and adaptable blueprint" using participatory approaches for the evaluation of SES variables, as proposed in this paper, may be useful for the managers and policy-makers, until more complete academic interdisciplinary studies become available. The use of SES variables permits understanding of unmeasured interactions between users and natural resources. This approach serves both SES monitoring and assessment purposes in ways that are useful for natural resource management and policy interventions. Combined with of field practice observations, adequate interpretation of empirical measures makes this approach useful in understanding and managing SES. Also, SES's complexity induces the need to develop new forms of gathering information. SES variables—including the processes by which they are measured—are a powerful instrument for decision-making and policy-making, and can be seen as an attempt to implement reflexive governance. The systematic use of the SES framework, setting the "tragedy" and "sustainability" scenarios as references, as done here, can help building a road map to sustainable development and guarantee the replication of the technique in other studies for the sake of comparison in space and time. The arapaima SES framework proposed in this article will obviously need further development. Cumulative use of the framework to address variable analysis and policy design in the coming years will improve the ability for solving problems related to the arapaima management.

We have proposed that participatory approaches for SES measurement be implemented on a continuum process between consensus-oriented cooperation looking for common interest and compromise-oriented negotiation aiming at the adjustment of individual interests. The use of the negotiation dimension can support measuring and evaluating SES variables. Also, these approaches suggest the use of divergence as a driver for decision-making through collective communication and learning processes. This is promising as a collective action mechanism.

The case study presented here highlights the critical role of multi-level institutional arrangements—from grassroots to central governments—in creating the conditions that make sustainable arapaima management possible. Where governments have not implemented effective regulatory systems for managing arapaima within their jurisdictions, the essential governance conditions required for sustainable management are not likely to exist. The state of Acre has implemented regulations and temporary monitoring and enforcement arrangements that have significantly reduced the market for illegal arapaima and enabled managed arapaima fishery to develop.

This article does not aim at confronting Hardin's image of the tragedy. The focus is rather exploring, from empirical evidence, the possibilities of managing commons in a participatory way. So that the process can be virtuous instead of vicious. Despite the context of institutional fragility, mainly of local institutions and government agencies, the arapaima SES seems to be more prone to sustainable use than to the "tragedy of the commons." The main recommendation for the next steps is to focus more objectively on Ostrom's key-variables (Table 2), including a suitable monitoring system, in order to tackle main gaps and fragilities in an adaptive management fashion.

Further application of SES to develop more effective co-management systems may depend upon the ability of users and government system to modify the collaborative enforcement structure, in order to promote the active participation of voluntary rangers and government managers. This SES should include the establishment of new forums for conflict resolution and graduated sanctioning. Such forums should encourage communication and learning among all representatives. In addition, forums act as an arena for decision-making and the analysis of rules for species and their ecosystems. Results indicate that even when rules are being made and implemented on the basis of local knowledge and scientific studies, there are challenges for knowledge sharing.

Such governance may become increasingly important to manage the sustainability of tropical SESs in Brazil. Exogenous drivers, such as climate change, logging, and illegal fishing (Oviedo 2011) have a growing impact on fisheries and ecosystems. The floodplain lakes in the state of Acre can be severely impacted by climate in the future, and the SES approach can be applied for adaptive management to future change.

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