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Research, part of a Special Feature on Community-based Management of Environmental Challenges in Latin America and the Caribbean

Local perceptions on social-ecological dynamics in Latin America in three community-based natural resource management systems

Maria del Mar Delgado-Serrano [1], *Elisa Oteros-Rozas* [1,2,3], *Pieter Vanwildemeersch* [1], *César Ortíz-Guerrero* [4], *Silvia London* [5] *and Roberto Escalante* [6]

The first two authors contributed equally to this work.

ABSTRACT. Several examples of community-based natural resource management in Latin American social-ecological systems exist in which communities control the management of common-pool resources. Understanding community perceptions of the performance of these systems is essential to involve communities in sustainable management strategies. In this analysis of three areas in Colombia, Mexico, and Argentina, we analyzed the local perceptions of the social and environmental challenges faced by these social-ecological systems and how these challenges and drivers affect their resilience. To do this, we combined prospective structural analysis to unravel stakeholders' perceptions of each system's functioning along with network analysis to assess resilience. We identified external variables as the most influential variables in the Colombian and Argentine cases. In the Mexican case, larger influence is exerted by internal variables, particularly those linked to the governance system. The case study analysis revealed that the community-based natural resource management approach needs external support and recognition to work effectively. In the Argentine and Colombian cases, megaprojects were perceived as controllers with medium or strong influence but low dependence. The use of ancestral knowledge (Colombia), the history of land use (Mexico), and the history of the artisanal fishery (Argentina) were all perceived as common challenges to community-based natural resource management. In terms of social-ecological resilience, framed within the three-dimensional model of the adaptive cycle, all three social-ecological systems were considered to be highly connected and resilient but with different degrees of capacity or cumulative potential.

Key Words: *Argentina; Colombia; common-pool resources; environmental challenges; governance; Mexico; network analysis; Ostrom; prospective structural analysis; social-ecological resilience*

INTRODUCTION

Current effects of human activities on the fundamental processes that regulate the functions of Earth's systems, namely, global change (Steffen et al. 2004), have defined a new geological era called the Anthropocene (Crutzen and Stoermer 2000, Ellis 2011). The recognition of this era has fostered the development of holistic and interdisciplinary approaches to understanding nature conservation and sustainability. Coupled human-nature systems are frequently treated as social-ecological systems (SESs), i.e., complex adaptive systems with key characteristics such as: (1) integrated biogeophysical and socio-cultural processes, (2) self-organization, (3) nonlinear and unpredictable dynamics, (4) feedback between social and ecological processes, (5) changing behavior in space (spatial thresholds) and time (time thresholds), (6) legacy behavioral effects with outcomes at very different time scales, (7) emergent properties, and (8) the impossibility to extrapolate the information from one SES to another (Holland 1995, Berkes and Folke 1998, Liu et al. 2007, Du Plessis 2008). Several theoretical and conceptual frameworks have been proposed to guide the understanding of linked social and ecological systems (e.g., Berkes and Folke 1998, Walker et al. 2002, Anderies et al. 2004, Ostrom 2009, Díaz et al. 2011, Becker 2012).

Among the aims for a better understanding of SESs is the adoption of natural resource management systems that allow their sustainable functioning and the integration of different levels of governance. Community-based natural resources management (CBNRM), as a conceptual approach, has evolved since the mid-1980s as an alternative to top-down strategies in natural resource management. There is no single definition of CBNRM, but the core of the concept is the coexistence of people and nature, as distinct from protectionism and the segregation of people and nature (Western and Wright 1994). CBNRM is characterized by local stakeholder involvement, public participation, and interorganizational collaboration (Tang and Zhao 2011). It assumes that communities and community-based organizations closely connected to natural resources are most likely to foster sustainable resource use and possess the knowledge required to do so (Blaikie 2006). Accordingly, CBNRM has been often considered as a suitable approach to govern the commons (Ostrom 2007), given that it aims to ensure community participation in decision-making and to integrate community ideas, local institutions, customary practices, and knowledge systems. The full incorporation of the community in management, regulatory, and enforcement processes is likely to prevent local resistance to conservation measures (Pomeroy 1995, Borrini-Feyerabend 1996, Barrett et al. 2001, Armitage 2005). However, even if the CBRNM approach has attracted considerable interest in the last few decades (Shackleton et al. 2010) because of its role in conservation strategies worldwide (Dressler et al. 2010), it is not a panacea (Berkes 2007). For instance, the institutions, endowments, and rights, as well as the social actors involved, highly influence CBNRM performance (Leach et al. 1999).

To explore the CBNRM management within a SES, we addressed the later as "a structure composed of a common-pool resource, its users and an associated governance system" (Janssen and

[1]Department of Agricultural Economics, Sociology and Policy, Universidad de Córdoba, [2]Social and Participatory Action Research Group, Universidad Pablo de Olavide, [3]Department of Geosciences and Natural Resource Management, University of Copenhagen, [4]Department of Rural and Regional Development, Pontificia Universidad Javeriana, [5]Departamento de Economía, Instituto de Investigaciones Económicas y Sociales del Sur, Universidad Nacional del Sur - CONICET, [6]Faculty of Economics, Universidad Nacional Autónoma de México

Anderies 2007:44). Given that the understanding of SES functioning is still limited, fragmented, and uncertain (Kates et al. 2001, Ives and Carpenter 2007, Bettencourt and Kaur 2011, Cumming et al. 2013), we address this knowledge gap by eliciting and analyzing the social perceptions of three SESs managed under CBNRM and the social and environmental challenges they face. Understanding the perceptions of natural resources dynamics, challenges, and crises in SESs are often decisive factors that influence the involvement of local communities in management and the emergence of local rules for sustainable resource use (Siar et al. 1992, Pomeroy et al. 2001, Ferse et al. 2010).

To examine the complexity of the elements and interactions present in a system and identify which key variables could determine the system's current and future conditions, we applied a participatory prospective technique that helps embracing complexity and analyzing current and future factors in a systematic way (Godet 1994, European Commission 2014). Prospective structural analysis (PSA) is a methodological tool included in the group of scenario-building methods, *"la prospective"* (Godet 1986), that contributes to strategic management, helps coping with uncertainty, and provides alternative perspectives in the face of challenges. Strategic foresight methods were initially designed to support public institutions in regional development, i.e., regional foresight (Kelly et al. 2004, Stratigea and Papadopoulou 2013), but have also been extensively used by the private sector, i.e., corporate foresight (Lafourcade and Chapuy 2000, Benassouli and Monti 2005, Chapuy and Gros 2010).

Given the complexity of SESs and of the human and natural discrete and heterogeneous elements that are connected by different types of interactions, links (e.g., causality or dependence), and flows (e.g., information, energy, or materials), SESs have been conceptualized as social-ecological networks (Janssen et al. 2006, Bodin and Tengö 2012). The universality of the network topography has allowed researchers from different disciplines to embrace network theory as a common paradigm (Barabási 2009), including social-ecological networks, of which properties can be analyzed quantitatively through network theory (Gonzalès and Parrott 2012). Increasing numbers of scientists are devoting efforts toward assessing the sustainability of SESs using network analysis (NA), i.e., metrics from network theory (Gonzalès and Parrot 2012). Networks were first studied by social scientists to understand the structure of communities (Borgatti et al. 2009), but have also been used by natural scientists interested, for example, in food webs (Tylianakis et al. 2007). NA also has been applied to the study of CBNRM. For instance, Bodin and Crona (2009) and Marín and Gelcich (2012) applied NA in SESs to study the role played by social capital in the management of fisheries at a community level in Kenya and Chile, respectively. Cumming et al. (2010) argued for the potential and challenges of NA in conservation biogeography. However, to our knowledge, no study has yet applied NA to a social-ecological network, within a CBRNM context, with different types of nodes (e.g., social, environmental, institutional), which has been pointed to as a challenge: "Can node attributes be used to link social and ecological aspects of the same system?" (Cumming et al. 2010:417).

Understanding the variables and links that constitute a social-ecological network is therefore critical to analyze the network's social-ecological sustainability and resilience, i.e., the degree of disturbance the system can absorb before changing to another stable regime that is controlled by a different set of variables organized in a different structure (Holling 1973). Social-ecological networks change and adapt over time according to their resilience, so a SES's sustainability depends on its capacity to assume different degrees of uncertainty and to face disturbances without losing its self-organizing capacity and the regulating mechanisms that determine its structure and functioning (e.g., Carpenter and Gunderson 2001, Folke et al. 2002, Gunderson and Holling 2002, Folke 2006). However, given that resilience is difficult to assess and the concept is difficult to translate into clear and measurable system variables, "in cases where a SES can be represented as a network, NA may provide tools to measure certain structural characteristics relevant to the system's resilience" (Gonzalès and Parrot 2012:79). Ostrom (2009) states that the application of a network approach to ecosystems provides a conceptual framework for assessing the consequences of perturbations at the community level. The study of networks can enable anticipation of change, provide early warning, and enable faster response to change (McCulloh and Carley 2008). In this sense, NA might be a useful heuristic framework, given that it requires few data but allows critical parts of the network to be identified (Bunn et al. 2000, Urban and Keitt 2001, Zetterberg et al. 2010). We integrated PSA with NA of the three social-ecological networks, integrated by social and ecological nodes, to explore the relation of the network metrics with the SESs' resilience.

Our main objective was to explore the local perceptions of the social-ecological dynamics in three SESs with different types of CBNRM in Latin America using PSA and NA. In particular, we: (1) identify the key variables influencing the dynamics of the SESs, (2) explore the influence and dependence of these key variables, (3) compare the three systems under Ostrom's (2009) framework by examining different and similar patterns, (4) zoom into the social-ecological networks and describe the roles played by the key variables as well as the feedback loops that occur among them, and (5) reflect on the resilience of the SESs (Appendix 1). The three case studies are based in Colombia, Mexico, and Argentina.

CASE STUDIES

The outcomes presented here are part of broader research aiming to identify sustainable community-based governance models in the management of environmental challenges. The case studies were selected because they present a gradient of interesting strategies of CBNRM in the face of environmental challenges considered representative of the region. The case studies examine water and biodiversity management for a Council of Black Communities in the Colombian Pacific, forest management for a community in the Mexican Sierra of Oaxaca, and marine and coastal area management for the Argentine Bahia Blanca Estuary and its adjacent coast (see http://www.comet-la.eu for more information).

Colombia case study

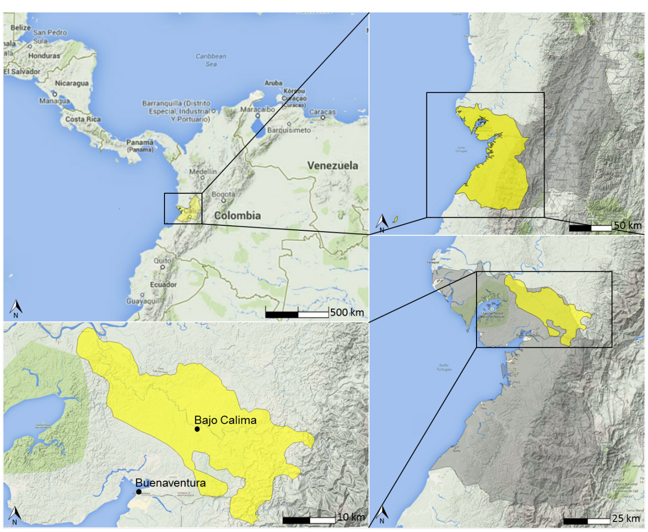
The selected SES corresponds to the collective territory of the Bajo Calima Community Council (Fig. 1, Table 1), located in the biogeographic region of Chocó, a biodiversity hot-spot

Table 1. Characteristics of the case study areas.

Characteristic	Colombia	Mexico	Argentina
Location	Chocó biogeographic region, Pacific coast, Buenaventura	Mesoamerican biocultural region, State of Oaxaca, Sierra Norte de Oaxaca, Santiago de Comaltepec	Southwestern coast of Buenos Aires region, Bahía Blanca Estuary region and adjacent coast
Population	3419 inhabitants; Afro-Colombian communities in Cuenca Baja del Río Calima (lower watershed of the Calima River)	1115 inhabitants; Chinantec indigenous commoners in a central nucleus (Santiago), and two agencies (La Esperanza and Soyolapam)	32,582 inhabitants (in the main urban centres); municipalities of General Daniel Cerri, Ingeniero White, Pehuén Co, Villa del Mar, and Monte Hermoso
Main livelihoods	Timber extraction and trading, artisanal mining, artisanal fishing, farming	Logging, farming, livestock raising, gathering, sawmill workers, ecotourism	Petrochemical industry, port, artisanal and conventional fisheries, tourism, livestock industry (slaughterhouses), fruit growing, and horticulture
Brief description of the social-ecological system (SES)	High biodiversity and abundant water; large presence of mineral, forest, and fishing resources; communal ownership of the land (Law 70, 1993); active participation of women; closely connected to Buenaventura and Cali cities and port, river transportation; recently structured (10–15 yr), strong, and well-structured local governance with large and seemingly inclusive participation; armed conflict and illegal activities (coca crops, mining, logging) affect the SES; aerial spraying of glyphosate to eliminate coca crops affects health and ecosystems; incipient ecotourism initiatives	Strong conservation values in highly diverse rainforest reserve (Forest Stewardship Council certified); temperate forests, mesophyll vegetation, evergreen tropical forests; communal property rights; long history of community-based natural resources management; no participation of women; clearly defined extraction and exclusion rights; local customary rules embedded in state and federal laws; payments for ecosystem services (water catchment); high level of poverty, only basic services, lack of employment opportunities fostering migration of youth	Important environmental and cultural resources such as the estuary and fossil footprints; unsustainable use of resources and disturbance of ecological functions (buffer and nursery) by interference of infrastructure, sand extraction, a dredging project, and the ports, affecting dune dynamics and coastal erosion; urban influence; noncommunal management of resources and weak local governance; high level of economic development (transport, infrastructure, and commodities)

(Arbeláez-Cortés 2013) characterized by high levels of rainfall and covered by tropical rain forests. The territory is part of the municipality of Buenaventura, where the most important harbor of the Colombian Pacific is located. Therefore, the zone is strategic for its environmental richness and biodiversity and for its geopolitical and economic position.

Fig. 1. Location of the Colombia case study.



The Community Council was created in 2001 under Law 70 of 1993; it owns 12,335 ha of the territory, inhabited by 3419 residents. The local population is divided into six settlements scattered across the territory. The index of unsatisfied basic needs reaches 98.1% for inadequate public services and 26.6% for inadequate housing (Departamento del Valle del Cauca 2013). The SES is managed under a complex and polycentric governance system in which public, private, and mixed institutions are integrated, and the Community Council plays a central role. The CBNRM is relatively recent, and some of the institutions and rules are not always recognized. Additionally, the monitoring, exclusion, and enforcement rights are still limited.

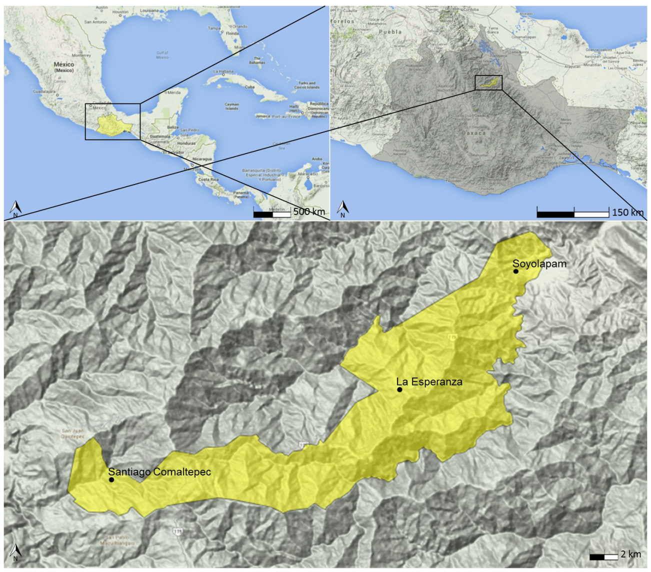
The local economy is based on natural resources, mainly logging, subsistence farming, fishing, and mining, and it is strongly influenced by traditional ecological knowledge. Legal and illegal wood extraction is commercialized in regional and national markets, whereas the products of hunting, fishing, and agriculture are mainly used for personal or local consumption. The intimate connection between the communities and their natural environment is the central axis of the social organization, and it reinforces the sense of belonging to the territory (Farah et al. 2012).

Nonetheless, the persistence of an armed conflict in recent years has generated tears in the social fabric because of the competition for natural resources and the displacement and oppression of the population. Powerful external actors linked to illicit crops (*Erythroxylum coca*) and mining do not recognize the community-based rules and are important drivers of conflict. Public policies have addressed the problem through actions such as aerial spraying of coca plots with glyphosate, which have resulted in indirect negative effects on agriculture and the health of local inhabitants. Other challenges to the sustainability of the SES are related to megaprojects, deforestation, weaknesses in formal education, poor solid residue and water management, and the effects of climate change.

Mexico case study

Santiago Comaltepec is a community located in the Sierra Norte of Oaxaca in southwestern Mexico (Fig. 2, Table 1). The area covers 18,366 ha and ranges from 200 to 3000 m above sea level. Temperate rain forests, tropical rain forests, and mountainous cloud forests are the main ecosystems, and each plays a key role in hydrological regulation. The area is characterized by high conservation values and is one of the most diverse ecosystems in Mexico.

Fig. 2. Location of the Mexico case study.



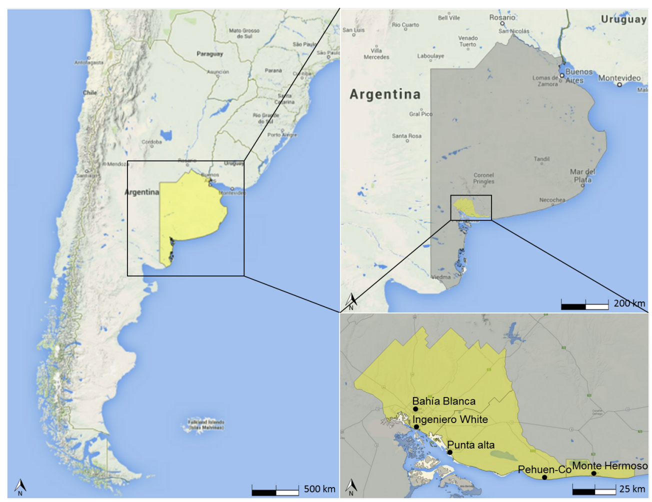
The resident population of 1115 inhabitants (INEGI 2010) is from the Chinantec ethnic group, speaks its own indigenous language, and is divided into three settlements. The governance regime is based on centuries-old customary practices. The collective property rights for land and resources were recognized by the Agrarian Law of 1953, but the government later gave a 25-yr timber concession to a paper factory, which caused massive deforestation. This is a sensitive subject for the community because, in the late 1980s, they confronted the government to stop the concession and succeeded. As a result, the citizens regained full rights to the forests. This outcome illustrates that the strength of the local formal and informal institutions evolved from a long history of resource management, through which the inhabitants have managed the land under a stable political system. The exclusion, monitoring, and enforcement rights are well established. Traditions inherited from one generation to the next are at the core of this SES, particularly the transmission of forest management knowledge and respect for existing rules for sustainable resource extraction. In fact, this population has become an example of conservation through a traditional and environmentally sustainable CBNRM system based on communal property (Chapela 2007).

The economy of the area relies on logging (managed by local community companies), which provides jobs for 10% of the active population, and subsistence agriculture. However, Comaltepec's SES is currently facing several challenges such as migration. The lack of individual income (local companies' benefits are reinvested in the same local companies or in collective goods) is causing important parts of the community, particularly the youth, to move to cities or the USA (remittances play an important role in households). In addition, there is a local perception that the delivery of ecosystem services provided through sustainable environmental management by the community is not sufficiently rewarded in economic terms (e.g., payments for ecosystem services), creating inequities between those that make profit (e.g., water provision for the production of beer in a beer factory downstream) and those that contribute to the delivery of ecosystem services.

Argentina case study

Monte Hermoso-Bahia Blanca Estuary is the second largest estuary in Argentina, at 230,000 ha in size. It is located on the southwestern coast of Buenos Aires Province (Fig. 3, Table 1). The estuary hosts salt marshes, a rich fauna, and a unique phytoplankton bloom that supports the trophic food chain for several species and is the basis of the local artisanal fishery. In addition, a section of the beach has been established as a Geological, Paleontological, and Archaeological Provincial Reserve because of the presence of well-preserved fossil footprints (Megatherium).

Fig. 3. Location of the Argentina case study.



The SES includes five villages over a stretch of 100 km and hosts the most important Argentine deep-water port. Thus, this territory is strategic for Argentina's economic development. The estuary communities base their livelihoods in port services and other industries (petrochemical, agri-food, etc.), and the beach communities base their livelihoods on tourism and artisanal fisheries.

Since the 1800s, the appropriation of land was characterized by a war against nomadic natives and the implementation of a private property regime related to agricultural production, with coastal management as a secondary concern. Since the 1900s, population growth has resulted from migration flows. The overall outcome is an absence of unique cultural roots, which hinders the creation of common cultural codes, norms, and rules. Marine and coastal resources are public property in Argentina, whereas the control of resource use (sand mining, fishing, etc.) mainly corresponds to different levels of the State (local, provincial, and national). The main activities (fishing and tourism) are developed by private actors, even though artisanal fishers exploit the common-pool resource. However, artisanal fishers face overlapping and often contradictory norms dictated by other administrations who do not recognize the community-based management.

The socioeconomic indicators of the area show a high level of development in terms of household income, infrastructure, and services. The educational institutions range from primary schools to universities, and there is a central hospital and decentralized healthcare in all of the villages. However, artisanal fishers recognize sustainability as one of the major challenges in the area. Fish catches are declining because of overexploitation (mainly by large fishing trawlers), pollution, and the disturbance of the estuary and the coast (untreated effluents pollute the bay, and changes to the tidal cycle affect phytoplankton production). Fishers also complain about the lack of options for transforming primary products to increase their value. The coast is also facing increasing erosion because construction near the sea blocks the normal circulation of the wind and dunes. Additionally, the sand needed for construction is mined from the dunes; although this sand mining is strictly prohibited, enforcement is not easy.

Recently, environmental organizations have fostered improvements in the performance of social capital. In particular, organizations of fishers have found a place for communication and discussions related to fisheries management. Other current social-ecological challenges confronted by the population are the joint effects of climate variability, coastal erosion, overfishing, overexploitation of beaches (including illegal sand mining from the dunes), and pollution.

METHODS

We used Ostrom's (2009) framework to characterize the SESs. The choice of this framework is motivated by various reasons: (1) it covers social and ecological aspects and their interactions, (2) it is applicable to common-pool resources, (3) it includes qualitative and quantitative data, (4) it proposes a broad and flexible spectrum of subvariables and allows them to be adapted to different SESs, (5) it can be used at different scales, (6) it emphasizes the governance rules to manage natural resources and the local stakeholders' roles, (7) it was designed to analyze the effects of users' self-organization rules on sustainability, (8) it provides the possibility to compare different case studies, and (9) it helps researchers and policy makers to deliver useful results for knowledge creation and policy planning (Delgado-Serrano et al. 2013, Delgado-Serrano and Ramos 2015). Because Ostrom's (2009) is a conceptual framework (Binder et al. 2013), some methodological adaptations have been proposed to operationalize it (Cox 2014, Delgado-Serrano and Ramos 2015, Leslie et al. 2015). Here, we adopted the operationalizations proposed by Delgado-Serrano and Ramos (2015). The research was conducted in four steps: data collection, PSA, statistical data analysis, and NA (Appendix 1).

Data collection

The research process was developed over two years, and the methodology was based on the development of a learning arena where scientific and local knowledge were shared and integrated. Participatory workshops with the local communities were organized every two to three months during the project. To select the participants (15–20 per workshop), we used stakeholder mapping techniques based on criteria such as knowledge of the SES, inclusion of inhabitants from all settlements, leadership roles, and gender and age balance. The first step was a comprehensive characterization of each SES using the applied version of Ostrom's framework for analyzing sustainability. In total, 132 variables were identified and described by the research team, which included local co-researchers and the local communities. The variables were organized in each of the eight Ostrom subsystems: Settings, Resource Systems, Governance Systems, Resource Units, Actors, Interactions, Outcomes, and Related Ecosystems. In a subsequent workshop, a PSA exercise was developed to select a more manageable number of variables and to identify the key variables in each SES and their roles in the current and future dynamics. The results of both exercises were presented to the communities, and the final outcomes were discussed and approved in a final workshop. Local stakeholders participated not only in the PSA process, but also in the process of adapting the methodologies to the local contexts.

Prospective structural analysis

We used PSA to address our first two objectives: identify the key variables in the dynamics of the SES and explore the roles they play in the SES. The influence-dependence relations constructed on the basis of stakeholder perceptions might: (1) be critical for characterizing what is important for the SES functioning according to different groups, (2) help determine how such functions could be affected by management decisions and practices, and (3) help explore the direct and indirect changes in the SES (Chan et al. 2012, Hicks et al. 2013).

The PSA was structured in three phases. In the first phase, participants were asked to select the most relevant of the 132 variables, including at least one variable from each of the eight subsystems. A list of 15–20 variables, identified by consensus, was then compiled. Each variable was clearly defined (Appendix 2), characterized, and understood by the participants. In the second phase, a cross-impact analysis was conducted to assess the variables' influences on each other, where 0 indicates no influence and 3 indicates the strongest influence, and positive and negative values indicate positive and negative influences, respectively. Thus, an $N \times N$ matrix (matrix of direct influence [MDI]) was constructed (Appendix 3). The third phase consisted of the analysis of the resulting data. To capture the indirect influences, the MDI was raised to the second, third, or higher power until the overall ranking of the influence and dependence of the variables remained constant. This stable matrix is the matrix of indirect influences (MII). The direct or indirect influence or dependence of any given variable, k, was calculated as the sum of the values of row k or column k in the MDI or MII, respectively (Appendix 4). This process allowed the variables to be ranked according to their influence and dependence values. Influence and dependence charts were constructed to plot the indirect influences. According to their position on the plot, the different roles played by a variable in the system could be identified as autonomous (low influence and dependence, which means a low effect on the system), determinant (high influence but low likelihood of being influenced), regulatory (medium dependence and influence, which indicates a leverage role), challenge (high capacity to influence and be influenced such that the variable can move the system but is unstable), and result (low capacity for influence but high dependence; these variables are considered to be indicators of system evolution). The MDI shows the actual condition of the system, whereas the MII shows its future evolution (for more details, see Delgado-Serrano et al. 2014). MICMAC software (version 6.1.2, Max Planck Institute for Demographic Research, Rostock, Germany; http://www.nidi.nl/en/research/al/micmac/software) was used for the analysis.

Statistical analysis

Given the small sample sizes, we used nonparametric Mann-Whitney tests to explore the variability in the influence and dependence of the variables according to their subsystem (Ostrom 2009). According to the characteristics of the case studies, we compared variables within and outside the Settings in the Colombian and Argentine cases. In the Mexican case, because very few of the variables belonged to Settings, we compared the variables within and outside the Governance System. The analyses were conducted with XLSTAT software (2012, Addinsoft, New York, New York, USA).

Network analysis

Following Janssen et al.'s (2006) approach to SESs as networks, we applied network analysis to address the final two objectives: to zoom into the social-ecological networks and describe the roles played by the key variables and the feedback loops that occur among them, and to reflect on the resilience of the SES. Networks are simplified representations composed of two simple elements (Gonzalès and Parrot 2012): nodes (or vertices), which represent discrete entities (in our case, the variables); and edges (ties or links), which represent the interactions between the nodes (in our case, the influence and dependence relationships).

We considered three measures of centrality and one measure of connectivity. The most central nodes are those than can more easily access the rest of the network. The three centrality measures were selected as the most relevant for our objectives according to the available literature on network metrics and resilience (e.g., Bodin et al. 2006, Janssen et al. 2006): distance-weighted directed betweenness (beta = 0.8), closeness, and the eigenvector parameters of the variables within each social-ecological network. Betweenness, calculated as the fraction of the total number of shortest paths between two given nodes divided by the total number of shortest paths between those two nodes passing through a third node, shows all of the shortest paths between two nodes that include a particular node. Closeness is a measure of the average shortest distance from each node to every other node; it is defined as the inverse of farness, which is calculated as the sum of each node's distances to all other nodes. We used the eigenvector as a measure of network connectivity because it considers not only how many connections a node has, i.e., its degree, but also the degree of the vertices to which it is connected. For our fourth objective, the higher the values for betweenness and eigenvector and the lower the value for closeness that a variable has in relation to the other variables in the network, the more relevant it is within the network. While the identification of the most influencing variables obtained in the PSA partly overlaps with the information given by the network centrality measures, the NA also allows the possibility to analyze the signs of the influences between variables (i.e., including negative edges), hence identifying both positive and negative feedback loops of influence between variables.

We also calculated the density of each network (Appendix 4) and depicted the network graphs. The density of the network indicates how interconnected the vertices are in the network, i.e., what is related with the issues such as knowledge exchange. Within each SES, we selected a smaller group of variables with the highest betweenness, eigenvector, and influence and lowest closeness and dependence, and discussed the group's relation to social-ecological resilience, following methods of previous work on the adaptive circle model (e.g., Holling et al. 2002*a*) and on traps outside the three dimensional space (Allison and Hobbs 2004). For the calculations and graphs, we used UCINET 6.0 network analysis software (Borgatti et al. 2002), NetDraw 2.139 (Borgatti 2002), and NodeXL 1.0.1.251 (Smith et al. 2010).

RESULTS

Variables identified and corresponding subsystems

The Colombian and Argentine case studies follow a similar pattern in which key variables are concentrated in the external subsystems (Settings and Related Ecosystems; Table 2). This finding reveals the high number of external influences on the SES (public policies and governance for natural resources and external [illegal] actions), as well as the interest of external actors in the SES resources (markets for natural resources, megaprojects). The internal variables are concentrated in the Actors and Governance System subsystems. In Colombia, the relevance of ancestral knowledge and population trends is highlighted, and the need for formal education and locally driven research is revealed. In Argentina, the focus is on the role of fishers' associations and the conservation measures they implement, the local markets and income, the need for community networking, and the history of the artisanal fishery. The Interactions subsystem comprises five variables in Argentina. Finally, the Outcomes are related to the lack of ecological sustainability in both the Colombian and Argentine SESs.

The Mexican case exhibits a different pattern. Stakeholders selected many variables included in the Actors and Governance System subsystems. They expressed that the governance institutions, property rights systems, collective-choice rules, extraction and exclusion rights, monitoring and sanctioning rights, and unpaid activities could most greatly affect the SES. Furthermore, the two variables selected within the Settings, i.e., political stability and environmental legislation, are those that could most greatly affect the current management system. Finally, as an Outcome, migration is perceived as relevant.

Prospective structural analysis

The indirect influence and dependence chart of the Colombian case study (Fig. 4) indicates that the system has almost no autonomous variables and has a predominance of regulatory and key variables. These latter variables can be influenced by and also provoke changes in the system; thus, the system is very dynamic. The variables within the Settings subsystem are less dependent than those in the other subsystems (Mann-Whitney U = 38,201,

Table 2. Description of participants and focus of the workshops (data collection).

Characteristic	Framework subsystem	Colombia	Mexico	Argentina
Participants		11 leaders and representatives from veredales committees	11 leaders, council members, farmers, livestock breeders, and citizens	16 leaders, local-scale decision makers, a ranger from the nature reserve, fishers
Focus		Biodiversity and water resources	Sustainability of the social-ecological system, particularly forest resources	Fishery and coastal management
Variables selected†	Settings (S)	Aerial spraying Megaprojects Markets for natural resources Armed conflict Impacts of public policies (formal education)	Political stability Environmental legislation	External governance of fishery Lack of political interest in environmental sustainability Dredging and liquefied natural gas project Petrochemical industry pole Conservation measures
	Resource System (RS)	Water management	Economic activities (forestry and agriculture for income) Sanitary infrastructure and services	Wildlife Seasonality of fishery and tourism Tourism
	Resource Units (RU)	Markets for natural resources	Economic value of natural resources	–
	Actors (A)	Formal education Population trends Ancestral knowledge Locally fostered research	Livelihoods (for subsistence) Importance of resources for inhabitants History of use (monitoring and sanctioning processes)	Income History of artisanal fishery Community networking
	Governance System (GS)	Formal institutions Impacts of public policies Regional institution for the environment Community as a social group Water management	Monitoring and sanctioning processes Unpaid activities of inhabitants Extraction and exclusion of natural resources Governance institutions Property rights system Collective-choice rules (political stability)	Fisher associations Local market Conservation measures
	Interactions (I)	Agriculture Fishing and hunting Mining	Livelihoods (for subsistence)	Catches Employment sources History of artisanal fishery Artisanal fishery
	Outcomes (O)	Deforestation Solid waste	–	Environmental changes in coast and estuary Overfishing Resource sustainability
	Related Ecosystems (ECO)	Illicit crops Tourism Climate change Fluvial transport	Migration	Changes in climate patterns Pollution

†Variables were formulated by participants in each of the study areas in the first phase of the prospective structural analysis. The variables are classified according to the eight corresponding subsystems of Ostrom's (2009) framework.

$P < 0.05$). An important role is attributed to external variables such as formal education, illicit crops, formal institutions, and mining. However, the community reclaims its control on the SES through ancestral knowledge, locally fostered research, and population trends.

The variables within the Mexican Governance System subsystem are more influential than the other variables (Mann-Whitney $U = 1177$, $P < 0.1$); thus, local natural resource management rules are central to the SES. Furthermore, few variables were perceived as key, so the system is dependent on the regulatory variables (Fig. 5). An important role is attributed to internal variables such as collective-choice rules, monitoring and sanctioning processes, and extraction and exclusion rights.

The Settings subsystem has lower dependence than the other subsystems within the Argentine case study (Mann-Whitney $U = 10{,}146$, $P < 0.05$). Given that the upper right quadrant of the

Fig. 4. Influence vs. dependence of the matrix of indirect influences (MII) for the Colombian case study.

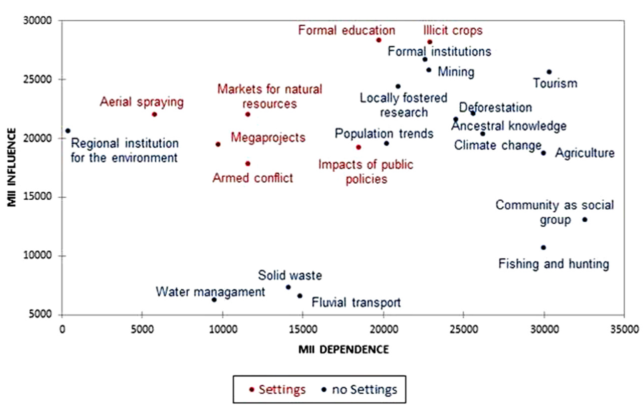
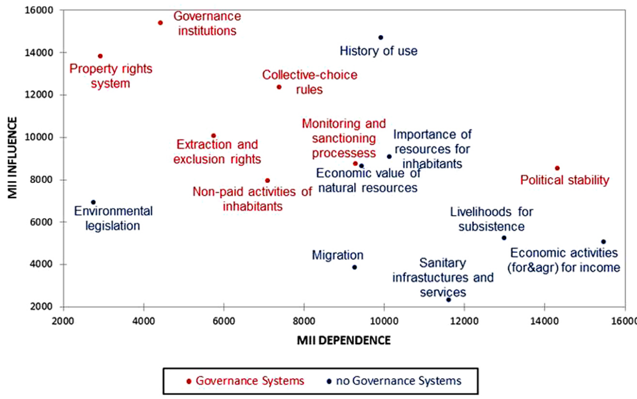
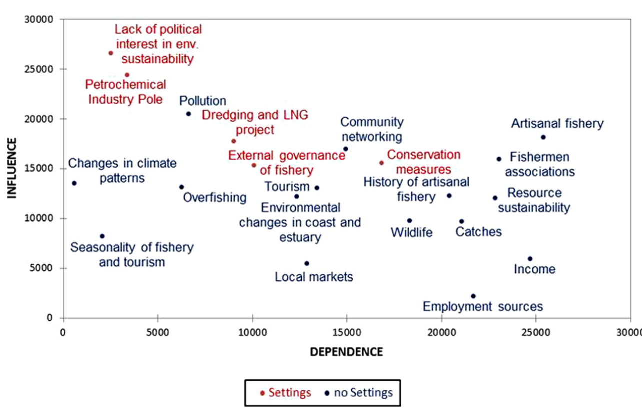


Fig. 5. Influence vs. dependence of the matrix of indirect influences (MII) for the Mexican case study.



influence and dependence chart is empty (Fig. 6), the system as a whole is rather stable and is thus relatively difficult to change. Community networking as well as artisanal fishery and fishers' associations have a high potential for changing the SES from within. Industry (petrochemical industry pole, pollution, and dredging and liquefied natural gas project) and politics (lack of political interest in environmental sustainability and external governance of the fishery) are important external threats, while tourism and conservation measures are key external opportunities.

Fig. 6. Influence vs. dependence of the matrix of indirect influences (MII) for the Argentine case study.



Finally, most elements in the Mexican and Argentine cases trended from low dependence and high influence to high dependence and low influence. In contrast, most variables in the Colombian case were perceived as highly influential and dependent (Fig. 7).

Network analysis: centrality and density parameters

In the Colombian case (Figs. 8 and 9A, B; Appendix 4), the variables with the highest betweenness were armed conflict and climate change. Water management and solid waste had greater closeness, while population trends showed the highest eigenvector value. Illicit crops showed high influence and betweenness and large eigenvector values. In contrast, megaprojects presented low values for all network parameters.

When zooming into the group of variables with outstanding network parameter values, we observed that community as a social group was negatively influenced by several factors and was only positively influenced by formal institutions and formal education. A positive feedback loop between armed conflict and illicit crops emerged (i.e., they positively influenced each other), which also negatively affected community as a social group, formal institutions, and formal education. In particular, illicit crops was strongly, negatively, and bidirectionally linked with these latter three variables. Population trends was connected by negative feedback loops with formal institutions, formal education, and climate change (i.e., the population variable positively influenced the other variables, which negatively influenced the population). The density of the entire network was 56%.

In the Mexican case study (Figs. 9C, D and 10; Appendix 4), political stability, which had high dependence, showed the highest betweenness, followed by collective choice rules. The highest value of closeness was achieved by environmental legislation, which showed lower dependence and influence than average and small betweenness and eigenvector values. Several variables had a maximum eigenvector: history of use, with low closeness and high influence; livelihoods (for subsistence), with high dependence and low influence; governance institutions, with low dependence, low betweenness, and the highest influence; and importance of resources, economic activities (forestry and agriculture), and economic value of natural resources.

When focusing on the most relevant variables based on their network parameter values, migration was subject to several negative influences, except from political stability (Fig. 9D). Political stability, in contrast, was positively influenced by all of the other variables except migration. The negative feedback loop between these two variables is significant for the dynamics of the network. The fact that all of the variables that negatively influence migration are also largely and mutually reinforced might be relevant for the resilience of this subnetwork. The density of the entire network was 67%.

In the Argentine case study, fishers associations had the highest betweenness, followed by artisanal fishery and pollution, which were also among the variables with lower closeness and higher eigenvector values (Fig. 11). Lack of political interest in environmental issues and petrochemical industrial pole were highly influential variables that had low betweenness and closeness and high eigenvector values.

Pollution, external governance of fishery, and, most importantly in the Argentine case study, lack of political interest in environmental sustainability negatively and strongly affected other variables, particularly artisanal fishery, resources sustainability, and wildlife (Fig. 9E, F; Appendix 4). In this subnetwork, there were several positive feedback loops with positive influences such as that between fishermen associations and artisanal fishery. Other relevant loops with tourism are as follows: (1) lack of political interest in environmental

Fig. 7. Influence vs. dependence of the matrix of indirect influences (MII) for the three cases, overlapping by average influence and average dependence. Blue, Colombian case study; green, Mexican case study, red, Argentine case study. Italic labels correspond to variables of the Governance System subsystem (according to Ostrom's [2009] classification) in the case of Mexico, and the Settings subsystem in the case of Colombia and Argentina.

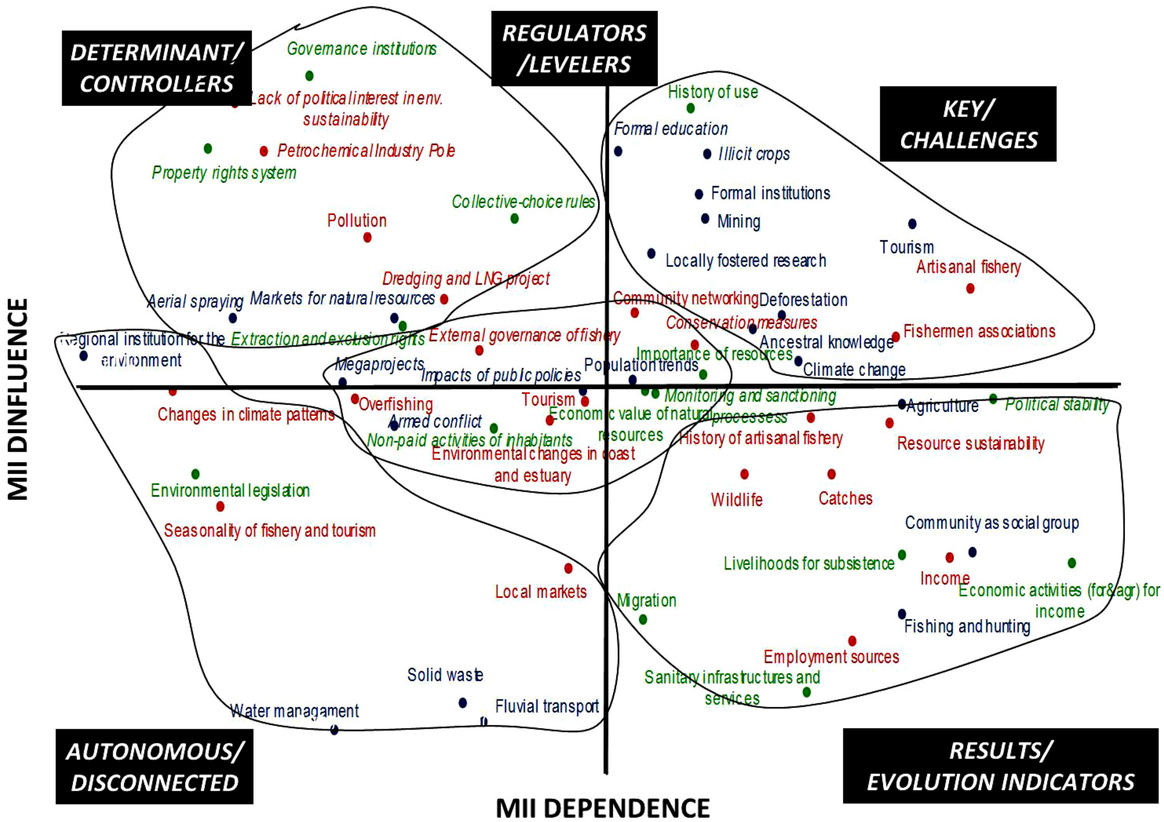
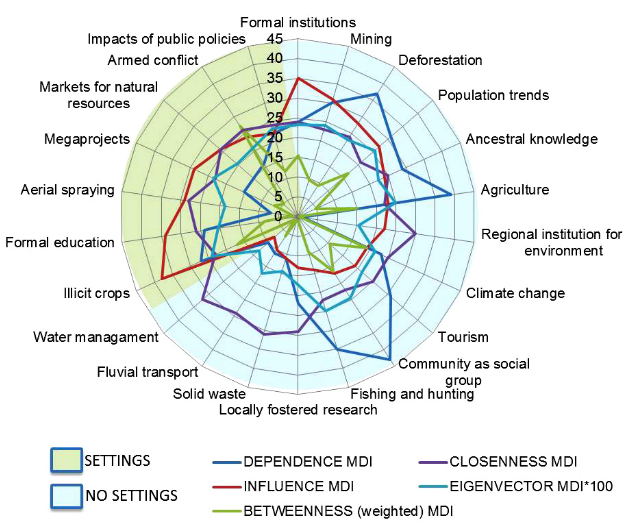


Fig. 8. Spider-net diagram of the Colombian case study representing dependence and influence values (matrix of direct influence [MDI]), weighted betweenness, closeness, and eigenvector. Green, variables from the Settings subsystem; blue, variables from the other subsystems.



sustainability negatively influenced tourism, whereas tourism positively influenced the former variable; (2) resource sustainability was negatively affected by tourism, which is fostered by sustainability; and (3) pollution is generated by tourism but also negatively affects tourism (Fig. 9F). Several interesting positive-positive relationships occur such as: external governance of fishery-fishers associations-wildlife, wildlife-artisanal fishery-resources sustainability, and fishers associations-artisanal fishery-tourism. The entire network exhibited a density of 60%.

DISCUSSION

Methodological aspects

The analysis of complex systems such as SESs requires methods that recognize this complexity and facilitate understanding. The experiences documented here illustrate that approaching SESs as social-ecological networks and using NA in combination with participatory PSA can: (1) reveal social perceptions of the structure of the studied SESs, (2) help visualize the key variables and drivers of the SES, (3) structure arguments for system management and decision-making by identifying the variable(s) that might be most critical for changing the system, and (4) facilitate participatory analysis among stakeholders to integrate scientific and local knowledge. The PSA approach promoted a

Fig. 9. Case study network diagrams. (A), (C), (E) Complete networks for the Colombian, Mexican, and Argentine case studies, respectively. The relative size of the arrow indicates the intensity of the influence (1, 2, or 3). Orange arrows, negative influence; green arrows, positive influence. (B), (D), (F) Subnetworks of the selected variables with the most relevant network parameters and influence and dependence values for the Colombian, Mexican, and Argentine case studies, respectively. The direction of the arrow indicates the direction of influence. Red arrows, negative influence; green arrows, positive influence.

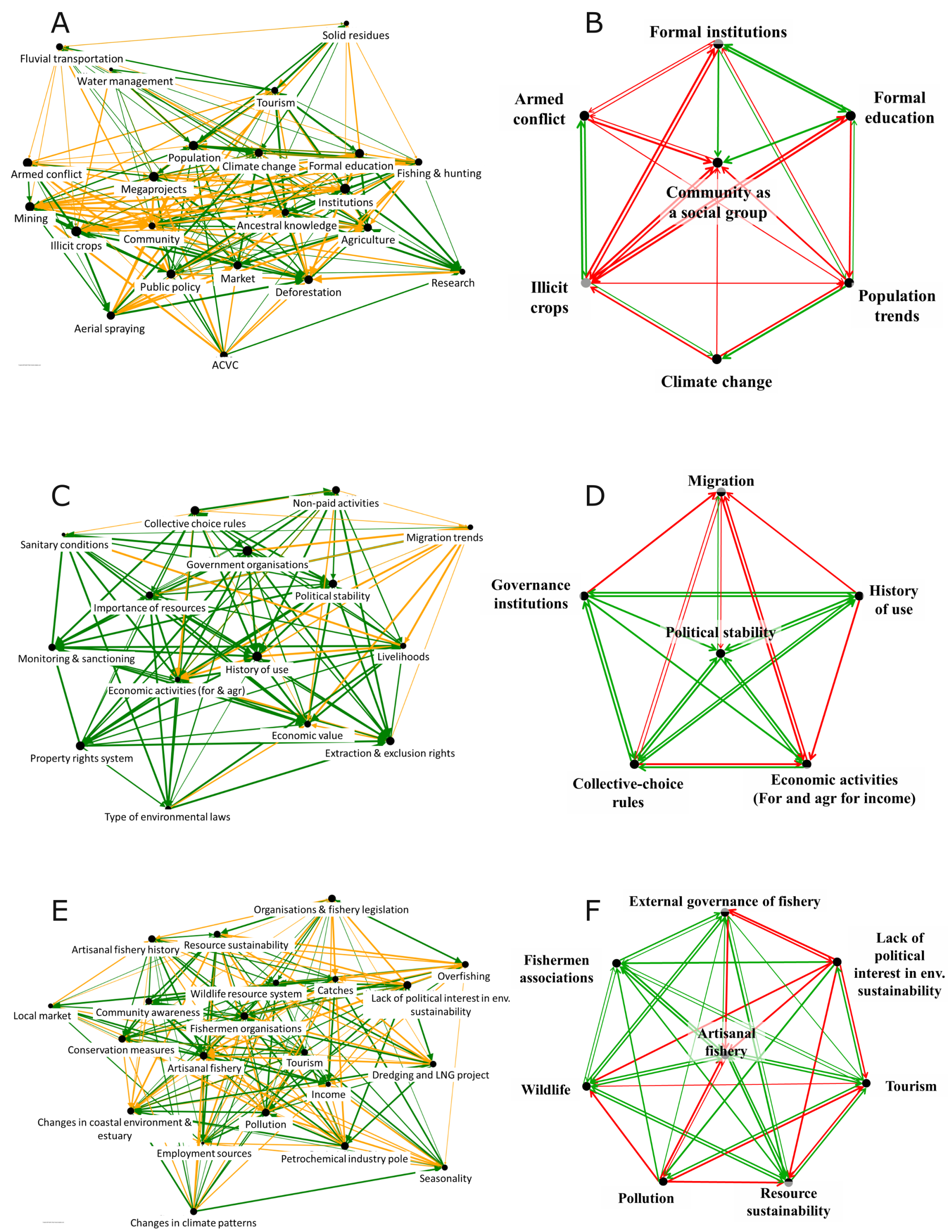


Fig. 10. Spider-net diagram of the Mexican case study representing dependence and influence values (matrix of direct influence [MDI]), weighted betweenness, closeness, and eigenvector. Green, variables from the Governance System subsystem; blue, variables from the other subsystems.

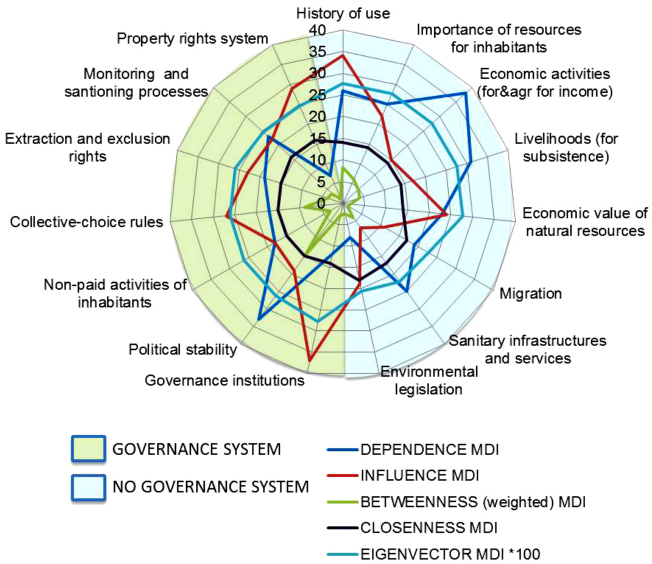
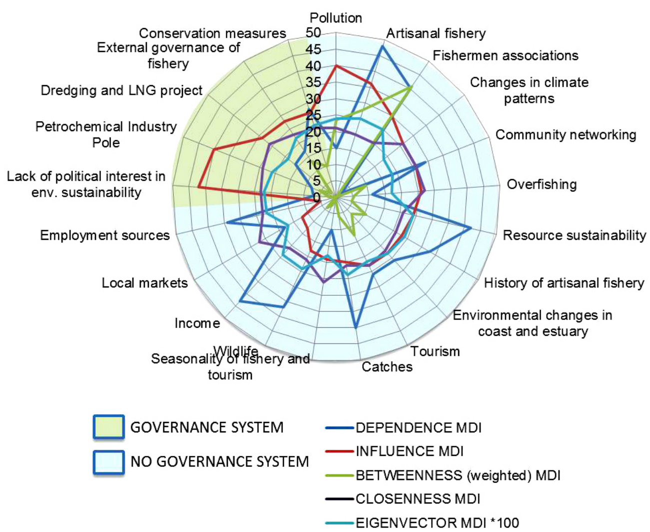


Fig. 11. Spider-net diagram of the Argentine case study representing dependence and influence values (matrix of direct influence [MDI]), weighted betweenness, closeness, and eigenvector. Green, variables from the Settings subsystem; blue, variables from the other subsystems.



socially constructed learning process, as had been previously noted in the literature (e.g., Gertler and Wolfe 2004), in which local perceptions of the SESs were condensed into a semiquantitative, analyzable form for detecting patterns and relationships in the subjective information. This bottom-up model stimulated discussions among the stakeholders (as also reported by Gavigan and Scapolo 2001), leading to better knowledge of the system's dynamics and of the necessary actions for sustainable management (e.g., to attract the attention of policy makers to how their actions influence the SESs or to identify the internal variables that can act as regulatory and therefore promote changes). Additionally, it created a common language, structured collective thinking, and allowed the participants' appropriation of results (as also reported by Godet et al. 2004).

As expected, the NA theory and PSA techniques proved to be compatible and complementary. Both have the same basic rationale and data structure, i.e., variables and influences in PSA, and nodes and vertices in NA. In addition, some centrality measures such as degree, betweenness, closeness, and eigenvector values were applicable and shed light on the roles of each variable within the SES, an aspect that PSA only superficially does. However, because the nodes represent the variables and the vertices represent the influences, as opposed to the more frequently used persons or institutions and information or physical flows, interpreting other NA parameters is complicated.

Some other questions and challenges arose during this exercise. Janssen et al. (2006) recognize that the nature of the relationships in social-ecological networks could be either entirely social, entirely ecological, or a mixture of both. However, we could not evaluate whether treating the ecological and social variables on the same level (node) could have consequences for the results or if the use of the more general influences as a vertex definition is equivalent to the typically used information or physical flows. Moreover, the correspondence between the potential influence value of the PSA and the concept of sleeping nodes (Janssen et al. 2006) should be explored in future research. By analyzing the networks created in the subsequent indirect matrixes of the PSA or by repeating the participatory analysis of influences, e.g., under different scenarios, it might be possible to capture the dynamic aspects of a social-ecological network, which is a current challenge (Cumming et al. 2010).

In addition, the process of variable selection influences the metrics of the network, i.e., if the network included different variables from the full set of variables identified in each SES, the network parameters would change (e.g., with more variables, density would increase). Given that we were interested only in comparing variables within a SES (for centrality measures) and between the three cases (for density), i.e., the relative values, this is not a problem in our case.

Finally, two more caveats need to be accounted for in relation to a participatory approach such as the one proposed here. First, given the difficulties of building a large PSA matrix in a participatory manner, a trade-off emerges between the number of variables and participation when integrating PSA and NA. Second, there is an inherent assumption that the social-ecological network is approached as a construct that the participants build, and hence the interpretation is not set in stone but rather is a tool that is meant to help understand the SES functioning as perceived by participants.

Common challenges and opportunities

Similar patterns could be identified in the case studies, for example, the roles played by megaprojects in Argentina and

Colombia. This type of project was observed as an element that exerts a moderate to strong influence in the SESs, but that could not be influenced (low dependence), and was thus determinant, or a controller, of the systems. Megaprojects such as dredging or the liquefied natural gas projects in Argentina and the industrial mining projects in Colombia have a strong influence on the SES and the CBNRM, but are controlled by external forces over which local communities have little power (e.g., Zilio et al. 2013, Göbel and Ulloa 2014). This fact, combined with the large influence of the Settings variables, which are exemplified by the power of external formal institutions in Colombia and the lack of political interest in environmental sustainability in Argentina, is dissimilar to the Mexican case study. In the first two cases, a polarization exists in the way public policies are developed and imposed top-down, with a high degree of political centrality (e.g., Cicalese 1997, SNUCMADS 2014). In contrast, in the Mexican case, the historical CBNRM tradition and the recent rebellion against the timber concession largely justify and sustain the highly empowered local governance system, including the collective-choice rules and the monitoring and sanctioning processes (Tucker 2010). Most likely, this history of strong local governance and struggle explains the perceived high importance of the Governance System variables compared with the other variables. In particular, collective-choice rules play a powerful role in the social-ecological network and hence the current state of the SES.

Subsistence activities such as agriculture, fishing, hunting, and mining are perceived as more relevant in the Colombian and Mexican cases than in the Argentine case, which is less rural and presents significant institutional fragmentation. In the Argentine case, both internal and external (Settings) governance-related issues are perceived to play more important roles than in the other two cases.

Negative outcomes such as pollution, deforestation, and solid waste only appeared in the Colombian and Argentine cases, whereas no negative outcomes were identified in the Mexican case. This might be because the Mexican community has implemented exemplary, environmentally sustainable forest CBNRM for centuries (García-López 2013). Because of the local awareness and international recognition (by the Forest Stewardship Council, for example), people perceive that the current land uses fully respect the environment.

A group of similar elements perceived as relevant in the three case studies were ancestral knowledge (Colombia), history of land use (Mexico), and history of artisanal fishery (Argentina), all of which are considered to be key to the three SESs. Land use history or resource management history can be observed as part of the social-ecological memory, which is a critical ingredient for social-ecological resilience (Folke et al. 2002). Forms of traditional ecological knowledge are considered fundamental in CBNRM contexts (Berkes 2004). In the case studies here, even if the development of CBNRM could be described as following a gradient from highly developed (Mexico) to an incipient stage (Argentina), the fact that variables such as history of land use and traditional ecological knowledge emerged as relevant can be interpreted as a sign of self-consciousness in terms of community power (e.g., Dadón et al. 2011, Velez and Lopez 2013).

Site-specific challenges and opportunities

The high number of variables identified within the Actors and Governance System subsystems in the Mexican case reveals the importance of community-based management. In Colombia, the relatively young governance system and the difficulties it faces to be recognized by external actors are evident (Ortiz-Guerrero et al. 2014).

From a resilience perspective, all three social-ecological networks exhibited high densities. This can be interpreted in four ways, as: (1) an opportunity for good information exchange and learning that might improve management (e.g., Pretty and Ward 2001), (2) the substrate for enhanced diffusion of innovations (e.g., Abrahamson and Rosenkopf 1997), (3) the potential for systems to become extremely connected and weak (Redman and Kinzig 2003), or (4) a "dark side" that potentially hinders collaboration with external actors and limits the freedom of actors to pursue ideas outside the norms of the group (Lechner et al. 2010). Even if most, or likely, all four, of these interpretations apply to the three case studies, one interpretation might be dominant in each case. In addition, the overall high density in the three case studies might be related to the adopted methodology, given the need in PSA to score the intensity of the link between all pairs of variables.

Under the adaptive cycle model (Holling et al. 2002*a*), which has three dimensions of potential or capacity, connectedness, and resilience, all three SESs could be considered (as perceived by participants) to be highly connected and resilient, but with different degrees of potential or capacity. According to the resilience literature, three types of traps outside of the three-dimensional space have been described (Allison and Hobbs 2004): rigidity traps, lock-in traps, and poverty traps. Rigidity traps occur when there is high potential for change, a high degree of connectedness among the structural variables, and high resilience to change; these traps may apply to social systems in which the members of organizations and their institutions become highly connected, rigid, and inflexible (Holling et al. 2002*b*). A lock-in trap is also characterized by a high degree of connectedness and resilience but a low potential for change (Allison and Hobbs 2004). The third and most well-known trap is the poverty trap, which is defined within the resilience framework as a situation in which connectedness and resilience are low and the potential for change is not realized (Holling et al. 2002*b,* Allison and Hobbs 2004). Following the aforementioned guidelines, a discussion of each case study follows.

Two particularities of the Colombian case study are worth mentioning. Illicit crops were perceived as one of the most powerful elements in the social-ecological network and, combined with armed conflict, emerged as a key node. Both factors appeared to be highly connected with the rest of the nodes and were thus likely to condition all of the dynamics and resilience of the social-ecological network. Therefore, this area might be considered an example of the disadvantages of a highly resilient SES in terms of the following: (1) the large control exerted by the combination of armed conflict and illicit crops (and aerial spraying), which disturbs the social cohesion and development of the community; (2) the undesirable state from a social-ecological sustainability perspective; (3) the high degree of connectedness; and (4) the low potential for change due to the feedback loop that might push the

SES into or near a lock-in trap. However, from the social-ecological network analysis, we observed that the negative feedback loop could be broken by formal institutions, the community, or environmental alterations due to climate change. Similarly, the second particularity of the Colombian case is that it was the only case in which research was mentioned. This outcome could be because of the perception by the local community that collaboration with research institutions is having positive effects. Explicitly defined as locally driven research, this element showed great connectedness, i.e., a great potential to behave as a bridge between otherwise disconnected elements, which might be an interesting insight on how to break the lock-in trap. However, scientific knowledge can only affect decision-making if it is used by the people involved in the decision-making process (Beunen and Opdam 2011).

The communities in the Mexican case seem to be captured in either a rigidity trap or a lock-in trap. After the struggle against the timber concession in the 1980s (a crisis in the SES), the local governance system was reinforced. Since then, the strong CBNRM has ensured environmental sustainability because the local governance structures and agreements have developed a great capacity to focus on this singular approach (Carpenter and Brock [2008] explain how this is related to rigidity traps). However, collective-choice rules that are very connected and that control the social-ecological network are perceived as responsible for SES rigidity because they hinder creativity and innovation. The low capacity of the system to explore alternatives (i.e., the "dark side" of resilience), particularly the lack of creativity and innovation, makes the system more vulnerable and appears as an urgent challenge. According to the literature, policy resistance (Sterman 2001) is a well-known phenomenon in system dynamics and is described as the bite-back paradox in large-scale systems (Gunderson et al. 2002).

In the Argentine case, the high network density might be interpreted as a sign of good information exchange and learning that might help to improve management. This research has triggered increased connection and awareness among the SES stakeholders, and it seems to be somewhat improving management. For example, fisher associations are realizing the utility and power of their union to communicate with formal institutions at higher levels of governance. The political interest in environmental issues is also increasing, and small steps such as the banning of plastic bags and the regulation of beach use are currently being implemented. In this case, the SES does not seem to be immersed in any trap, but it might be in a dynamic phase of increasing self-organization. Nevertheless, Argentina's history shows that political and macroeconomic instability act as the main obstacles to self-organization. The sequence of dictatorial and democratic governments has affected the development of social networks, producing a high degree of uncertainty in the local dynamics (Vezzetti 2002).

Although climate change was a common issue in two of the three case studies and was considered in both cases to have a moderate degree of influence, it was perceived as extremely dependent in Colombia and almost independent in Argentina. Several studies highlight how individuals' perceptions of climate change are linked to equity, development, perceived economic power, socio-political context, and the connection between management and science. Other studies state that more rural or urban contexts play an important role in risk perceptions (Wolf and Moser 2011), which could explain this difference.

Thoughts and insights for decision makers and policy makers

The role that CBNRM can play in the sustainable management of environmental challenges is receiving increased attention, but an important number of the key drivers and variables identified are external to the SESs or linked to external stakeholders, e.g., policy makers or armed actors. Our results suggests that the CBNRM approach needs external support and recognition to work effectively. Interesting insights and information emerged from this study that could be useful in policy-making. Internally, the participatory and locally adapted approach helped to integrate local knowledge and perceptions in the exploration of SES dynamics and thus helped to identify better strategies and decisions that might be adopted by all stakeholders. At a higher level, a place-based approach that avoids one-size-fits-all results, which frequently do not recognize the singularities of the resources and the interactions within each SES, might also support research and decision-making in other contexts that are currently facing social-ecological challenges and increasing uncertainty, such as those identified here.

In the three case studies, participants selected as key variables public policies and governance systems, legal frameworks for the management of natural resources, markets, and external megaprojects. All of these variables profoundly affect both system performance and community-based management, but they cannot be influenced locally. Policy-making should increase flexibility and create options for local actors to express their understanding and willingness to change dynamics. Opportunities to collaborate could help neutralize the main obstacles, foster the levers, and enable sustainable management.

The different functioning that community governance currently has or could have in the different SESs might be of interest for decision-making at all levels. In fact, this strength (either already in action, incipient, or potential) could not only be used in the most common, defensive way, but also with the strong potential for interfering with external or larger institutions, particularly when dealing with social-ecological challenges.

CONCLUSIONS

Local perceptions and understanding are essential for fostering changes, particularly those linked with internal variables that can be moved by local actors. For this reason, we found the PSA and NA approaches to be complementary and useful for revealing the complexity and understanding of SESs.

In the different case studies, the PSA process allowed active community participation and acquisition of new skills that had four subsequent effects. First, it improved the decision-making process at the community level. For example, in Comaltepec, more informed decisions are now taken at the Assembly, and the Community Council is participating in other research projects analyzing the sustainable use of natural resources. In the Argentine case, some old disputes between use and conservation of beaches are now being settled. Second, it increased local residents' capacity for planning their own development and managing and resolving conflicts. For example, the three areas are now undertaking integrated development plans. Third, it enlarged the visibility of local governance institutions outside of their territories, beyond the conventional vision as objects of development and biodiversity conservation programs. For example, the artisanal fishers association now has a voice in the discussion of an Argentina law on artisanal fisheries. Finally, it revealed and challenged existing patterns of power and authority.

The level of community-based control of natural resources appeared to determine the concentration of key variables in the internal or external subsystems in the SES. The role that CBNRM plays in each SES, and in relation to current social-ecological challenges, is largely dependent on key factors that are external to the SESs in the Argentine and Colombian cases, whereas CBNRM is basically linked to the local governance system in the Mexican case. This finding reveals the importance of adequately identifying and redistributing responsibilities, and generating a mosaic of institutions with different and partially overlapping geographic and temporal scales that can effectively address the complexity of social-ecological issues (Meadowcroft 2002). Policies designed at the community level may introduce configurations that are better in terms of public and aggregated (e.g., community) private benefits (Carmona Torres et al. 2011).

Planning and decision-making with limited knowledge and high uncertainty are challenging tasks; however, acknowledging the difficult balance between local knowledge and power and globalized or globalizing forces and external powers is even more difficult. We believe that this research and its participatory focus provides a thorough understanding of three SESs. It also highlights the key SES drivers and variables, the roles they play or can play in the future, and how they interact to create blocking or triggering effects in the path toward social-ecological sustainability and equity.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/7965

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Appendix 1.

Table A.1. Summary of the five specific objectives of this paper, each connected with the adopted methods and the related outcomes.

OBJECTIVES	METHODS	RELATED OUTCOMES
a) To identify the key variables influencing the dynamics of each social-ecological system	Prospective Structural Analysis	Table 2, Appendix 2, Discussion
b) To explore the dependence and influence between these key variables and their roles within each social-ecological system	Prospective Structural Analysis (MII)	Figures 4, 5, 6 and 7, Appendix 3, Discussion
c) To compare the most influential subsystems using Ostrom's framework for analyzing the sustainability of each social-ecological system by identifying different/similar patterns	Prospective Structural Analysis (MII) Mann-Whitney tests	Figures 4, 5, 6 and 7, Appendix 3, Discussion
d) To describe the role played by the key variables within the social-ecological networks in which they are embedded	Prospective Structural Analysis Network Analysis (MDI)	Figures 8, 9, 10 and 11 Table 2, Appendix 4, Discussion
e) To reflect on the resilience of each social-ecological system	Prospective Structural Analysis Network Analysis (MDI)	Figures 8, 9, 10 and 11 Table 2, Discussion

Appendix 2. Brief descriptions of the variables selected in the PSA.

COLOMBIA

Population trends: The increase and decrease of population. These trends are based on the natural growth of the local population, despite the relatively high migration rate of young people, and the influx into the territory of new stakeholders for the exploitation of natural resources. As the population increases there is intensification in the demand for resources and services provided by the ecological subsystem.

Mining: Mining activities, when are carried out improperly, affect biodiversity and water. Extraction procedures and the use of chemicals destroy and pollute the habitat of different species of flora and fauna inhabiting the SESs. It should be clarified that artisanal mining does not affect the ecosystem at the same level as industrial mining does. The artisanal techniques and local knowledge related to this activity are passed from generation to generation. In general, since the 1990s there is an increase of gold mining, which is linked to international gold price trends.

Fishing and hunting: Fishing, conducted by the communities in the studied SESs, is artisanal. The most common artisanal tools are cast nets and fixed traps. In the Calima river, explosives have been used for fishing, although this has been reduced due to institutional and community council control. There are no catch records for fishing in the area. Hunting, in particular related to the illegal wildlife trade for regional markets, is considered as a variable that directly affects the populations of native species. Similarly, the role of various species is highlighted as they transport seeds, so a reduction of these species is reflected in the reduction of forest resilience. Hunting affects biodiversity by causing a decrease in the resources and services provided by the different components of the system. It is clear for the workshop participants that this activity should be allowed just as a subsistence activity linked to livelihoods. The Regional Corporation Valle del Cauca considers it as an activity with a strong impact, but currently strictly controlled. The Council also have regulatory mechanisms.

Deforestation: Timber extraction affects biodiversity because, among other things, ecological niches are destroyed, some species become endangered and erosion processes are generated. This human activity has affected local ecosystems and the members of the Community Council report that deforestation generates significant negative impacts on agriculture and soil. The timber extraction in the eighties and nineties increased with activities carried out by a private enterprise (Cartón de Colombia), which destroyed significant forest areas in Bajo Calima. Timber extraction represents an important income source for these communities. Deforestation was also mentioned as one of the main causes of global warming.

Illicit crops: The coca crops and various environmental and social problems associated with this activity. Coca cultivation is carried out with intensive technology based on the use of agrochemicals. The use of agrochemicals and deforestation are two factors that directly affect biodiversity and water. This is considered a foreign activity. This crop competes with agriculture for food and generates various social tensions. The dynamics of violence linked to the coca trade and control of the activity have affected local people, in some cases displacing them from their homes.

Formal institutions: The set of formal institutions that carry out direct actions on the territory. It is considered that the existence of the Community Council has allowed the persistence of ethnic groups, which in turn has helped to preserve traditional knowledge. This means that resources are maintained and retained. The analysis of this variable generated a debate during the workshop in relation to the entity of the Community Council and its role in the governance system. There is a concern about its limited regulation and the meaning of self-government in the territories. It is important to note that there is a generational difference between how older and younger people understands the institutions and structure of the governance system of their specific SES. The Community Council interacts with various local and international NGOs and public and private institutions in order to manage and put into practise different development actions. In general, workshop participants recognize the role of some institutions (mainly CVC, SENA, departmental government and ministries) that offer training, support programs and regulate natural resource extraction. However, they criticize the role of institutions such as the Mayor´s office and the Colombian State oil company (Ecopetrol) due to their limited support and presence in the territories of Community Councils.

<u>Climate change:</u> Climate change is a relevant variable for agricultural systems that are developed with traditional techniques based on crop rotation, low use of agrochemicals and with high dependence on seasonal rainfall. Crops are planted in the river valley and highlands, which allows the management of various crop species. Due to the limited infrastructure for drinking water supply, inhabitants use rainwater for consumption. Thus, any change in the rainfall and in the rainy and dry seasons directly affects agro-biodiversity and the social subsystem, impacting directly in the local livelihoods. Moreover, there is a gradual consolidation of local knowledge on climate variability, and communities have a clear perception of how this has evolved. In general, three aspects were mentioned in the workshops: increased rainfall, shorter dry periods, and increased extreme events, including floods and landslides. This dynamic of change is starting to cause problems in relation to the planning of crops throughout the year, their advancement in plain areas of the rivers and streams, increased pests and diseases and problems associated with fruit trees flowering. Although not much research in this field exists, the IDEAM projections presented these findings in its third technical report support (IDEAM, 2010).

<u>Agriculture:</u> Agriculture is for subsistence, applying ancestral cultural practises with little technological inputs. This type of agriculture is carried out in small plots (no more than 5 hectares), in which poly-crops are established, looking for associations between different species of plants and animals for a better crop development. A guiding principle to create the crop mix is to ensure diversity and permanence of a balanced diet throughout the year. Similarly, this combination of species responds to other aspects such as pest and disease control, income diversification, and efficient use of the available labour force. Workshop participants recognize that although agriculture is guided by traditional ecological knowledge, agrochemicals are used, in particular for the control of pests and diseases, which affect biodiversity, soil, water and ecosystems. The use of agrochemicals is growing as new generations do not adopt appropriate cultural and traditional customs linked to agriculture.

<u>Tourism:</u> Tourism has become one of the various sources of income for livelihoods in the studied SES. However, this activity generates a number of direct impacts on biodiversity and water resources. A major cause is the very limited regulation of the activity and the construction and operation of spa infrastructures in the rivers. As a result, various problems are observed such as washing cars, motorcycles and clothes,

solid waste and sewage disposal directly into water sources, and uncontrolled use of river beaches.

Megaprojects: These are large infrastructure projects that are currently under development and have a direct impact on the Councils territories. The Port of Aguadulce and the double-way road that connects Buenaventura to Buga and Cali are two of the most important megaprojects. During the process of implementation of these projects, significant impacts are generated on biodiversity and water resources, like destruction of forests, wildlife, flora and even some places of cultural significance to the community.

Impacts of public policies: This variable refers to the impacts, positive and negative, that generates public policies on biodiversity and water resources. An emphasis is posed in explicit contradictions, for example, between the National Biodiversity Policy and promotion of megaprojects and mining by the National Development Plan, which currently drives various large-scale projects in the municipality of Buenaventura. Another important example in this area is the national policy for the control of illicit crops though aerial spraying of glyphosate.

Water management: Inhabitants build artisanal structures to collect and storage rainwater in each of the houses. Currently, the communities are facing a crisis with a political dimension. Water is a common resource that is involved in most of the economic activities and livelihoods of the Community Council (agriculture, mining, river material extraction and tourism). In this sense, the Council currently controls water management, but there is not an entity that regulates the quantity of water for each human use.

Formal education: This variable refers to formal education in primary and secondary schools. The role of SENA is highlighted as an important institution for the promotion of environmental education, preservation of natural resources and promoting sustainable tourism. Also, the education institution José María Córdoba promotes education for children and youth, environmental awareness and sustainability programs. Workshop's participants agree that formal education is a mechanism that stimulates the migration of young people, since rural education is decontextualized and traditional knowledge and cultural dynamics are not included in the curricula.

Locally fostered research: The research is part of the Council initiatives and is reflected in activities such as the environmental impact studies for the construction of a double-way road and other mega-projects in the area. There has been some progress such as the characterization of biotic, abiotic, socio-cultural, political and economic components of the SES. Some of the aspects in the Community Council research agenda are: biodiversity protection, conservation of natural resources, delimitation of protected areas and areas for the protection of water sources, good practices in landscape use, creating recreational areas, ecological corridors (connectivity) and ecotourism trails (research and education). In this sense, some NGOs support the Community Council in this research, which has been linked to development and innovation processes in rural areas, aiming at improving the quality of life of the local inhabitants. People mentioned the need for progress in this field since research is essential for the conservation of biodiversity and water resources. However, they also suggested that the research conducted by external actors could have negative impacts when ancestral knowledge is looted.

Aerial spraying: Aerial spraying with glyphosate is an instrument of the national drug policy. Glyphosate is a systemic herbicide that destroys coca crops. However, the way it is used also affects the forest, food crops and other commercial agriculture, as well as the health of people and animals.

Community as social group**:** This variable refers to issues directly related to the social group and affects biodiversity and water resources. It describes the inhabitants of the Community Council as a social group. It highlights the responsibility of the community in using and conserving biodiversity and water resources. It does not refer to demographics. For example, when the community is not aware of the importance of resources and the need to take care of them, they may sell those resources, e.g. gold and wood to outside actors, thinking individually and not on the collective interests. Although the bargaining power of the community to deal with large infrastructure project providers has improved, it is not the same with other challenges such as illicit coca crops and gold mining actors. Moreover, the poor management of water and biodiversity by communities affects negatively. People emphasize that there is no culture of waste management and sewage flows directly into rivers and streams without any treatment.

Ancestral knowledge: This variable involves the body of knowledge, practices and beliefs of the community about the relationships among living beings (including humans) and their immediate environment. In other words, it is the ancestral knowledge regarding the SES in what they live, that evolves through a process of historical adaptation and that is transmitted from one generation to the next. In the past, people had very clear hierarchies of authority, but now there is no credibility in them. Ancestral knowledge is usually transmitted by the elderly, which in turn affects the creation, maintenance and administration rules regarding the use of biodiversity and water resources. The migration of the young and the increasing links of the Council with urban centres, among other external factors, impact negatively on this variable, by eroding important cultural aspects such as identity and sense of belonging.

Regional institution for the environment (Corporación Autónoma Regional del Valle del Cauca CVC): This is the public institution responsible for decisions regarding environmental issues in the department of Valle del Cauca. The territory of Calima is under the jurisdiction of this institution, and the established rules and regulations must be followed. This institution issues permissions and licenses for certain timber extraction activities, and for hunting and fishing. It also regulates the activities related with the use of biodiversity by communities and supports sustainable agricultural activities taking place in the territory.

Markets for natural resources: Natural resources extracted from the ecosystems, such as agricultural products, are usually not processed and are sold in local and regional markets. Some of these products (gold, timber and *chontaduro -Bactris gasipaes-*, a local fruit) go to other markets such as Cali and Bogota. Some resources such as gold, timber, tagua or Pecari (*Catagonus wagneri*) and tatabro (*Tayassu albirostris*) have a high demand, which encourages their continued extraction and increasingly affects their availability. The workshop participants recognize an important and growing influence of regional markets on natural resource extraction, which directly affects biodiversity and water resources.

Solid waste: There is no solid waste treatment system. Burning garbage in the community is a common practice, which generates direct impacts on biodiversity and water resources. It is considered that this affects directly tourism through water and beach pollution. Workshop participants agree that improper handling of solid waste currently represents a major problem for public health.

Armed conflict: This variable refers to the interference of illegal armed groups in the control of territory. The actions of these groups have been associated with the control of coca crops, illegal mining and control of strategic corridors for drug trafficking. These activities have a direct impact on biodiversity and water resources. Sometimes, these groups cause the displacement of people, which directly impacts the social structure of the SES.

Fluvial transport: This variable refers to transport on the Calima River. The boats with big engines generate waves that impact the river valleys, which contributes to their erosion and ecosystem damage. Similar to ground transportation, boat maintenance represents a major source of pollution (waste and oil), affecting biodiversity.

Water management: None of the communities has sewage infrastructure, although some families have septic tanks. In some cases, especially in the houses scattered along the railway and road, sewage drains into nearby water sources, especially in the river or open fields. These practices directly affect biodiversity and water resources by polluting rivers and streams that are in turn used in agriculture, for human consumption and for recreation. Sewage is a problem identified as a priority for the health of the communities, as it is a source of infection, disease and epidemics and a public health issue.

MEXICO

Economic activities (forestry and agriculture for income): These economic activities represent a source of income for the community members. By and large, people produce their own food (maize, beans, and several vegetables). Forest resources are extracted and the community owns a sawmill to add value to timber. The benefits obtained from the sawmill go to the community to finance public goods and services.

Livelihoods (for subsistence): The day-to-day activities performed by all inhabitants for the subsistence of the families and the community regardless of whether or not they generate monetary income. The economy of the community is mostly of self-sufficiency, though this is increasingly not fully achieved and families currently need to buy maize from shops.

Non-paid activities of inhabitants: Activities that are performed by the commoners without payment and on a mandatory basis. These activities strengthen the community ties. Some of the most important activities in this category are: service to the community (*cargos* and commissions), unpaid labour for the community (*tequios*), domestic labour, and monitoring activities.

Migration: Migration refers to changes in the migration patterns and to the nature of such changes over the years, as well as to the reasons for the changes. This variable also includes identifying who migrates, why and where to. In the SES, migration started in the eighties and nineties and there has been a stable trend since then, showing some declining tendency in the last few years, due to the stronger USA regulations.

Political stability: Political stability is related to the political conditions at the regional, national and local levels, whether stability or conflict prevails. It also refers to the degree of compliance with the rules due to the knowledge that community members have of them and to the community's enforcing power. The trust and predictability of behaviour and reciprocity among commoners is important for migration and political stability. The same can be said about the trust in the authorities' performance.

Environmental legislation: This variable includes environmental laws affecting the interrelations among the resource units on the regional, national and local levels. For instance, whether the community performs or stops performing certain activities related to the natural resource management due to regional environmental laws.

Monitoring and sanctioning processes: These processes allow the strengthening of operational rules within the system. The commoners monitor the correct use of the system resources and verify compliance with the established rules. When compliance with the rules is not effective or the resources are used inappropriately, the authority imposes sanctions (penalties, community labour, imprisonment).

Governance institutions: The multilevel organisations affecting the system, their performance and their structure. The Commoners' Assembly, the Citizens Assembly, the municipal authorities, the Communal Property Commissioner, and the Surveillance Council are some of these institutions.

Property rights system: It describes the existence or absence of formal property rights regarding the resource system and the common pool resources.

Collective-choice rules: Rules for collective action and community-based management of resources. For example, there are protocols to act collectively if a fire breaks out or for forest harvesting.

Extraction and exclusion rights: This variable refers to the rights of people to access the resources and to their management. The Assembly of Commoners defines who can use the resources and how, and intervenes in the decision making process related to exclusion and extraction rights. It makes a difference whether these rules are clear or not.

Economic value of natural resources: It refers to the prices of the natural resources, such as timber and forest product prices. These prices are externally set so the community has little or none capacity of negotiation.

Importance of the resources for inhabitants: This variable is related to how important the resources are for the lives and economy of the commoners and how much they depend on such resources.

History of use: It is the history of the community, regarding land use and natural resource management. It also comprises how the interactions among the resource units have changed over the years.

Sanitary infrastructures and services: This is related to the infrastructure and services that improve health conditions in the community.

ARGENTINA

Petrochemical Industry Pole: The cluster of industries and companies located near the Ing. White Port, between the communities of White and Cerri. The Petrochemical Industry Pole is perceived as an external power group, with capacity for lobbying against the direct interests of users on top of being a possible threat as one of the major pollution sources.

Employment sources: Sources for possible jobs for the stakeholders. According to the SES delimitation, they are mainly situated in the fishery and tourism sectors. Commerce and public sector employment are the most important secondary employment sources.

Tourism: Selling tourism services and products. The “beach and sun” tourism is one of the main sources of income for the communities of Pehuén Co and Monte Hermoso. This activity entails the intensive use of coastal resources and is both complementary and conflicting with artisanal fishery.

Local Markets: The set of relations between sellers and buyers in the local context of fishery. Local markets condition consumers and price determination.

External governance of fishery: Groups of organizations belonging to different government levels that have some legal authority over the resource, as well as formal legislation and norms on controlling, monitoring and sanctioning the use and appropriation of the resource. For stakeholders, it is an external variable since they have no influence power on them.

Lack of political interest in environmental sustainability: The attitude of external decision makers towards legislation on resource units and resource system. It depends on external stakeholders. According to the workshop participants, the lack of political interest in environmental sustainability can be seen through different actions or omissions by decision makers.

Fishermen associations: Internal networks (associations and chambers) related to the management, use and marketing of resources. Such unions increase the social capital of users. Through these network structures, fishermen share information and develop collective actions.

Catches: Number of fishery resource units extracted by artisanal fishery.

Seasonality of fishery and tourism: Seasonality is a characteristic of fishery activity since it represents the extraction of a resource with regeneration periods. Seasonality is also a characteristic of tourism activity because of the “beach and sun” tourism which normally takes place in summer.

Wildlife: The relevance of biodiversity and the equilibrium of species’ interactions in a biological sense.

Income: Income as a measurement of quality of life. This is directly linked with the use of resource since the two main income sources of communities are fishery and tourism.

Artisanal fishery history: History of the use of fishery resources. Artisanal fishery is based on traditional extracting methods. Fathers often teach their sons the techniques to fish and the traditional knowledge about the SES. The history in the Argentinean case is relatively new (see Deliverable 4.2, chapter 2 at URL: http://comet-la.eu/index.php/en/publications.html) and fishery is mostly related to the Italian immigrants in the region.

History of artisanal fishery: The history, traditions and type of activity carried out by small crafts and boats with traditional techniques as hand line, trammel or gill net, shrimp net funding, etc.

Dredging and LNG (Liquefied Natural Gas) Project: The expansion of the Petrochemical Industry Pole and the enlargement and deepening of the *Canal Principal* (main channel), promoted by external users and decision makers. This is an important infrastructure project consisting of building a plant to transform LNG into regular gas near Cerri. The project caused a conflict among internal and external stakeholders.

Conservation measures: Group of activities and procedures made by users (mainly internal stakeholders, but also external, although to a lesser extent) in order to achieve sustainability of the resource.

Community networking: Ideas and perceptions about activities realized by a user may affect other users and the common use of resources. This type of thinking has become relevant and has pushed the community to reflect about the importance of networking activities.

Environmental changes in coast and estuary: A series of physical changes in coastal environment and estuary, as observed by users. This variable depends on human and environmental factors, including climate change and variability.

Overfishing: The excessive catches of fish and shellfish. The effects of overfishing are recognized in biological terms (reduction of the resources) and bio-economics terms (less profitable activity). The stakeholders point at offshore fishery as the main responsible.

Resource sustainability: The possibility to maintain equilibrium between the resource extraction and its regeneration, in order to achieve the ecologic and economic sustainability of the SES.

Changes in climate patterns: Changes in climate patterns perceived by users. Some of these changes are a decrease in rainfall, an extension in drought periods, an increase in water temperature and an increase in the rotation and speed of winds.

Pollution: Pollution patterns affecting the SES and users' activities, such as air pollution caused by toxic emissions from factories and water pollution caused by industrial waste and sewage.

References

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Appendix 3.

Table A3.1. Matrix of Direct Influence (MDI) and type (+ or -) of influences/dependences of Colombia

	Deforestation	Mining	Aerial spraying	Population trends	Fishing and hunting	Agriculture	Megaprojects	Regional institution for the environment	Markets for natural resources	Tourism	Climate change	Community as social group	Solid waste	Illicit crops	Armed conflict	Fluvial transport	Impacts of public policies	Water management	Ancestral knowledge	Formal institutions	Formal education	Locally fostered research
Deforestation	0	0	0	-2	-3	2	0	0	0	-2	3	-3	0	1	1	0	1	0	-3	-2	-3	-2
Mining	2	0	2	2	-2	-2	0	0	0	-2	0	-3	0	2	2	-1	2	0	-3	-3	-1	-2
Aerial spraying	3	0	0	-3	-3	-3	0	0	-3	-3	3	-2	0	2	1	0	0	0	-1	0	-2	0
Population trends	2	2	0	0	3	2	2	0	0	0	3	-2	2	0	0	1	1	-3	-1	-1	1	1
Fishing and hunting	0	0	0	2	0	-2	0	0	0	1	1	2	0	0	-1	0	0	0	2	1	1	1
Agriculture	1	0	0	0	-2	0	0	0	3	-2	1	2	0	-2	0	0	1	0	3	2	2	2
Megaprojects	3	2	0	3	-2	2	0	0	2	-1	2	-3	2	-1	2	1	0	-1	-1	0	1	0
Regional institution for the environment	-2	-3	0	2	-2	0	-3	0	-2	0	0	2	0	0	0	0	2	1	0	1	0	2
Markets for natural resources	3	3	0	2	2	3	0	0	0	0	3	-2	1	3	-1	0	1	0	-2	0	0	0
Tourism	-2	0	0	3	0	0	0	0	0	0	-1	0	3	-2	0	2	0	0	2	2	2	0
Climate change	0	-1	1	-3	-3	-2	1	0	-2	0	0	-1	0	-2	0	0	1	0	-1	0	0	1
Community as social group	-3	-3	0	0	-1	0	-2	0	0	0	0	0	0	-2	-1	-2	0	1	2	0	0	0
Solid waste	0	0	0	0	-1	-2	0	0	0	-3	2	-2	0	0	0	-1	0	0	0	0	0	0
Illicit crops	2	3	3	-1	-2	-2	0	0	0	-2	1	-3	0	0	3	-1	3	-2	-3	-3	-3	1
Armed conflict	-1	2	0	-1	-1	-2	-2	-1	-1	-2	0	-3	0	2	0	-1	-3	0	-1	-1	0	0
Fluvial transport	0	0	0	0	-1	1	0	0	1	1	1	-2	1	1	-1	0	0	0	0	0	0	0
Impacts of public policies	-2	2	1	2	1	0	2	0	1	1	0	-3	0	0	-2	0	0	0	-1	2	1	1
Water management	0	0	0	2	0	2	0	0	0	2	-2	0	0	0	0	0	0	0	0	0	0	0
Ancestral knowledge	-2	-3	0	0	3	3	0	0	0	3	0	2	0	-2	0	0	0	0	0	2	1	3
Formal institutions	-3	-3	0	1	1	3	-3	0	0	3	0	2	-1	-2	-1	-1	3	1	1	0	3	3
Formal education	-3	-3	0	-2	-2	3	0	0	0	3	0	3	-1	-3	0	0	3	1	1	3	0	3
Locally fostered research	-3	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	1	0	1	1	3	0

Table A3.2. Matrix of Direct Influence (MDI) and type (+ or -) of influences/dependences of Mexico.

	Economic activities (for&agr for income)	Monitoring and sanctioning processes	Livelihoods (for subsistence)	Non-paid activities of inhabitants	Migration	Political stability	Environmental legislation	Extraction and exclusion rights	Governance institutions	Property rights system	Collective-choice rules	Economic value of natural resources	Importance of resources for inhabitants	Sanitary infrastructures and services	History of use
Economic activities (for&agr for income)	0	0	3	1	-2	3	0	0	0	0	3	0	0	3	0
Monitoring and sanctioning processes	2	0	3	1	0	3	0	2	0	0	0	3	2	3	3
Livelihoods (for subsistence)	3	1	0	0	-3	2	0	0	0	0	0	3	-2	-3	0
Non-paid activities of inhabitants	-2	0	2	0	-1	2	0	3	1	0	0	-2	1	-1	3
Migration	-3	0	-2	0	0	-1	0	0	0	0	-1	0	3	1	0
Political stability	2	2	1	2	1	0	0	0	0	1	3	2	2	1	2
Environmental legislation	3	0	3	0	0	0	0	3	0	0	2	-2	3	3	0
Extraction and exclusion rights	-3	2	2	3	-1	3	0	0	0	1	1	-2	2	0	3
Governance institutions	3	3	2	3	-3	3	2	3	0	2	3	2	2	3	3
Property rights system	3	3	2	2	0	3	2	3	3	0	2	2	1	0	3
Collective-choice rules	-3	3	2	3	-1	3	1	2	3	0	0	-1	2	0	3
Economic value of natural resources	3	3	3	0	-3	3	0	0	0	0	0	0	3	3	3
Importance of resources for inhabitants	3	3	2	0	-2	2	0	0	2	0	0	3	0	2	3
Sanitary infrastructures and services	-2	0	1	0	0	2	2	0	0	0	0	0	0	0	0
History of use	-3	3	-3	3	-2	3	1	3	3	3	2	1	2	2	0

A3.3. Matrix of Direct Influence (MDI) and type (+ or -) of influences/dependences of Argentina.

	Changes in climate patterns	Resource sustainability	Catches	Seasonality of fishery and tourism	Petrochemical Industry Pole	Tourism	Employment sources	Local markets	Income	History of artisanal fishery	Community networking	Conservation measures	Artisanal fishery
Changes in climate patterns	0	-2	-2	3	0	2	1	0	-2	1	2	-2	-3
Pollution	2	-3	-3	-3	0	-3	-2	-1	-3	-2	3	-3	-3
External governance of fishery	0	3	-3	0	0	1	-2	-1	-2	-2	0	-1	-3
Fishermen associations	0	2	2	0	1	1	-3	2	2	3	1	2	3
Lack of political interestest in env. sustainability	0	-3	-2	0	3	-2	-1	0	-2	-2	3	-1	-3
Dredging and LNG project	0	-3	-3	0	2	0	0	0	-2	-2	3	0	-3
Environmental changes in coast and estuary	0	-3	-1	1	0	-3	-2	0	-1	-1	2	-2	-2
Overfishing	0	-3	-3	-1	0	0	2	-1	-2	-2	0	-2	-3
Wildlife	0	2	2	0	0	0	2	0	1	2	2	2	2
Resource sustainability	0	0	2	0	0	2	3	1	2	2	2	3	2
Catches	0	-1	0	0	0	0	1	3	3	2	0	0	-3
Seasonality of fishery and tourism	0	0	3	0	0	3	-2	-2	-3	0	0	0	-2
Petrochemical Industry Pole	0	-3	-3	-2	0	-1	-2	0	-2	-2	3	-1	-3
Tourism	0	-2	0	0	0	0	2	-2	3	0	2	2	2
Employment sources	0	0	0	0	0	0	0	0	3	0	0	0	0
Local markets	0	0	1	0	0	0	2	0	3	-2	0	0	2
Income	0	2	2	0	0	0	3	1	0	1	0	0	2
History of artisanal fishery	0	2	2	0	0	2	1	1	2	0	1	2	3
Community networking	0	3	1	0	-2	1	0	0	0	2	0	3	2
Conservation measures	0	2	2	0	0	3	0	1	2	2	3	0	2
Artisanal fishery	0	3	3	0	0	2	3	2	3	3	2	2	0

Appendix 4

Table A4.1. PSA (MDI and MII dependence and influence) and NA (betweenness, closeness and eigenvector) parameters of Colombia.

Settings	Subs.	Variables	Dependence MDI	Influence MDI	Dependence MII	Influence MII	Betweenness (weighted) MDI	Closenness MDI	Eigenvector MDI
no Settings	GS	Formal institutions	24	35	22618	26636	15,456	24	0,233
no Settings	RS/I	Mining	30	31	22892	25686	9,711	23	0,241
no Settings	O	Deforestation	37	28	25655	22019	9,389	24	0,232
no Settings	A	Population trends	31	27	20215	19526	16,698	21	0,256
no Settings	A/I	Ancestral knowledge	29	24	24585	21497	4,71	25	0,223
no Settings	RS/I	Agriculture	39	23	29978	18654	15,159	22	0,248
no Settings	GS	Regional institution for the environment	1	22	428	20531	0,267	30	0,154
no Settings	ECO	Climate change	23	19	26220	20298	19,16	25	0,213
no Settings	ECO	Tourism	31	19	30389	25529	10,577	25	0,213
no Settings	A/GS	Community as social group	43	17	32558	12974	16,344	22	0,244
no Settings	RS/I	Fishing and hunting	35	14	29995	10655	9,325	22	0,249
no Settings	A	Locally fostered research	22	13	20940	24338	1,132	29	0,173
no Settings	O	Solid waste	11	11	14130	7305	1,062	31	0,144
no Settings	O/ECO	Fluvial transport	11	10	14874	6512	6,006	29	0,171
no Settings	RS/GS	Water managament	10	8	9507	6210	1,261	32	0,131
Settings	S/ECO	Illicit crops	27	38	22939	28122	16,979	23	0,24
Settings	A/(S)	Formal education	24	34	19737	28268	8,64	26	0,204
Settings	S	Megaprojects	15	29	9784	19411	6,712	23	0,236
Settings	S	Aerial spraying	7	29	5797	21943	1,449	28	0,188
Settings	S/RU	Markets for natural resources	15	26	11611	21931	4,745	26	0,204
Settings	S	Armed conflict	16	24	11625	17783	27,318	26	0,208
Settings	S/GS	Impacts of public policies	22	22	18490	19139	11,9	24	0,232

Table A.4.2. PSA (MDI and MII dependence and influence) and NA (betweenness, closeness and eigenvector) parameters of Mexico.

Governance System (GS)	Subs.	Variables	Dependence MDI	Influence MDI	Dependence MII	Influence MII	Betweenness (weighted) MDI	Closenness MDI	Eigenvector MDI
no GS	A	History of use	26	34	9923	14715	8,27	14	0,277
no GS	A	Importance of resources for inhabitants	25	22	10123	9069	6,046	14	0,277
no GS	RS	Economic activities (for&agr for income)	38	15	15463	5072	4,853	14	0,277
no GS	A(I)	Livelihoods (for subsistence)	31	17	12984	5241	4,063	14	0,277
no GS	RU	Economic value of natural resources	23	24	9433	8658	1,679	14	0,277
no GS	ECO	Migration	19	11	9259	3852	1,352	17	0,227
no GS	RS	Sanitary infrastructures and services	25	7	11607	2313	4,06	17	0,222
no GS	S	Environmental legislation	8	19	2765	6938	2,391	18	0,206
GS	GS	Governance institutions	12	37	4420	15388	2,834	14	0,277
GS	S(GS)	Political stability	33	19	14319	8545	14,687	15	0,263
GS	GS(A)	Non-paid activities of inhabitants	18	18	7090	7936	3,444	15	0,263
GS	GS	Collective-choice rules	17	27	7389	12380	8,96	15	0,261
GS	GS	Extraction and exclusion rights	19	23	5760	10081	3,711	15	0,261
GS	GS(A)	Monitoring and santioning processes	23	22	9286	8735	3,369	16	0,246
GS	GS	Property rights system	7	29	2935	13833	1,283	16	0,245

Table A4.3. PSA (MDI and MII dependence and influence) and NA (betweenness, closeness and eigenvector) parameters of Argentina.

Settings	Subs.	Variables	Dependence MDI	Influence MDI	Dependence MII	Influence MII	Betweenness (weighted) MDI	Closenness MDI	Eigenvector MDI
no Settings	O/ECO	Pollution	15	40	6630	20522	23,54	21	0,24
no Settings	RU	Artisanal fishery	48	36	25392	18106	27,688	20	0,25
no Settings	GS/I	Fishermen associations	40	30	23047	15982	40,739	20	0,25
no Settings	ECO	Changes in climate patterns	2	26	582	13516	0	26	0,185
no Settings	A	Community networking	29	26	14974	17003	9,69	26	0,184
no Settings	O	Overfishing	11	26	6265	13168	5,569	27	0,17
no Settings	O	Resource sustainability	42	24	22838	12020	4,754	21	0,24
no Settings	A/I	History of artisanal fishery	33	23	20426	12280	10,456	21	0,24
no Settings	O	Environmental changes in coast and estuary	26	23	12346	12229	6,752	22	0,231
no Settings	I/O	Catches	40	20	21085	9699	5,925	21	0,238
no Settings	RS/RU	Seasonality of fishery and tourism	10	19	2063	8226	0,679	26	0,178
no Settings	RS	Wildlife	37	18	18331	9789	2,734	21	0,24
no Settings	A	Income	43	13	24725	5904	4,306	21	0,239
no Settings	GS	Local markets	18	12	12903	5442	0,408	27	0,17
no Settings	I	Employment sources	34	5	21715	2176	0	23	0,217
Settings	S	Lack of political interestest in env. sustainability	7	42	2545	26611	2,208	23	0,22
Settings	S	Petrochemical Industry Pole	8	40	3408	24373	5,559	24	0,209
Settings	S	Dredging and LNG project	16	29	9045	17717	2,202	26	0,187
Settings	S	External governance of fishery	17	28	10119	15307	13,163	23	0,218
Settings	S/GS	Conservation measures	28	27	16847	15559	9,932	22	0,228
Settings	S	Tourism	26	23	13411	13068	12,695	23	0,217
no Settings	O/ECO	Pollution	15	40	6630	20522	23,54	21	0,24
no Settings	RU	Artisanal fishery	48	36	25392	18106	27,688	20	0,25
no Settings	GS/I	Fishermen associations	40	30	23047	15982	40,739	20	0,25