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Governance structures for ecosystem-based adaptation: Using policy-network analysis to identify key organizations for bridging information across scales and policy areas

Raffaele Vignola [a,b,c,*], *Timothy L. McDaniels* [b,a], *Roland W. Scholz* [c]

[a] *Chair of Environmental Decisions for Global Change, Climate Change and Watershed Program, CATIE, 7170-Turrialba, Costa Rica*

[b] *Institute for Resources, Environment and Sustainability, School of Community and Regional Planning, University of British Columbia, Canada*

[c] *ETH Zurich, Institute for Environmental Decisions, Natural and Social Science Interface, 8092 Zurich, Switzerland*

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ABSTRACT

Ecosystem service degradation, exacerbated by climate change, requires flexible and effective communication within governance systems to foster actions that reverse current trends and can cope with changing conditions. Key organizations bridge information to a variety of actors across administrative scales and policy areas in complex governance networks concerned with ecosystem services. In this paper, we use quantitative analysis of information flows, perceived influence and competence within a multi-actors' governance network to identify key information bridging organizations (BrO) for an example involving soil regulation services in a watershed in Costa Rica. Here, heavy soil erosion (due to intense cultivation on steep slopes, and increasing frequency of extreme precipitation events) affects both farmers (by loss of fertile topsoil) and hydroelectric generation (by rapid siltation of reservoirs downstream). To gauge the information-bridging capacities of organizations we use the network parameter betweenness centrality, and we created two new parameters to measure the extent of cross-scale and cross-policy area exchange of information of the organizations. The regional agricultural extension office is identified, among others, as a crucial BrO in keeping with other studies of agricultural systems. The results also show that network analysis provides an empirical basis for understanding information flows and influence in governance networks, in order to identify key organizations. In this manner, we can diagnose potential bottlenecks, when these organizations lack the resources to achieve their mandates and need support to strengthen their efforts in information provision and influence in governance for ecosystem services.

* *Corresponding author at*: Chair of Environmental Decisions for Global Change, Climate Change and Watershed Program, CATIE, 7170-Turrialba, Costa Rica. Tel.: +506 25582528.
E-mail addresses: rvignola@catie.ac.cr, raffavig@yahoo.it (R. Vignola).
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1. Introduction

The Millennium Ecosystem Assessment documents the rapid growth in demand for and decline in supply of ecosystem services (ES)[1] (MEA, 2005), a situation made even more disturbing when the disruptive effects of climate change are considered (Fischlin et al., 2007). Coordinated adaptation efforts are required for these social–environmental systems, within complex institutional and governance contexts, if ES supplies are to better meet ES demands under the pressures of climate change (Hulme, 2005; Bodin and Crona, 2009). Yet often those relying on a specific type of ES are spatially and administratively separate from (i) those who influence the quality and quantity of that ES provision and (ii) those who generate, analyze and disseminate information that is relevant for managing those ES. Managing *soil regulation services* (SRS) at the watershed scale is a case in point. Farmers on upstream sites clearly have individual incentives to avoid erosion and retain soils on their farms, but often lack necessary technical knowledge, equipment, capital, time or cooperation of others to identify and implement good practices to reduce erosion. Downstream neighbors and more distant water users, such as hydroelectric facilities, bear costs that could be avoided if formal or informal governance would bring forth more resources for upstream erosion control. Yet the potential positive externalities of SRS in avoiding siltation of reservoirs are not internalized into decisions of the concerned actors, unless governance mechanisms, mutual support and information-sharing can be established (Southgate and Macke, 1989; Pimentel et al., 1995; Guo et al., 2000). Climate change is expected to increase the intensity of rainfall, and thus increase erosion, in many tropical countries, including Costa Rica, the location of interest in this paper. Although actors involved in SRS management need appropriate information to guide adaptation choices, societal ecosystem-based adaptation responses are typically in the initial stages of compiling information about future climate impacts and analyzing feasible responses (IUCN, 2008; UNCBD, 2009; Vignola et al., 2009; Eastaugh et al., 2009).

How information is created and transferred within complex and ambiguous social networks is a topic of growing interest for research on environmental governance (Adger, 2003; Folke et al., 2005; Pelling and High, 2005). Information-sharing among organizations is shaped by an existing set of formal and informal institutional structures and governance arrangements that determine the capacity for collective responses to ES degradation problems (Uitto, 1997; Koiman, 1999; Hodge, 2001; Ostrom, 2007). Governance structures frame, oversee and implement resource management policies from broader levels of governance (e.g. regional or national or international) to individual land users at the local level (Adger et al., 2005a).

Recent studies have identified the role of boundary organizations in supporting information and knowledge exchange across scales among organizations belonging to different communities such as science, government, and civil society (Agrawala et al., 2001; Cash et al., 2003; Turton et al., 2007). This research indicates many factors play roles in determining whether a given entity serves as a key boundary organization within a specific institutional context. In this paper we consider whether key potential boundary organizations can be identified with quantitative analysis of information flows and reputation within a policy network. We seek to examine the bridging positions of key organizations, to identify the potential for bottlenecks in the flow of information (e.g. if the organization lacks the resources to maintain its current function and status in the network). We use the term ‘‘bridging organization’’ (BrO) to refer to potential boundary organizations that play important roles in sharing information across domains and scales. This term has been used in the past (Brown, 1991) in related contexts, though in reference to local organizations with horizontal and vertical linkages in developing countries.[2] Our approach to identifying BrOs addresses only some of the characteristics of boundary organizations. An analysis of these broader characteristics would require more qualitative assessments to identify, among other things, their history of relations and trust creation with partners as well as effective creation and use of boundary objects and standardized packages from these interactions (Guston, 2001).

The main contribution of this paper is its use of a quantitative survey and network analysis (Borgatti, 2009) to characterize information flows in a network of organizations and actors involved in Costa Rica water management and governance. The case study is situated in the Birris sub-watershed of central Costa Rica, where high rates of erosion caused by farming practices on steep volcanic slopes lead to siltation that reduces the output of important hydroelectric facilities, greatly increasing costs for power replacement and siltation removal.

The paper has the following structure. In Section 2 we discuss concepts and definitions for governance, scales and the importance of bridging organizations relevant for ecosystem-based adaptation to climate change. We also introduce concepts of network analysis employed in this paper. In Section 3, we describe briefly the case study, highlighting the drivers of SRS degradation and the contexts shaping actors who provide and would benefit from enhancing SRS in the Birris watershed. In Section 4, we present the methods, including how the network was bounded, the structure of policy network questionnaire and how the network analysis was conducted. In Section 5 we present results, followed in Section 6 with discussion, with particular attention to one organization, the watershed's regional agricultural extension office which can play an important role in the different stages of problem-detection and solutions' design and evaluation.

2. Relevant concepts

This section briefly introduces three concepts that comprise the intellectual landscape in which the paper is situated,

[1] These include: *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, esthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005, p. 9).

[2] We thank an anonymous reviewer for this suggestion.

including: information and knowledge exchange, multiple scales of governance, and the role of bridging organizations. Then it outlines some basic concepts needed to guide a quantitative network analysis.

2.1. *Information and knowledge exchange for governance of SRS*

Huitema et al. (2009) define governance as the result of both formally stated rules (e.g. policies, laws, etc.) and informal interactions of actors in networks that promote collective responses to environmental degradation problems. Hence governance involves both (1) formal rules defined by laws and official mandates that establish the legitimacy of actors in relation to the environmental degradation problem at hand, and (2) informal policy structures characterized by interactions in networks (Piattoni, 2006) that influence the sharing of information and knowledge across governance scales and policy communities.[3] Information-sharing mechanisms in such governance networks provide actors with opportunities to regularly update information and knowledge to cope with changing conditions and uncertainties that characterize ES degradation (Van Noordwijk et al., 2004). Sharing information in networks can promote common perception and understanding of the problem as well as the capacity to plan and monitor responses in a wider set of organizations (Cash, 2001; Van der Brugge and van Raak, 2007; Pahl-Wostl et al., 2007).

Exchange of information regarding potential impacts of alternatives for climate change adaptation are important aspects of effective ecosystem governance across administrative scales (Cash and Moser, 2000; Adger et al., 2005a; Brass et al., 2004). These advantages are particularly important for ES contexts involving a variety of actors, who have different experiences, interests, mandates and varying understanding of the functioning of ecosystems, their degradation and of the possible responses (Fisher et al., 2009).

2.2. *Defining scales of SRS governance*

Land use decisions influencing both the provision and use of ES typically occur within institutional structures that span across administrative and governance scales (Rotmans and Rothman, 2003). Such scales are social constructs and their definition depends on the perspective taken (Cash and Moser, 2000). In the words of Cash and Moser (2000): ''scale refers to a specific geographically or temporally bounded level at which a particular phenomenon is recognizable''. Specifically in this case, degradation of SRS as a social–ecological problem involves components that range from the local level (e.g. topography and soil; farm land use decisions) to the watershed (e.g. microclimatic conditions; presence of conservation programs, dynamics of sediment transport), to the national (e.g. distribution of precipitation; laws and incentives), and finally to the international (i.e. Central American policies and governance) and global levels (e.g. climate change; markets; and international agreements and funding). Recognition of multiple scales of governance in global change issues naturally leads to questions of potential gaps and mismatches in terms of regulatory coherence (McDaniels et al., 2005).

2.3. *Information-bridging organizations for SRS-governance network*

Structural interactions of actors in cross-scale governance networks have received increasing attention in social sciences (Borgatti, 2009) and specifically in studies of environmental degradation problems and adaptation to climate change (Adger, 2003; Brooke, 2002; Jost and Jacob, 2004). Information exchange in networks is strategically important to plan effective adaptive responses (Duit and Galaz, 2008). Bridging organizations are key actors in information-sharing networks, capable of spanning information across scales and knowledge systems. They can potentially promote opportunities for mutual understanding of preferences and meanings among different epistemic communities. They can potentially play a role as knowledge-brokers (Weible, 2008) by potentially helping to create collaborative partnerships between farmers, scientists, and policy makers (Cash, 2001; Guston, 2001; Cash et al., 2003).

Structural analysis of information-sharing networks can allow the identification of key bridging organizations (Burt, 2005). Their bridging positions can help building a network's capacity to (i) identify the problem and shape the nature and location of ES degradation priorities, by disseminating knowledge of local contexts to science and regulatory communities targeting appropriate research and incentives respectively, (ii) identify technological solutions that are feasible and acceptable to farmers, (iii) promote institutional mechanisms to best implement and monitor responses building alliances among national and watershed actors with farmers' organizations (Carlsson and Sandstrom, 2008). Structural analytic methods provide proxy measures of actors' capacities to mediate and influence relations (Bodin and Crona, 2009) and generate contagion of ideas (Borgatti, 2009).

2.4. *Network analysis to identify key bridging organizations*

Reflecting the work of Borgatti (2009), we consider four basic concepts that are key to analyzing multi-actor interactions considered in social network theory: the *theoretical framework*, *research question*, *relations and structure*. Our *theoretical framework* rests on the intersection of institutional theory (DiMaggio and Powell, 1983), organizational learning theory (Levitt and March, 1988) and the theory of adaptive governance (Duit and Galaz, 2008) all of which consider the role of information transmission among actors' networks to promote learning and the design of collective responses. As noted in the introduction, our specific *research question* is to identify key BrOs in order to subsequently contrast their boundary-spanning positions (Borgatti and Everett, 1992) with their current and potential contribution to the network's adaptive capacity.

[3] Policy communities are defined by a sub-set of actors in larger networks that share experience and common specialist language. Actors belonging to a ''policy community'' share a common identity in terms of languages and day-to-day policy-making. For examples, scientists might have limited presence in the day-to-day policy-making activities of the regulators' communities and vice-versa (Howlett and Ramesh, 1998).

Relations refer to the content of the connection among pairs of actors. In our case *relations* includes information flows connecting two or more actors in terms relevance for governance of SRS (Duit and Galaz, 2008). In this study we analyze three types of relations, drawing from previous research (Knoke, 1990; Cash et al., 2003; Raab and Kenis, 2006):

(1) **Position** in inter-organizational information-flow networks as a proxy for their bridging functions between the local watershed level and national policy and science-making; position was calculated through the analysis of actor's Betweenness Centrality parameter from the policy network matrix (see Sections 4 and 5) (Borgatti and Everett, 1992);
(2) **Perceived influence** as a proxy for the persuasive power of an actor, determined by the degree to which a specific actor is perceived as influential by others (Weible, 2005);
(3) **Perceived competence** as a proxy for the perceived credibility of information produced by an actor, as determined by other actors, which shapes how influential that information is in promoting responses (Chi-Cui et al., 2002).

The concept of *structure* in network analysis is reflected in the relative position of nodes (i.e. organizations) and linkages to others. In this paper, we employ a measure of structure termed *Betweenness Centrality* (*BC*) (Freeman, 1977), a structural parameter that measures the bridging capacity of an actor to connect other pairs of actors. We return to this issue in Sections 4 and 5.

3. Context of the Birris watershed

The Birris sub-watershed is a component of the upper Reventazon watershed (1500 km^2) in central Costa Rica, with an area of almost 5 km^2 and a population density above the national average (INEC, 2002). Here, a combination of extreme precipitation, steep topography and questionable land use has led to heavy erosion and impairment of SRS. Its steep lands suffer serious soil erosion due to intensive use by horticulturalists and grazing of dairy-cattle, which comprise the major economic activities in this watershed. Its vulnerability to climate change is characterized by observed increases in extreme precipitation events over the last forty years (Aguilar et al., 2005) and by the projected climate change scenarios for the region (Magrin et al., 2007). A high level of fragmentation among small, family-owned agricultural plots is an obstacle for existing conservation incentive mechanisms such as Costa Rica's Payment for Environmental Services scheme (given high transaction costs and high opportunity costs of devoting land to the payment scheme on relatively small plots) (Pagiola, 2008). Downstream, hydropower dams of the Administrative Board of Electric Service of Cartago (JASEC) and of the National Electric Institute (ICE) suffer the off-site effects of upstream erosion. Over one million US dollars are spent each year to flush and dredge sediments out of these dams (Bernard et al., 2009). This situation is a national concern given that (i) the Reventazon watershed is the most important site for hydropower production in the country; (ii) dams provide more than seventy per cent of electricity generated in Costa Rica; and (iii) the emphasis on increasing hydropower production in the current national energy strategy (ICE, 2007).

4. Methods

4.1. *Defining network boundaries*

A first step was to define boundaries for the governance network relevant for shaping soil retention efforts in the Birris watershed (Knoke, 1990; Wasserman and Faust, 1994), recognizing that governance for ES is the result of interactions of actors from different policy communities (Hodge, 2001; Ostrom, 2007). We identified actors through two parallel and complementary procedures (Jost and Jacob, 2004). First, we reviewed relevant laws and official policies (Penker and Wytrzens, 2008) to identify organizations explicitly mentioned as holding responsibilities relevant for water and ES provision. Second, we complemented this initial list of organizations with suggestions provided by key informants using reputational snowball techniques (Farquharson, 2005).[4]

More specifically, we asked those interviewed to mention organizations (associations, ministries, private companies and NGOs) and the correspondent contact-person engaged in policy communities contributing to setting political agendas, activities and proposals in areas relevant to SRS provision and use.[5] Similar to the pluralistic approach of Cowie and Borrett (2005),[6] and the trialogue model for water governance (Turton et al., 2007),[7] we identified four subsets within the policy communities in this governance system:

(1) Direct users of off-site benefits of SRS (e.g. hydropower dams downstream);
(2) Direct users of on-site benefits of SRS who influence provision of off-site benefits (i.e. farmers, their associations, civil society interested in upstream conservation);
(3) Scientists providing information on technical aspects of SRS provision (role of forests, soil, agriculture and climate on soil erosion) and those involved in the dissemination of scientific findings; and,
(4) Regulators providing policy guidelines relevant for the management of watershed and SRS.

[4] Those interviewed were asked to indicate organizations that they considered to be influential for each policy community and scale in issues such as soil conservation, climate change-related science, land planning, watershed conservation and hydropower production.

[5] Each organization or its sub-units are represented in the network by the individual that was mentioned in the snowball exercise.

[6] Cowie and Borrett (2005) point out potential stakeholders to involve in the design of collective actions for watershed management planning including rules-makers (e.g. government agencies), actors directly linked to benefits or costs of decisions (i.e. providers and users of SRS) and parties with technical knowledge (e.g. scientists and technical agencies).

[7] These authors identify government (rule makers), scientists and civil society (actors directly and indirectly affected by ES management decisions) as three important pillars of water governance.

Because individual respondents at one scale within an organization may not acknowledge all interactions of all departments of an organization (Brinkerhoff, 1996), we consider sub-units of such organizations (e.g. departments) as separate actors.[8] Thus, we identified the organizations concerned with administration, information collection and dissemination, policy formulation, advocacy and selection of alternatives to respond to erosion control problems (Knoke, 1990).

4.2. *Organizations across scales in the SRS governance network*

Based on the information provided by key informants and the analysis of policy documents we identified 42 organizations within the network (i.e. the constellation of actors). In this section, we review their main functions and interests in relation to the governance of soil regulation services, relying on their acronyms for brevity, since their full Spanish names may not be informative for many readers. A complete summary of the extended names of these organizations, their mandates and regulatory framework is provided in Appendix 1.

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Linking the *international with the national scale*, actors such as *IICA* and *CRRH* disseminate information on climate or agriculture-related agreements[9] that influence benefits and costs of policies dealing with ES-related land uses in the country by providing inputs to design laws, research programs and mechanisms to promote SRS conservation. Similarly, a civil society organization such as *UICN* (for the acronym in Spanish IUCN) organizes and participates in national and international awareness-raising initiatives regarding climate change and the importance of ecosystems in adaptation policies.

At the *national scale*, we find organizations *regulating and providing incentives* for water resources and watershed management, such as *FONAFIFO*, *ARESEP* and *Aguas-MINAE*. These types of organizations establish rules that affect the extent and economic benefits of SRS provision to hydropower production while regulating water use fees (environmental tariffs) for public service provision. In the science policy area, we have organizations such as *IMN* (*IMN-IMN-Direccion*, *IMN-Tecnicos*), *CIA-UCR*, *PROGAI-UCR*, *CADETI* and *INTA-ST* (and its watershed initiative *INTA-Planton*) dedicated to preparing *scientific studies* on the expected and observed impacts of climate change, and on best practices for SRS. Scientific information is mainstreamed to national policies through governmental initiatives such as *IPN* and *ENCC* which promote strategic partnerships for both mitigation and adaptation actions. Other organizations such as *CNE*, the Ministry of Agriculture (through its watershed decentralized office *MAG-Regional* and the Birris watershed agriculture extension office *ASA-Pacayas*) and the national service controlling water concessions (through its decentralized office *SENARA-Regional*) use scientific information to define land use policies promoting SRS provision through land use management regulations in accordance with technical standards. We also find *government agencies* such as *IMAS* (through its decentralized office *IMAS-Regional*), *CNP*, and *IDA-Nacional* and its decentralized office *IDA-Regional* that support programs to improve farmers' well-being and reduce their vulnerability to markets and to climate extremes through training, dissemination of technical information and by promoting partnerships of farmers' associations (thus improving their land management practices). In this respect, both *CIA* and *CNP* (through its decentralized *CNP-Regional* and *CNP-Subregional*) support farmers by ensuring (i) adequate technical assistance for complying with national soil conservation standards and (ii) their access to agricultural markets, respectively. On the *provision side of* SRS, we also find the National system of protected areas SINAC which (through its dependencies *ACCVC-Cartago*, *SINAC-ACCVC*, *SINAC-Central*) regulates and enforce activities that can be undertaken near protected areas such as the upper part of the Birris watershed. On the *demand side of SRS*, the hydropower company *ICE* (and its various offices *ICE-Ambiente*, *-PISA*, *-Electricidad*, *-CENPE* and *-Produccion*) has an interest in and promotes (through its decentralized *UMCRE*) watershed management in its priority watersheds (such as the Birris in the Reventazon watershed) thus facilitating and supporting partnerships with other actors sharing interests in controlling erosion.

At the *watershed scale*, we find organizations such as the watershed committee *COMCURE* empowered by a national decree to establish participatory and decentralized actions to conserve priority catchments. In downstream location of the Birris watershed, JASEC (and its departments *JASEC-Proyectos*, *-Gerencia* and *-Produccion*) are interested in the soil conservation efforts having hydropower facilities receiving the direct benefits of soil conservation from the Birris watershed. At upstream locations, under the recent decentralization efforts of the national government, the local municipality (*MUNI*) is mandated to regulate land management. In upstream *local areas*, farmers' associations, representing small to medium producers (*ADICO*, *ADAPEX* and *COOPEBAIRES*), share common goals of improving productive capacities and marketing of agricultural products as well as exchanging information on alternative technologies relevant for SRS. In sum, the large number of organizations in Table 1 and the intricately linked mandates suggest that the Birris watershed is not lacking in institutional structures for encouraging SRS. Yet, the capacities of these organizations to act, and their relative influence, differ greatly, as will be seen in subsequent sections (see also the extended mandates and policy reference in Appendix 1).

4.3. *Network survey*

The survey instrument was informed by questions and approaches from previous literature (Knoke, 1990; Weible

[8] Following the language used by interviewees, we added the suffix ''regional'' to these departments and sub-units.

[9] United Nation Framework Convention on Climate Change or the US-Central America Agreement on Free Trade (CAFTA; with a strong agricultural component).

Table 1 – Network structural parameters for governance organizations by their scales and policy area.

Scale	Policy area[a]	Organization	*BC*	*Pi*	*Pc*	*In*	*Out*	*SHI*	*AHI*	Function
International to National	S	CRRH	12.9	3.3	2.9	6	2	16.7	50.0	Disseminator of results from research on climate and hydrology
	S	IICA	5.5	2.6	2.5	6	1	20	80.0	Dissemination and advocacy on sustainable agriculture
	S	UICN	.6	2.6	2.8	1	4	0	33.3	Disseminator of information on climate change impacts and ES management
National	S	IMN Técnicos	52.2	3.3	2.8	11	7	23.1	61.5	National meteorological producer/communicator of technical information on weather and climate
	D	ICE Ambiente	47.4	3.2	2.7	5	15	44	76.0	National electric utility corporate environmental department
	S	CNE	39.2	3.3	2.8	8	5	57.1	81.0	National policy advocate and facilitator for disaster prevention
	D	ICE Electricidad	37.1	3.4	3.1	2	16	34.8	69.6	National electrical system production planning and implementation
	R	SINAC Central	31.4	3.4	2.5	6	10	35	65.0	National regulator for natural parks
	S	PROGAI-UCR	31.3	2.8	2.7	9	5	45.5	72.7	University producer/disseminator of scientific results on land use impact on water and soil
	S	IMN Direccion	31	3.4	2.8	9	4	25	66.7	National meteorological disseminator of scientific information on climate change
	S	ENCC	27.4	3.1	2.5	9	5	21.4	42.9	Disseminator and user of climate information for the national mitigation and adaptation strategy
	R	Aguas MINAE	24.4	3.4	2.7	9	3	33.3	53.3	National water regulator
	S	INTA ST	23.2	3.1	2.7	3	9	23.5	58.8	National level designer and implementer of research on SRS
	P	IDA Nacional	20.1	3.1	2.3	9	3	44.4	66.7	National implementer agricultural policies
	R	FONAFIFO	15.5	3.4	3.2	9	2	30	50.0	National Regulator and provider of incentives for ecosystem services
	S	IPN	13.9	2.8	2.1	9	2	0	66.7	Disseminator of scientific information on climate change and land use planning
	D	ICE CENPE	7.6	3.3	3	5	5	11.1	66.7	National electrical system generation planning and expansion
	R	ARESEP Energía	6.8	3.3	2.5	7	1	50	50.0	Regulation of tariffs for use of water for public uses (e.g. hydro-energy production)
	D	ICE Pisa	6.8	3.1	2.8	3	6	35.7	50.0	National electrical system planning and implementation of investment for infra-structure
	R	CIA	5.8	2.6	2.3	3	5	18.2	90.9	Regulation of private technical assistance
	S	CADETI	3.7	3.5	2.5	0	6	11.1	44.4	Design and implementation of research on SRS and diffusion of results
	D	ICE Production	2.5	3.5	3.3	3	2	44.4	22.2	National electrical system manager of power production
	S	CIA-UCR	2	2.1	2.3	2	3	50	25.0	University-based producer and disseminator of SRS-relevant research findings
Watershed	S	ASA Pacayas	38	3.3	2.8	2	9	46.2	84.6	Watershed agricultural extension office
	P	MAG Regional	29.8	3.6	3.1	4	7	50	86.4	Implementer of national guidelines regarding services to farmers
	R	ACCVC-Cartago	28.2	2.7	2.5	5	8	52.9	88.2	Implementer and enforcer of regulations on national parks
	S	INTA Planton	27.2	2.7	2.4	7	6	62.5	62.5	Watershed level designer. Implementer and disseminator of research on SRS
	P	CNP Regional	18.1	2.7	2.1	6	3	50	66.7	Regional source of technical assistance and credit to agricultural producers
	R	SENARA Regional	17.3	3.2	2.5	5	7	52.4	85.7	Designer and implementer of research on water resources
	P	IDA Regional	16.6	2.9	2.7	2	6	52.9	64.7	Regional implementation of guidelines on technical assistance and inputs to producers
	D	JASEC-Proyectos	16.6	3.2	2.9	6	6	57.1	78.6	Regional utility environmental planner and implementer of SRS initiatives in the watershed
	P	CNP-Subregional	13.9	2.1	1.9	2	4	30	50.0	Regional implementer of CNP national guidelines for Cartago province
	D	JASEC-Gerencia	13.5	3.2	2.8	5	5	66.7	44.4	Local utility generation planner
	D	UMCRE	13.3	3.3	3.2	4	6	52.6	68.4	Planning and implementation of watershed management for electricity production
	D	COMCURE	10	3.3	2.9	10	1	25	50.0	Official watershed stakeholder committee for Implementation of watershed management plan

	P	IMAS-Regional	7.1	2.8	2.8	3	2	33.3	55.6	Planning of environmental-friendly poverty-reduction activities for producers
	D	JASEC-Producción	5.7	2.6	2.6	1	7	70	40.0	Regional utility generation manager for electricity infrastructure and production
	R	SINAC-ACCVC	3.8	3.1	2.4	3	5	76.5	64.7	National designer and implementer of guidelines on land use for protected areas
Local	R	MUNI	13.8	3.1	2.3	5	6	92.3	76.9	National and regional regulator and administrator of local land use planning
	P	ADAPEX	6	2.2	2.9	5	0	0	0	Implementation of environmental-friendly practices among agricultural producers
	P	ADICO	5.1	1.7	2.5	1	4	66.7	33.3	Technical assistance and credits for producers
	P	COOPEBAIRES	4.6	2.3	2.4	4	1	66.7	66.7	Technical assistance and credit to producers

[a] N–I, National to International; N, National; W, watershed; L, Local; R, Regulation; S, Science; D, demand; P, Provision.

and Sabatier, 2005), and pre-tested to insure its utility for the research design. The survey was implemented by a team of researchers who made appointments and completed interviews with all the 42 organizations that were part of the network (the list of organizations is provided in Table 1). We interviewed the key representative of each organization who had been identified during the snowball-based key-informant interviews. The survey was conducted as an in-person interview, in which we asked participants questions about their organization's mandates in respect to SRS management (see Appendix 1). We also asked each respondent to fill out a network questionnaire that provided a list of all the organizations within the boundary of the network, to every respondent. Specifically, each interviewee was asked to indicate how their organization related to other organizations, as shown in the following questions:

a. *Please check the corresponding box beside those organizations from which you receive information useful for your duties and functions in your own organization (i.e. yes or no)*[10]
b. *Please check the corresponding box beside those organizations to which you give information produced by your own organization (i.e. yes or no)*
c. *On a scale from one to four please rate how influential*[11] *you perceive each of the organizations in the list to be (where no check is no opinion, 1 is very low influence and 4 is the highest perceived influence)*
d. *On a scale from one to four please rate how competent*[12] *you perceive each of the organizations in the list to be (where no check is no opinion, 1 is very low competence and 4 is the highest perceived competence)*

4.4. *Network analysis*

The network data were organized in a symmetrical matrix (i.e. an adjacency matrix) in which all organizations (i.e. the network's nodes) are listed in the first column and in the top row. More specifically, responses to network questions (a) and

[10] The term ''useful information'' was explained to interviewees in reference to ''information that given the mandate of the organization can be used to comply with its goals''. For example, in the case of the extension office it refers to information that they can use to promote soil sustainable management as (i) regulations for soil management provided by the Ministry of Agriculture, (ii) technologies designed and research evidence that can be transmitted to motivate farmers' adoption. For farmers, useful information refers to information that helps them in tasks associated to agricultural production including the management of soil fertility.

[11] In framing the question we introduced respondents to the definition of ''influence'' in the context of policy network analysis for natural resources management (Weible, 2005), namely: ''the ability that another organization to affect your organization behavior for example by controlling resources (e.g. information, ability to make decisions, etc.) skillfully and willfully''.

[12] Here, we introduced respondents to the definition of competence as defined in managerial science literature where it is referred to as an organization's perceived ability to perform a given task to the expected standard (Chi-Cui et al., 2002). This is especially relevant in promoting trust and cooperative behavior in multi-organizations' networks.

(b) above were converted into binary data (Yes = 1, No = 0). These were organized in an adjacency matrix which presents the response assigned by each actor (in the rows of the first column) about its relation to the others listed in the first row of all columns with the same sequence (Hanneman and Riddle, 2005). For our study, each relation was analyzed through its specific matrix, although combinations of relations can be visualized in a single graph. To analyze the matrices we used UCINET (Borgatti et al., 2002). We first confirmed information flows by checking whether a stated outward information flow is confirmed as an inward information flow by the receiver. Then, we used network algorithms for structural analysis of overall network characteristics such as density (defined by the total number of existing ties out of all possible ties) and *Betweenness Centrality* among the actors (Freeman, 1977). Density, defined as a measure of group cohesion, is "the average of the standardized actor degree index as well as a fraction of the network ties for a given relation and ranges from 0 (no ties) to 1 (all actors inter-linked to each other)" (Wasserman and Faust, 1994, p. 181). *Betweenness Centrality* measures the bridging position of an actor and is determined by an actor's position with respect to two others (i.e. the minimum required for defining bridging positions) (Knoke, 1990). Following Wasserman and Faust (1994), this position measure of an actor is formally defined by: $C_B(n_i) = \sum_{j<k}(g_{jk}(n_i))/(g_{jk})$, where $C_B(n_i)$ is the Betweenness Centrality of actor i, and g_{jk} represents the number of geodesics linking actor *j* with actor *k*. Then $g_{jk}(n_i)$ is the number of geodesics between these two actors that passes through actor *i*. This measure implicitly assumes that links (i.e. information paths) have equal weight (i.e. probability to be chosen), and that communications will travel along the shortest route (regardless of the actors along the route), as a basis for its centrality assertion. This index is then a sum of probabilities with a minimum of 0 (if the actor falls on no geodesics) and maximum given by the number of pairs of actors (not including n_i) reached when *i* falls on all geodesics (Wasserman and Faust, 1994). Finally, we analyze the mean perceived influence (*Pi*) and perceived competence (*Pc*) attributed to each actor by the others in the network. We calculated a simple indicator to measure the number of linkages going from one organization to another as proxy-measures of activities to disseminate information to other actors in the network. To extend the analysis, we introduced two indicators to measure the degree to which a node n_i with a high bridging capacity, in terms of a prominent role in informing others (i.e. rather than being a receiver) and high bridging across scales (i.e. beyond its scale of operations) and policy area (i.e. beyond its policy area). We created two new indicators for these respective functions: the *Scale Heterogeneity Index* (*SHI*) and the *Area Heterogeneity Index* (*AHI*). These are defined as:

$$SHI_i = \frac{\sum_1^n t_i^{OthSc}}{\sum_{i=1}^n t_i} \quad \text{and} \quad AHI_i = \frac{\sum_1^n t_i^{OthPol}}{\sum_{i=1}^n t_i},$$

where t_i^{OthSc} and t_i^{OthPol} measure the number of ties to other scales and policy areas, expressed in the indices as a proportion of the total number of ties t_i of actor *i*. Finally, we used NetDraw[13] to display nodes, relations, and network parameters.

[13] Available at: http://www.analytictech.com/Netdraw/netdraw.htm.

5. Results

In this section we present the overall as well as node-specific structural parameters of the network highlighting the key organizations that are of special relevance given their scores in *BC*, *Pi* or *Pc* parameters and/or are of special relevance given their importance in the direct provision of soil regulation services such as farmers' associations.

Considering that a density of ties equal to one represents full connections of all nodes (Wasserman and Faust, 1994), the overall density of our network is low (*D* = .12), in that that the 42 organizations show only 214 linkages compared to a possible 1722 linkages. Table 1 provides results in terms of the calculated network parameters of organizations, ordered by scale of operation and their values of *Betweenness Centrality* (Table 1).

As shown in Table 2, the vector measuring *Perceived Influence* (Pi_{max} = 3.6; Pi_{min} = 1.7; $Pi_{average}$ = 2.9; Pi_{median} = 3.1) correlates with vectors measuring *Perceived Competence* and *Betweenness Centrality*, suggesting that bridging positions in the network might be associated with persuasive power and reputation. The Pearson's correlation analysis shows that the capacity to bridge across scales and policy areas (as measured by *SHI* and *AHI*) indicates that *Betweenness Centrality* is significantly and positively correlated to organization capacity to span across cross-policy area. The Scale Heterogeneity Indicator (*SHI*) does not correlate to any of the other network parameters (Table 2).

The visualization of the whole network structure (Fig. 1) shows the intricate web of information-exchange linkages across scales and policy communities as well as the bridging capacity of different actors, shown in proportion to node size. The size of each node reflects its *Betweenness Centrality* score, which measures its linking power. Note that the quadrant in which change in farm practices could be accomplished is at the origin, where local providers of SRS are found. The network extends like a corona around the origin, yet, only a few nodes link directly into the organizations near the origin.

At the local level, the majority of organizations belong to the SRS-provision policy area and are directly involved in promotion of agricultural production activities in support to farmers (*ADICO*, *ADAPEX*, *COOPEBAIRES*) except for the local Municipality (*Muni*) which is involved in SRS-Regulation policy area. This last tops the list of most bridging organization also

Table 2 – Correlation among governance network parameters regarding organizations' Perceived Influence (*Pi*), Perceived Competence (*Pc*), Betweenness Centrality (*BC*), percentage of contacts with organizations at other scales (*SHI*) and policy areas (*AHI*) (*n* = 42).

	Pi	Pc	BC	SHI
Pc	.542**	–		
BC	.402**	.136	–	
SHI	−.062	−.134	.045	–
AHI	.314*	−.127	.478**	.252

* Correlation is significant at the .05 level (2-tailed).
** Correlation is significant at the .01 level (2-tailed).

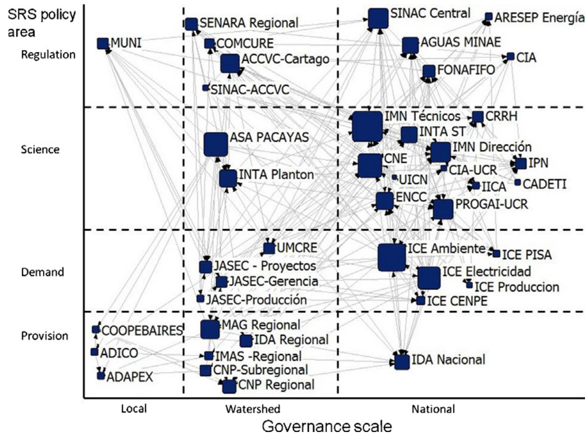

Fig. 1 – Structure of the information network showing the actors (node) in quadrants by scale (*x*) and policy areas (*y*), the confirmed information flows (arrowed links) and its Betweenness Centrality (size).

reflecting its active role in land use planning which include, among other duties, running land tenure census and provision of land use change permissions based on land information provided by technical agencies. The local municipality presents low information bridging values but shows the highest cross-scale information exchange activity (*SHI*) across the network probably due to the notable presence of national and watershed level organizations that are involved in highly productive agricultural areas of the country. Actors such as private providers of agricultural inputs and farmers' associations (*COOPEBAIRES*, *ADICO*, *ADAPEX*) show very small *Betweenness Centrality* values. Our analysis regarding perceptions of influence and competence of farmers' associations (i.e. represented by *COOPEBAIRES*, *ADICO*, *ADAPEX*, *CNP-Regional*, *CNP-Subregional*) reveals which organizations are of special importance in the network, in that their dissemination of information to producers might affect their decisions on soil management practices and SRS provision. Results of this analysis reveal that a limited number of nodes located mainly at the watershed scale and directly related to support for agricultural production are those who receive the highest ratings in terms of both indicators *Pi* and *Pc*, the prominent organizations being the sub-National offices of the Ministry of Agriculture (*MAG-Regional* from which *ASA-Pacayas* depends[14]) and the Institute for Agricultural Development (*IDA-Regional*).

At the watershed scale, we find an even presence of organizations belonging to SRS-demand and SRS-provision while very few belonging to the regulatory and science policy areas. Here, sub-units of SRS-use organizations such as *JASEC* and *ICE*, exchange information among themselves and with initiatives and organizations such as *INTA-Planton*, *MAG-Regional* and *ASA-Pacayas* which are focusing on design and dissemination of SRS science. The regional agricultural extension office *ASA-Pacayas* is the only watershed organization represented in the top ten *betweenness centrality* values (all the others correspond to National organizations). Moreover, this organization presents also among the highest values regarding *Perceived Influence* and *Perceived Competence* and those measuring cross-policy area information exchange (*AHI*) (i.e. ranking forth among fifteen organizations at the watershed scale and fifth among all the forty-two organizations in the network). The Reventazon watershed committee *COMCURE* shows low information-bridging activity and relatively low and medium values to cross-scale (*SHI*) and cross-policy area (*AHI*) information exchange indicators respectively.

At the national scale, the most prominent represented policy area is that of science including organizations researching and disseminating results on climate change and its potential impacts on agriculture and soil erosion measurement and control. Many of these have relatively low values of exchange of information cross-scales (*SHI*, where only *INTA-Planton* and *CNE* are among top ten organizations) and policy areas (*AHI*, where *ASA-Pacayas*, *CNE* and *IICA* are among top ten organizations). Organizations belonging to SRS-regulation and demand are evenly represented at this scale. These include those addressing regulations for the agricultural sectors such as the Ministry of Agriculture (*MAG*) as well as the energy sector such as *ARESEP-energia* whom, based on technical information,[15] influences the possibility to allow permissions to include environmental tariffs in the electric bill. At this scale, we find an organization, the National Meteorological Institute (*IMN-Tecnicos*), with the largest *Betweenness Centrality* (*BC*) value of the network; it apparently concentrates its exchange of information to the national level, as indicated by low indicator of information exchange across scales (*SHI*). Similarly, *ICE-Ambiente* and the National Emergency Committee (*CNE*) (at the top of the *BC* values) show strong activities to exchange information across scales (*SHI*) and policy areas (*AHI*). Indeed, these organizations connect to users of SRS at national and watershed scales (e.g. *ICE-Pisa* and *JASEC* respectively), as well as at level of scientific (i.e. national *INTA* researching on soil conservation alternatives) and SRS-provision organizations (e.g. MAG-Regional) as well as local municipality. Finally, among actors bridging information from the international to the national level we only find science-related organization such as *IICA*, *CRRH* and *IUCN* whom show low *Betweenness Centrality AHI* and *SHI* values but relatively high *Perceived Influence* and *Competence* values.

6. Discussion

A quantitative network analysis allowed us to identify key bridging organizations that help communicate information across scales and policy areas for the design and implementation of responses to SRS degradation. The following discussion is structured to reflect the analysis of information flow across scales and policy areas for SRS governance in Costa Rica.

[14] It is worth noting that MAG-Regional also shows the second largest *BC* values at the watershed scale.

[15] A close analysis to the case of environmental tariffs reveals that in order for ARESEP-Energy to allow inclusion of environmental tariff in the electric bill they need technical information that justify that watershed conservation investments are actually production costs incurred by the hydropower company. This requires scientific evidence that watershed investment incurred is returned in reduced costs of sediment management in their dams.

6.1. *Cross-scale governance network for SRS management*

6.1.1. *National scale*

Although national policies should provide an enabling institutional environment for ES governance (Adger et al., 2005a; Duit and Galaz, 2008), a complex legal framework influences collaborative efforts among organizations in support of SRS provision in Costa Rica (Segura, 2004; Miranda et al., 2006). Along with (and in spite of) this complex legal context, organizations exchange information in the network in order to design and implement a wide variety of collective efforts. For example, the position of *IMN-Tecnicos* (the most central among the list of National organizations) reflects its past and current involvement in efforts such as (i) the implementation of water-related adaptation projects requiring exchange of information and collaboration with national (*IMN*, *ICE* and *MINAE*) and local organizations, (ii) collection, analysis and dissemination of climate data relevant for understanding climate change impacts on national natural resources (Brooke, 2002), or (iii) the exchange and analysis of information proceeding from different organizations to communicate to the United Nations Framework Convention on Climate Change about national contexts for mitigation and adaptation (IMN, 2010). Similarly, the relevance of National Emergency Commission (*CNE*) (also topping the list of National organizations) indicates its strong activity to communicate with a variety of stakeholders that are involved in regulation, science and actual implementation of SRS conservation in landscapes as well as involvement in local committees mandated to promote activities to reduce vulnerability to extreme events.

6.1.2. *Watershed scale*

Organizations operating at the watershed scale are particularly relevant given their role to bridge information and knowledge across scale. It is at this level that potential bottlenecks may potentially inhibit coordinated efforts to maintain SRS as observed in the evaluation of performances of several watershed-level partnerships in addressing environmental degradation problems (Leach et al., 2002). In that vein, more institutional efforts could be devoted to enhancing the role of the watershed committee *COMCURE* to mediate across scales and sectors given that evidence from literature indicate that its intended role supported by formal National policy decisions is not corresponded by adequate human and financial resources (Diaz et al., 2011). The agricultural extension office *ASA-Pacayas* (topping the list of bridging organizations at this scale) plays a strategic role in the governance network given its scope of action at the intermediate geographic scale of the watershed, and its position at the interface between scientific communities and farmers' agricultural production contexts. Evidence from our field visits with the technical staff of *ASA-Pacayas* suggests that they are involved in different activities that highlight this strategic role such as (i) supporting interchange of information among farmers and soil-management experts (from National universities and technical research offices of the Ministry of Agriculture) on soil erosion and on the establishment of field trials for different soil management practices, and (ii) promoting and/or participating in group discussions on erosion control and agricultural production strategies among farmers and downstream hydropower companies to identify soil management measures to reduce erosion and strategies to promote their adoption (e.g. providing technological inputs, financial incentives, technical assistance, etc.). Thus, actors such as *JASEC* and *ICE* promote initiatives for planning and implementing responses to SRS degradation through their production departments but require information on where priorities are, what solutions are feasible technically and socially (i.e. by ensuring adoption by farmers). In this respect, these actors' collaborations with the *ASA-Pacayas*[16] agricultural extension office help supporting the dissemination of innovative soil conservation practices and support the recollection of information from field experiments to estimate how much these practices can actually reduce (i) erosion from upstream areas, and (ii) the sediment management costs faced by downstream hydropower managers.

6.1.3. *Local scale*

At the local level, farmers' decisions are concerned with agricultural production issues (including soil erosion control) and are also shaped by the information they receive from associations and organizations that support their production activities (Vignola et al., 2010). Their process of searching information regarding technological alternatives to reduce SRS degradation pass through organizations whose scope of action is closer to their locations such as many watershed-scale organizations. Interviews with these organizations revealed that they receive support by extension agents together with decentralized State (e.g. *SENARA-Regional*, *MAG-Regional*, *IDA-Regional*) and non-State agencies (*CNP-Regional* and *CNP-Subregional*) dedicated to support agricultural production (i.e. through credits, technical assistance, identification of erosion control practices, etc.). They also revealed that they face significant transaction costs given weaknesses at the level of coordination among actors' objectives and operations[17] as well as at the level of regulations which in

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[16] *ASA-Pacayas* bridging role in the adaptive management cycle of erosion control consist also in (i) participating in soil management projects such as those funded by hydropower companies in the watershed (i.e. *ICE* and *JASEC*) to promote practices to recycle organic matter from livestock to produce energy and manure for soil fertility management (jasec.co.cr/ambiente/biogestores.html), and (ii) research on effectiveness and adoption of soil management practices by farmers funded by international and national collaborations including organizations from hydropower and agricultural sector (http://www.mag.go.cr/bibliotecavirtual/a00167.pdf).

[17] Interviewed representatives from farmers' associations suggested that farmers' productive activities are supported by many different organizations focusing on different component of the production system (i.e. land use zoning, credit, marketing, technical assistance on soil management and environmental education). They highlight that the lack of a coordinated systemic approach among these efforts produces contrasting results. A specific example they mentioned is related to land use zoning efforts that provide information on what crops and what land management would be most appropriate for a specific geographic area to reduce soil degradation. However, efforts in targeting credit for specific crops and practices are delinked from this information. As a result, farmers in high erosion-risk zones might receive financial support from credit organizations for crops or land management practices that should not be promoted in those sensitive areas.

some cases are not applied (e.g. the Soil Conservation Law)[18] or non-existing.[19]

6.2. *Implications of an analysis by policy areas for SRS governance*

The four policy areas of SRS-management are characterized by organizations that belong to either knowledge or action communities among whom information need to be exchanged in order to address the complex environmental degradation problems (Cash et al., 2003). More specifically to our case regarding SRS-management, the former is composed by organizations producing scientific and regulatory information while those in the action communities are more closely linked to decisions that directly affect the provision or use of soil regulation services. Our results show that regulatory and scientific organizations are little represented at sub-national scales (i.e. watershed and local), in contrast to actors directly involved in SRS demand and supply. Thus, scientific and regulatory organizations require the bridging capacity of organizations such as *ASA-Pacayas* at the intermediate scale of the watershed to provide them information, gathered from field visits to farmers, useful to create or adjust norms on soil management or design new research to identify soil management feasible solution. Similarly, farmers also require this bridging capacity to transfer information on rules, incentives and technical solutions to improve their soil management practices.

In this respect, the relatively high values of perceived influence and competence of *ASA-Pacayas* show that network actors from different policy communities and scales acknowledge its information-sharing potential.[20] *ASA-Pacayas* plays an important bridging role in (i) communicating research across scales, which might be relevant in the flow of scientific information at the different stages of detection of the erosion problem, its remediation and evaluation of response measures over time (Vogel et al., 2007), (ii) translating messages into appropriate languages for actors belonging to different policy communities, and (iii) mediating among the different interests characterizing them. This result is in accord with the findings of Cash (2001), whom outlined the key role of agricultural extension organizations in the US to transmit knowledge and information across scales and policy areas (Cash, 2001). The results also support the findings of Mahanty (2002), who shows that intermediary positions (between the state and villagers in India) are crucial in building trust to facilitate conservation interventions. Similarly, other studies (Ayensu et al., 1999; Joyce, 2003) found that the bridging role of extension offices has the potential to inform the identification of new research and monitoring needs concerning the complex degradation of ES under climate change.

Finally, we can highlight two important limitations of this study, which point to gaps to be addressed in further research on network governance for adaptation to climate change. The first limitation concerns the type of relationships addressed in this network analysis. Although information spanning across scales and policy areas is essential for collective action to adapt to climate change (Adger et al., 2005b), many type of other tangible (e.g. financial and physical inputs) and intangible (e.g. moral support, advocacy, mutual trust, knowledge generation, etc.) resources are exchanged in social networks (Adger, 2003). Research on the flow of these resources along with information exchanges could inform a better design of collective action for adaptation to climate change by accounting for intangible resources which, though often overlooked, motivate many interactions among actors. The second limitation concerns the static perspective on the network structure. Information-exchange among organizations is subject to change over time along with changes in the institutional and resource-context of a specific country. Change in economic policy decisions can significantly change the institutional enabling conditions and resources available to network organizations for producing, disseminating and using information to respond to global environmental change. More specifically, Eakin and Lemos (2006) document how the governance capacity of Latin American countries (i.e. to face global environmental degradation issues through institutional frameworks that enhance information flow among organizations) has been substantially affected by economic policies of the past decades in which public resources supporting agricultural extension services were significantly reduced (Leclerc and Hall, 2007).

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References

Adger, W.N., 2003. Social capital, collective action, and adaptation to climate change. Economic Geography 79 (4) 387–404.

[18] For example, this law provides for the creation of local soil conservation commissions which are currently inexistent.

[19] One of these organizations mentioned that although they cooperate with the Ministry of Agriculture (MAG) in promoting sustainable potato production through certified products, there are no formal rules defined by MAG in this respect.

[20] A similar use of *Betweenness Centrality* can be found in the analysis of Leydesdorff (2007) on the knowledge-sharing potential of scientific journals where high *BC* values indicated journals with strong trandisciplinary contents (i.e. able to transmit, translate knowledge from different academic fields).

Adger, W.N., Brown, K., Tompkins, E.L., 2005a. The political economy of cross-scale networks in resource co-management. Ecology and Society 10 (2) .

Adger, W.N., Arnell, N.W., Tompkins, E.L., 2005b. Successful adaptation to climate change across scales. Global Environmental Change 15, 77–86.

Agrawala, S., Broad, K., Guston, D.H., 2001. Integrating climate forecasts and societal decision making: challenges to an emergent boundary organization. Science, Technology, & Human Values 26 (4) 454–477.

Aguilar, E.T., Peterson, C., Ramırez, P., Frutos, R., Retana, J.A., Solera, M., Soley, J., Gonzalez Garcıa, I., Araujo, R.M., Rosa Santos, A., Valle, V.E., Brunet, M., Aguilar, L., Alvarez, L., Bautista, M., Castañonp, C., Herrera, L., Ruano, E., Sinay, J.J., Sanchez, E., Hernandez Oviedo, G.I., Obed, F., Salgado, J.E., Vazquez, J.L., Baca, M., Gutierrez, M., Centella, C., Espinosa, J., Martınez, D., Olmedo, B., Ojeda Espinoza, C.E., Nuñez, R., Haylock, M., Benavides, H., Mayorga, R., 2005. Changes in precipitation and temperature extremes in Central America and northern South America 1961–2003. Journal of Geophysical Research 110, D23107.

Ayensu, E., Van, R., Claasen, D., Collins, M., Dearing, A., Fresco, L., Gadgil, M., Gitay, H., Glaser, G., Juma, C., Krebs, J., Lenton, R., Lubchenco, J., McNeely, J.A., Mooney, H.A., Pinstrup-Anderson, P., Ramos, M., Raven, P., Reid, W.V., Samper, C., Sarukhas, J., Schei, P., Tundisi, J.G., Watson, R.T., Guanhua, X., Zakri, A.H., 1999. International ecosystem assessment. Science 286, 685–686.

Bernard, F., de Groot, R.S., Campos, J.J., 2009. Valuation of tropical forest services and mechanisms to finance their conservation and sustainable use: a case study of Tapanti National Park, Costa Rica. Forest Policy and Economics 11, 174–183.

Bodin, O., Crona, B.I., 2009. The role of social networks in natural resource governance: why relational patterns make a difference. Global Environmental Change 19, 366–374.

Borgatti, S.P., Everett, M.G., 1992. Notions of position in social network analysis. Sociological Methodology 22, 1–35.

Borgatti, S.P., Everett, M.G., Freeman, L.C., 2002. Ucinet for Windows: Software for Social Network Analysis. Analytic Technologies, Harvard, MA.

Borgatti, S., 2009. Network analysis in the social sciences. Science 323, 892–895.

Brass, D.J., Galaskiewicz, J., Greve, H.R., Tsai, W., 2004. Taking stock of networks and organizations: a multivelel perspective. Academy of Management Journal 24 (6) 795–817.

Brinkerhoff, D.W., 1996. Coordination issues in policy implementation networks: an illustration from Madagascar's Environmental Action Plan. World Development 24 (9) 1497–1510.

Brooke, C., 2002. Climate change, vulnerability and conservation in Costa Rica: an investigation of impacts, adaptive environmental management and national adaptation networks. PhD Thesis. School of Geography and the Environment, Oriel College, Oxford University, Oxford, UK.

Brown, L.D., 1991. Bridging organizations and sustainable development. Human Relations 44 (August (8)) 807–831.

Burt, R.S., 2005. Brokerage and Closure: An Introduction to Social Capital. Oxford University Press, UK, 279 pp.

Carlsson, L., Sandstrom, A., 2008. Network governance of the commons. International Journal of the Commons 2 (1) 33–54.

Cash, D.W., Moser, S.C., 2000. Linking global and local scales: designing dynamic assessment and management processes. Global Environmental Change 10, 109–120.

Cash, D.W., 2001. In order to aid in diffusing useful and practical information: agricultural extension and boundary organizations. Science, Technology and Human Values 26 (4) 431–453.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jager, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Science of the United States of America 100 (14) 8086–8091.

Chi-Cui, A., Ball, D.F., Coyne, J., 2002. Working effectively in strategic alliances through managerial fit between partners: some evidence from Sino-British joint ventures and the implications for R&D professionals. Research and Development Management 32 (4) 343–357.

Cowie, G.M., Borrett, S.R., 2005. Institutional perspectives on participation and information in water management. Environmental Modelling & Software 20, 469–483.

Diaz, A., Locatelli, B., Vignola, R., Prins, K., 2011. Evolución de instituciones adaptativas frente a problemas hidrológicos en dos cuencas de Costa Rica. Revista de Recursos Naturales y Ambiente, CATIE, Costa Rica (59–60), 10–16.

DiMaggio, P.J., Powell, W.W., 1983. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. American Sociological Review 48, 147–160.

Duit, A., Galaz, V., 2008. Governance and complexity: emerging issues for governance theory. Governance: An International Journal of Policy, Administration and Institutions 21 (3) 311–335.

Eakin, H., Lemos, M.C., 2006. Adaptation and the state: Latin America and the challenge of capacity-building under globalization. Global Environmental Change 16, 7–18.

Eastaugh, C., Reyer, C., Gonzalez-Moreno, P., Jian, W., Biscaia, A.G., Pentelkina, O., 2009. Forest Agencies' Early Adaptations to Climate Change. International Union of Forest Research and Organizations (IUFRO) Occasional Paper 23, ISSN 1024-414X.

Farquharson, K., 2005. A different kind of snowball: identifying key policymakers. International Journal of Social Research Methodology 8 (4) 345–353.

Fischlin, A., Midgley, G.F., Price, J.T., Leemans, R., Gopal, B., Turley, C., Rounsevell, M.D.A., Dube, O.P., Tarazona, J., Velichko, A.A., 2007. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Ecosystems, Their Properties, Goods, and Services. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 211–272.

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68, 643–653.

Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social–ecological systems. Annual Review of Environmental Resources 30, 441–473.

Freeman, L.C., 1977. A set of measures of centrality based on betweenness. Sociometry 40 (1) 35–41.

Guo, Z., Xiao, X., Li, D., 2000. An assessment of ecosystem services: water flow and hydroelectric power production. Ecological Applications 10, 925–936.

Guston, D.H., 2001. Boundary organizations in environmental policy and science: an introduction. Science, Technology, & Human Values 26 (4) 399–408.

Hodge, I., 2001. Beyond agri-environmental policy: towards an alternative model of rural environmental governance. Land Use Policy 18, 99–111.

Howlett, M.H., Ramesh, M., 1998. Policy subsystem configurations and policy change: operationalizing the postpositivist analysis of the politics of the policy process. Policy Studies Journal 26 (3) 466–481.

Hanneman, R.A., Riddle, M., 2005. Introduction to Social Network Methods. University of California, Riverside,

Riverside, CA. , Available at:http://faculty.ucr.edu/∼hanneman/.
Huitema, D., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C., Yalcin, R., 2009. Adaptive water governance: assessing the institutional prescriptions of adaptive (co-) management from a governance perspective and defining a research agenda. Ecology and Society 14 (1) , www.ecologyandsociety.org/vol14/iss1/art26/.
Hulme, P.E., 2005. Adapting to climate change: is there scope for ecological management in the face of global threat? Journal of Applied Ecology 42, 784–794.
Instituto Nacional De Estadística y Censo Centroamericano de Población (INEC), 2002. Estimaciones y proyecciones de población 1970–2050. San José, Costa Rica, 112 pp.
Instituto Costaricense de Electricidad (ICE), 2007. Plan de expansión de la generación eléctrica: periodo 2008–2021. San Jose, Costa Rica, 131 pp. Available at: http://www.grupoice.com/esp/ele/planinf/plan_exp.htm.
IUCN, 2008. Ecosystem-based adaptation: an approach for building resilience and reducing risk for local communities and ecosystems. In: A submission by IUCN to the Chair of the AWG-LCA with respect to the Shared Vision and Enhanced Action on Adaptation. UNFCCC.
Jost, F.G., Jacob, K., 2004. The climate change policy network in Germany. European Environment 14, 1–15.
Joyce, L.A., 2003. Improving the flow of scientific information across the interface of forest science and policy. Forest Policy and Economics 5, 339–347.
Knoke, D., 1990. Political networks: the structural perspective. Cambridge University Press, USA, 290 pp.
Koiman, J., 1999. Social–political governance: overview, reflections and design. Public Management 1 (1) 67–92.
Leach, W.D., Pelkey, N.W., Sabatier, P., 2002. Stakeholder partnerships as collaborative policymaking: evaluation criteria applied to watershed management in California and Washington. Journal of Policy Analysis and Management 21, 645–670, http://dx.doi.org/10.1002/pam.1007.
Leclerc, G., Hall, C.A.S., 2007. Making World Development Work: Scientific Alternatives to Neoclassical Economic Theory. UNM press, USA, 645 pp.
Levitt, B., March, J.G., 1988. Organizational learning. Annual Review of Sociology 319–340.
Leydesdorff, L., 2007. Betweenness centrality as an indicator of the interdisciplinarity of scientific journals. Journal of the American Society for Information Science and Technology 58 (9) 1303–1319.
Magrin, G., Gay García, C., Cruz Choque, D., Giménez, J.C., Moreno, A.R., Nagy, G.J., Nobre, C., Villamizar, A., 2007. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Latin America. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 581–615.
Mahanty, S., 2002. Conservation and development interventions as networks: the case of the India ecodevelopment project, Karnataka. World Development 30 (8) 1369–1386.
McDaniels, T.L., Dowlatabadi, H., Stevens, S., 2005. Multiple scales and regulatory gaps in environmental change: the case of salmon aquaculture. Global Environmental Change 15 (1) 9–21.
Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human Well-being: Hydrological Ecosystem Services Report. Island Press, Washington, DC, USA.
Miranda, M., Monge, C., Otoya, M., 2006. Formulacion de políticas para la adaptación del sistema hídrico al cambio climatico. Proyecto Fomento de las Capacidades para la Etapa – II de Adaptación al Cambio Climático en Centroamérica, México y Cuba. PNUD-MINAE-IMN. Centro Internacional de Política Económica de la Universidad Nacional (CIMPE-UNA), San José, Costa Rica, 84 pp.
Ostrom, E., 2007. A diagnostic approach fro going beyond panaceas. Proceedings of the National Academy of Science of the United States of America 104 (39) 15181–15187.
Pagiola, S., 2008. Payments for environmental services in Costa Rica. Ecological Economics 65 (4) 712–724.
Pahl-Wostl, C., Sendzimir, J., Jeffrey, J., Arts, J., Berkamp, G., Cross, K., 2007. Managing change toward adaptive water management through social learning. Ecology and Society 12 (2) art 30.
Pelling, M., High, C., 2005. Understanding adaptation: what can social capital offer assessments of adaptive capacity? Global Environmental Change 15, 308–319.
Penker, M., Wytrzens, H.K., 2008. Evaluating landscape governance: a tool for legal–ecological assessments. In: Hadorn, H.H.,Hoffmann-Riem, H.,Biber-Klemm, S.,Grossenbacher-Mansuy, H.Joye, D., Pohl, C., Wiesmann, U.,Zemp, E. (Eds.), Handbook of Trandisciplinary Research. Springer, The Netherlands, p. 448.
Piattoni, S., 2006. Informal governance in structural policy. Perspectives on European Politics and Society 7 (1) 56–74.
Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267 (5201) 1117–1123.
Raab, J., Kenis, P., 2006. Taking stock of policy networks: do they matter? In: Fischer, F., Miller, G.J., Sidney, M.S. (Eds.), Handbook of Public Policy Analysis: Theory, Methods, and Politics, Number 125 in Public Administration and Public Policy. Taylor & Francis CRC Press, Boca Raton, Florida, USA.
Rotmans, J., Rothman, D.S., 2003. Scaling in Integrated Assessment. Swets and Zeitlinger Publishers, Lisse, The Netherlands355.
Segura, O., 2004. Agenda Ambiental del Agua en Costa Rica. Revista Geografica de America Central 40, 39–50.
Southgate, D., Macke, R., 1989. The downstream benefits of soil conservation in Third World Hydroelectric Watersheds. Land Economics 65 (1) 38–48.
Turton, A.R., Hattingh, H.J., Maree, G.A., Roux, D.J., Claassen, M., Strydom, W.F., 2007. Governance as a Trialogue: Government–Society–Science in Transition. Springer-Verlag, Germany, 354 p.
Uitto, J.L., 1997. Environmental governance and the impending water crisis. Global Environmental Change 7 (2) 167–173.
UNCBD, 2009. Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series No. 41, 126 pp.
Van der Brugge, R., van Raak, R., 2007. Facing the adaptive management challenge; insights from transition management. Ecology and Society 12 (2) art 33.
Van Noordwijk, M., Poulsen, J.G., Ericksen, P.J., 2004. Quantifying off-site effects of land-use change: filters, flows and fallacies. Agriculture, Ecosystems and Environment 104, 19–34.
Vignola, R., Locatelli, B., Martinez, C., Imbach, P., 2009. Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? Mitigation and Adaptation of Strategies for Global Change, http://dx.doi.org/10.1007/s11027-009-9193-6.
Vignola, R., Koellner, T., Scholz, R.W., McDaniels, T.L., 2010. Decision making by farmers regarding ecosystem services: factors affecting soil conservation efforts in Costa Rica. Land Use Policy 27 (4) 1132–1142.
Vogel, C., Moser, S.C., Kasperson, R.E., Dabelko, G.D., 2007. Linking vulnerability, adaptation, and resilience science to

practice: pathways, players, and partnerships. Global Environmental Change 17, 349–364.
Wasserman, S., Faust, K., 1994. Social Network Analysis: Methods and Applications. Cambridge University Press, Boston, USA, 825 pp.
Weible, C.M., Sabatier, P.A., 2005. Comparing policy networks: marine protected areas in California. The Policy Studies Journal 33 (2) 181–201.
Weible, C.M., 2005. Beliefs and perceived influence in a natural resource conflict: an advocacy coalition approach to policy networks. Political Research Quarterly 58 (3) 461–475.
Weible, C.M., 2008. Expert-based information and policy subsystems: a review and synthesis. The Policy Studies Journal 36 (4) 615–635.