Networks and the Politics of the Environment[1]

Ramiro Berardo[2], Isabella Alcañiz[3], Jennifer Hadden[4], & Lorien Jasny[5]

Abstract

In this chapter we survey recent research that utilizes the measures and techniques of social network analysis (SNA) to explain socio-ecological outcomes. The chapter focuses on the role of key characteristics of networks – including density and fragmentation, bonding and bridging social capital, brokerage and leadership – in promoting adaptive governance and co-management, and in turn, successful environmental management outcomes. We argue that network structures affect the ability of actors to coordinate their behavior, cooperate with one another, share information, and adapt their behavior to new circumstances. We conclude by discussing limitations and future directions for research, drawing attention to the need for more work integrating ecological and social networks, comparative social network analysis, and analyses of network formation and evolution.

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[2] Assistant Professor. School of Environment and Natural Resources. The Ohio State University.

[3] Assistant Professor. Department of Government and Politics. University of Maryland.

[4] Assistant Professor. Department of Government and Politics. University of Maryland.

[5] Lecturer. Department of Politics. University of Exeter.

Introduction

Social scientists have made significant progress in the last three decades in understanding how societies tackle critical environmental problems. This progress has been facilitated by the development of behavioral models that recognize that the networks of interactions in which actors are embedded affect the way they respond to environmental problems.

Studies of networks in environmental policy and politics ask critical questions regarding how networks form and evolve, and in turn, how the interaction between networks and individual-level variables shape socio-environmental outcomes. Do networks transmit information and promote learning, ultimately altering attitudes and behavior? Do they provide social structures through which actors can overcome collective action problems and affect the governance of the environment and the management of natural resources at local, national, and supra-national scales?

A rich body of research has emerged to answer these questions across multiple scales of political activity. A sustained stream of literature has demonstrated how the links between components of social-ecological systems can be carefully analyzed through the application of social network analysis (SNA) techniques (Bodin and Tengö 2012; Bodin et al. 2014; McAllister et al. 2015). At the local level, studies have shown how relational ties that configure local and regional networks have an important role in averting conflict among users of common pool resources[6] (Ostrom 1990; Schneider, Scholz et al. 2003; Betsill and Bulkeley 2006; Marshall 2007; Ostrom 2008). At the international level, scholars use SNA to examine how environmental global governance is shaped by the interaction of a wide range of actors, including transgovernmental organizations (Cao et al. 2013), independent experts (Andonova, Betsill, and Bulkeley 2009; Paterson et al. 2013; Stephens et al. 2011), state experts (Alcañiz 2016a; Alcañiz 2016b), and social movements and NGOs (Hadden 2015; Hadden and Jasny 2016).

In this chapter we review some of the main themes tackled by scholars who study environmental policy and management of natural resources through the use of social network analysis. While this is a diverse field, the members of this scholarly community share an interest with what we term the "politics of the environment": a moniker that encompasses a wide variety of human decision-making processes that may affect the likelihood of successfully responding to environmental problems at different scales. Since it is beyond the scope of this chapter to provide a comprehensive review of all the literature loosely connected under this rubric, we focus our discussion on contributions that employ SNA measures and techniques to connect actor-level behavior, network-level activity, and socio-environmental outcomes. We start by proposing a

[6] Common pool resources (CPRs) are goods that are non-excludable (i.e. they are open access and thus can be used by multiple users) yet are subject to rivalrous consumption (i.e. a unit of the good used by a user is not available to other users), which leads to problems of congestion in use and the associated cooperation dilemmas that may end up resulting in the exhaustion of the resource.

simplified model of how these relationships take place, and then offer a review of research that have zoomed into these relationships. We end our chapter by discussing potential venues for future research.

A Model of Networks, Actor Behavior, and Socio-Environmental Outcomes

Figure 1 illustrates a basic, general model of the relationship between the key themes in our discussion. The figure portrays a connection between activity that takes place in networks and micro-level behavior, which social network analysts usually view as intertwined in a co-evolving relationship. We focus on three network characteristics that have been well explored in regards to their effect on individual behavior and group-level performance: density and fragmentation, bridging and bonding social capital realized in network structures, and structural role performance (e.g. brokerage and leadership).

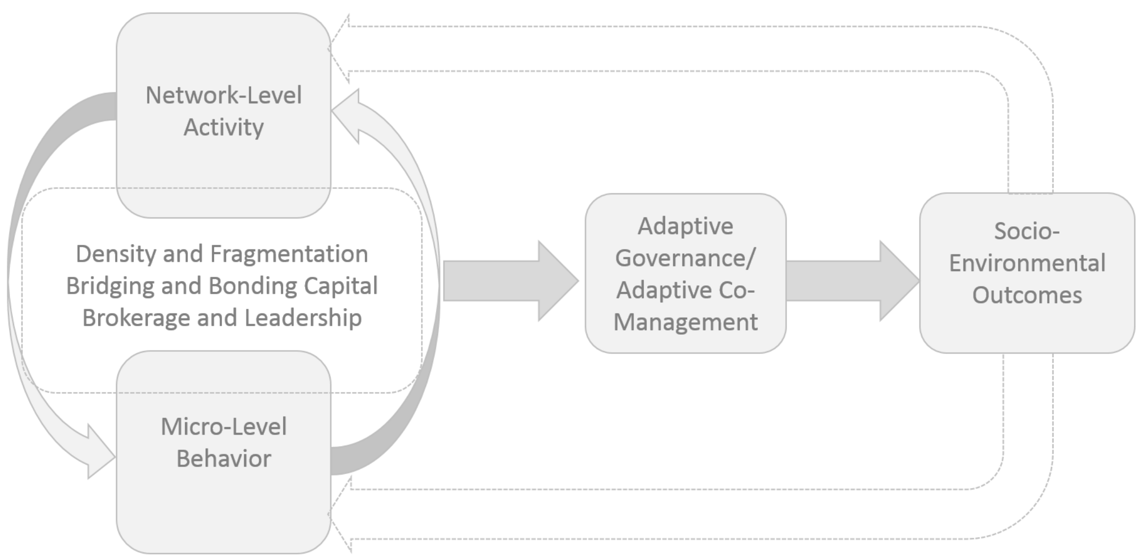

Figure 1. Network Processes in Environmental Policy and Politics [7]

The coevolving relationship between network-level activity and micro-level behavior affects the likelihood of groups achieving *adaptive governance* and/or *adaptive co-management* in the

[7] As it would be the case with any schematic representation of how networks affect individual behavior and systemic variables, Figure 1 contains a simplified depiction of the relationships between these variables. For instance, the figure does not incorporate the effect that macroculture (a system of widely shared assumptions and values that guides actions) has on the behavior of the network actors. A strong macroculture may promote shared understandings of the need for cooperative behavior, which in turns positively affects governance processes (Robins, Bates, and Pattison 2011).

environmental realm. The terms *adaptive governance* and *adaptive co-management* explicitly acknowledge the role of collective learning processes in sustainable practice and thus replace other concepts such as management or adaptive management, which referred purely to implementation of management actions on individual natural resources or whole ecosystems without paying much attention to the social-political environments where those management actions took place (Dietz, Ostrom, and Stern 2003; Bodin and Tengö 2012).[8] Both terms evoke a continuous problem-solving process that is realized through collaborative work by a rich variety of actors coupled by socio-political relationships.

We argue, along with many others, that the focus on complexity and facilitation of cooperation among decentralized actors lends itself to a network perspective. The network structures that contribute to the ability of actors to coordinate their actions, cooperate with each other, share information, and adapt in their decision-making process are more likely to facilitate social-environmental outcomes valued by a majority of involved stakeholders (Ostrom 1990; Folkes et al. 2005; Plummer and Armitage 2007; Blackmore 2007; Newman and Dale 2007; Armitage et al. 2008; Bodin and Crona 2008; Bodin and Crona 2009; Berkes 2009). The achievement of an adaptive governance of adaptive co-management outcome, in turn, shapes socio-environmental outcomes such as rate of conservation of natural resources or the resilience of social-ecological systems.

In a final stage, as socio-environmental outcomes take place, our model proposes that they have a feedback effect on both network-level activity and micro-level behavior. Examples of this feedback process abound. For instance, Dell'Apa et al. (2013) use regular equivalence analysis to study the network of trade of spiny dogfish to the European Union before and after the introduction of regulations in the U.S. to protect the species. They show that the regulations, prompted by a decision by the U.S National Marine Fisheries Service to declare the stock as overfished in 1998, led to changes in the structure of the trade network, in which the U.S. was the main exporter of the species prior to the introduction of the regulations. After the regulations were enacted, the main exporter role went to Canada, while other countries also became more central as exports from the U.S. dwindled. Thus a decision made in response to the level of

[8] Specifically, *adaptive governance* describes the evolution of institutions capable of generating sustainable policy solutions to environmental problems through the coordinated actions of previously independent systems of users, knowledge, authorities, and organized interests (Scholz and Stiftel 2005, 5). *Adaptive co-management*, on the other hand, also describes situations in which actors explicitly cooperate in order to achieve common goals, but places a less explicit emphasis on the role of institutions in the process. The term institution has been historically hard to define. North (1990) provided perhaps the most widely used definition, seeing institutions as "rules of the game" that are used to coordinate human activities. Hodgson (2006) extends that definition, noticing that institutions should not only include formally designed rules, but also self-organizing emergent strategies around coordination problems that are rarely studied in detail. Ostrom (2009) picks up the baton and devises a more comprehensive definition, which describes institutions as rules, norms, or strategies that people derive to coordinate or cooperate more successfully in collective endeavors.

network activity by one node led to network-level rearrangement and subsequent change in a global socio-environmental system.

The Co-evolution of network-level activity and micro-level behavior

Scholars interested in the study of environmental policy and natural resource management from a network perspective have identified: a) ways in which networks can affect the behavior of the actors that form them; and b) how the behavioral patterns of actors can in turn produce changes in the network. This coevolving relationship can be studied in a myriad of ways. Here, we focus on reviewing research that examines how certain network characteristics – their density and fragmentation, the bridging and bonding capital structures that form in them, and the brokerage and leadership positions that certain nodes occupy-- affect governance processes and socio-environmental outcomes. We note that these network characteristics often co-vary; for example, denser networks typically have more bonding capital, while less dense networks facilitate the emergence of central actors occupying brokering positions that are more likely to produce higher levels of bridging capital. However, we analytically separate these concepts in order to review the ways in which, according to the specialized literature, they connect with our outcomes of interest for this chapter.

***Network density and fragmentation*.** Network density and fragmentation are the two most widely-used indicators of network cohesion. Density is simply the proportion of possible ties in a network that actually exist. Fragmentation, on the other hand, is the proportion of pairs of nodes in a network that cannot reach each other, either directly or indirectly (through others).[9] Both of these measures correlate with network activity. The greater the level of activity in the network (i.e. the greater the number of links), the higher the density and the lower the chances of fragmentation.[10]

As noticed by different scholars, a common expectation among students of environmental policy and natural resource management is that more cohesive networks – denser, less fragmented - should be able to facilitate better, more adaptive responses to environmental problems (Bodin, Crona, and Ernstson 2006; Sandtröm and Rova 2010). Scholars generally expect that higher level of activity, and lower levels of network fragmentation, facilitate the exchange of information and

[9] In other words, for the network to be fragmented more than one component needs to exist. A component is a subgraph in the network which is connected –i.e. there is a path between all pairs of nodes that form it (Wasserman and Faust 1994, 109).

[10] There is a linear positive relationship between activity and density. Any new link in a network will increase its density by the same amount, regardless of how many links already exist. However, there is no such linear relationship between level of activity and the level of fragmentation in a network. A link that connects two nodes that could have reached each other through intermediaries in the absence of the new link will not reduce fragmentation. This will only happen if the new link connects two nodes that are members of different components (i.e. different connected subgraphs). Of course, as new links are created, the likelihood of separated components drops, so eventually a network with high levels of activity is more likely to see less fragmentation.

reduce bargaining costs, thereby leading to better coordination of different individual views and positions and thus to greater collective learning (Scholz et al. 2008). This, in turn, facilitates the emergence of adaptive management practices that are conducive to the solution of environmental problems (Newig, Günther, and Pahl-Wostl 2010).

Schneider et al. (2003) provide a good example of the relationship between network cohesion and governance outcomes in their research of the National Estuary Program (NEP). The NEP program was created by the 1987 amendments to the Clean Water Act (Section 320), and allowed state governors in the U.S. to identify estuaries of significant importance that require protection against pollution resulting from human activities. According to directives contained in section 320, in each of the selected estuaries a Comprehensive Conservation and Management Plans was to be developed by a Management Conferenced attended by multiple stakeholders from both governmental and nongovernmental sectors, with support from the U.S. Environmental Protection Agency.[11] Schneider et al. collected data in 22 estuaries (10 with NEP status, 12 without it) and found that stakeholder networks in estuaries with NEP status were significantly denser than networks in non-NEP status estuaries. Additionally, actors participating in the former had more faith on the results of collaborative processes, nurtured stronger interpersonal ties with other stakeholders, and exhibited higher levels of faith in the procedural fairness of local policies (Schneider et al. 2003), all variables thought to facilitate adaptive governance at a regional scale (Scholz and Stiftel 2005). Scholz et al. (2008) then used parts of the same dataset to extend these findings, reporting that actors participating in denser networks were more likely to exhibit higher levels of agreement on the causes of environmental problems in the estuaries, which they ascribe to the fact that denser networks facilitate redundancy of information and heightened levels of trust among the network participants.[12]

Bodin and Crona (2008) provide another example of the relationship between density and fragmentation in networks and responses to management problems that might result when multiple users access a common-pool resource. In their study of a rural coastal fishing village in Kenya, they link the low level of fragmentation in the network of exchange of information among fishermen with a higher ability to generate useful social capital that may help avoid the problem of resource overuse.

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[11] A total of 28 estuaries were identified through this process in the country. For a list of these estuaries, point a web browser to http://www.epa.gov/nep

[12] Other research shows that activity level in networks is in turn affected by the type of actors and issues that are discussed in networks. Berardo and colleagues study meetings of the South Florida Ecosystem Restoration Task Force through a five-year period. The task force is a collaborative partnership of 14 federal, tribal, state, and local agencies, which has the goal to restore the Florida Everglades. Using the discussion on each agenda item in a meeting as a separate “network of engagement”, where a link between two nodes indicates that both actors partake in the same discussion, the authors find that the level of technical complexity of issues being discussed, but also the types of actors that voice their opinions in the discussions, have an effect on the overall level of engagement (Berardo, Heikkila, and Gerlak 2014).

Despite the evidence that has shown the positive effects that activity levels in networks may have in realizing adaptive governance and adaptive co-management, it bears keeping in mind that this positive relationship is by no means ubiquitous. For example, some research shows that excessive density can impede, instead of facilitate, collective action (Oh et al., 2004) and lead to a homogenization of knowledge that can inhibit innovative solutions to existing problems (Bodin and Norberg 2005). Smythe, Thompson, and Garcia-Quijano (2014) examine two cases of collaborative marine ecosystem-based management planning in Rhode Island and New York. The authors find that a lower-density network is more effective for collaborative marine EBM planning because this type of network is more likely to remain diverse and provide decision makers with non-redundant information that can help tackle problems in a more innovative way.

In general then, studies that question the value of high density in networks to achieve desirable environmental outcomes point to the fact that denser network face two problems. First, they may result in the excessive homogenization of positions or visions held by network participants. Second, and as result of the first problem, denser network might be less able to adapt to exogenous shocks simply because the members are more likely to become locked in a form of 'groupthink' that is calcified by the lack of informational diversity (Crona et al. 2011). Thus, research points to a 'middle ground' between excessive and insufficient density, although what this ideal middle point might be is difficult to determine *ex ante*.

Bridging and Bonding capital. Existing scholarship often outlines a positive relationship between successful collaboration and management of natural resources and high levels of social capital among users (Folke et al. 2005; Plummer and Armitage 2007). Bourdieu defines social capital as "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition" (Bourdieu, p.248-9, see also Coleman 1988).[13] Social capital is valuable for adaptive co-management because it lowers the vulnerability of actors embedded in networks by improving their chances of detecting and punishing uncooperative behavior, facilitates learning, and aids communities in generating better responses to environmentally risky situations (Adger 2010). Social capital does all these things by helping lower transaction costs, increase trust, and trigger the adoption of norms at the group level that facilitate cooperation (Pretty and Ward 2001).

Network researchers often brand social capital in networks as either bonding or bridging capital. Bonding capital emerges when connections among members of a network (or a subgroup in it) create structures that favor closeness in relationships. Specifically, bonding capital results when

[13] As a concept, social capital has been problematic, but engaging in a discussion over the merits of different definitions is clearly beyond the scope of this chapter. For a more detailed discussion on different definitions and meanings of the term social capital, see Pretty and Ward 2001.

the members of a network tend to build their connections to others in a way that increases their ability to exert influence or control over their ego network. In this regard, bonding structures promotes cooperation by providing assurance against behavior that might be deemed undesirable. Bridging capital, on the other hand, results when nodes build ties in ways that facilitate access to more distant parts of the network. This kind of capital is more likely to produce non-redundant information, making it valuable in generating innovation or learning.

In addition, which type of capital dominates in a network may have a critical effect on how resilient the network is to external threats. According to Newman and Dale (2005), bonding social capital can hinder innovation by cutting off actors from novel sources of information, in turn reducing adaptability and resilience. Networks characterized by a wide availability of bridging social capital can provide links to a diverse web of resources, making the community more adaptable in the face of change (Newman and Dale 2007; Ernstson, Sörlin, and Elmqvist 2008). This expectation has been supported with considerable empirical evidence. For example, in their study of adoption of farming management practices in cocoa agroforestry systems in Ghana, Isaac et al. find that certain producers provide bridging social capital in their communities by connecting local groups of produces to outside experts through informal networks of advice, resulting in more adaptive management practices (Isaac et al. 2007). Further probing onto the relationship between bridging social capital and individual performance of natural resource users, Isaac (2012) shows a positive and significant correlation between the bridging capacity of farmers in communication networks and the agrodiversity in their farms (measured as "richness of tress species"), which contributes to sustainable agrarian management. Another example of the importance of bridging relationships in the management of natural resources is contained in a study on the management of wetlands in Sweden, where the authors found that bridging relationships among stakeholders allowed for the increase in levels of trust that serves as a catalyst for the implementation of better management actions (Hahn et al. 2006).

Research has also found that actors tendency towards bonding modes and homophily –whereby similar groups are more likely to engage than diverse ones (McPherson et al. 2001) – may impede the development of bridging organizations (Newman and Dale 2007). This in turn affects social learning in the network, as new information, skills, and ideas are less likely to emerge among homogenous actors. The rather pessimistic view of bonding social capital presented here must be taken with a grain of salt. Bonding capital might not be particularly conducive to the spread of information that can be used for solving problems in an innovative way, but it is beneficial in promoting trust and reciprocity among members of a group. This facilitates the detection and quick punishment of uncooperative behavior (Bodin and Crona 2008) and thus contributes to a sustained use of shared resources.

Recent scholarship has moved from a static analysis of social capital in networks and started to examine how social capital emerges and evolves. Conducting research in a set of ten U.S. estuaries, Berardo and Scholz (2010) analyzed how networks self-organize by testing of the "risk hypothesis." According to the hypothesis, when actors face high-risk situations, they tend to form bonding structures that generate overlapping information more likely to help detect and punish free-riding behavior in the use of common-pool resources. On the other hand, when actors face low-risk situations, assurance against defection is not a priority and thus actors tend to form bridging structures that facilitate access to non-overlapping information that comes from more distant parts of the network, a type of information that is more useful to solve coordination problems.

Findings showed that there was a predominant tendency for the actors in the networks toward the formation of bridging structures where a central stakeholder had the potential to fulfill a coordination role. Berardo and Scholz claimed that this tendency was explained at least in part by the fact that the regional governance systems in the estuaries were not characterized by high risks of defection among stakeholders, which lowered the likelihood of cooperation dilemmas. This low level of risk, in turn, allowed stakeholders to not have to focus on the formation of bonding structures, instead forming structures that could be valuable to solve coordination problems, which resulted in the appearance of star-like configurations in which a central node bridged otherwise separated actors. This research thus suggested that low-risk situations are indeed associated with the emergence of bridging structures in networks. Since then, other research in environmental policy and natural resources management has found additional support for the risk hypotheses (Henry and Vollan 2012; Lubell, Robins, and Wang 2014), though more work is needed to create richer models of the coevolving relationship between risk perception and network behavior and to gauge whether and how participation in networks affects individual perceptions of risk. Fortunately, ongoing efforts tackle this limitation. In a recent article on the efforts to manage the Swiss landscape, Angst and Hirschi (2016) examine the evolution of a network of actors involved in the governance of natural resources in a regional nature park project in Switzerland. They test two hypotheses based on Berardo and Scholz's risk hypothesis using separable temporal exponential random graph modeling (STERGM) and find that the network evolves (as they expect given the conditions the network actors face) toward bonding capital. But interestingly enough, they also find that the generation of bonding capital does not mean that the network becomes less hierarchical over time. This is an important finding because it hints that the relationship between bonding and bridging in networks is not necessarily antagonistic, something that previous work has also established. In fact, Berardo and Scholz observed that, regardless of the fact that bridging structures were dominant in the networks they examined, bonding structures were also present although to a lesser extent. Based on this result, they contended that stakeholders in complex social-ecological systems might form relational structures that address both coordination and cooperation problems simultaneously, a finding that has been replicated elsewhere (Berardo 2014a; R. R. J. McAllister, McCrea, and Lubell 2013).

Finally, it is worth noticing that other recent scholarship is beginning to extend the study of social capital beyond the familiar confines of one-mode networks, where almost all of the research has been produced. For instance, Berardo (2014b) has proposed utilizing some of the structural configurations available in software packages for fitting exponential random graph models to two-mode networks as good proxies for the social capital that actors generate when they interact with each other through their participation in certain events. For instance, Berardo claims that actors might generate "weak" forms of bonding capital when they participate in activities together and "stronger" forms of bonding when they participate in multiple activities. This approach to the study of social capital in two-mode networks continues to evolve as researchers further investigate how policy stakeholders create bonding and bridging structures through their participation in policy venues or forums where decisions are made that affect the sustainability of common pool resources (Berardo and Lubell 2016).[14]

Brokerage and leadership. The literature on environmental policy and management of natural resources stresses that in order to achieve adaptive governance in complex social-ecological systems, individual actors need to be able to steer decision-making processes towards the production of collaborative outcomes (Ostrom 2009). How leaders and policy brokers shape change has been a central preoccupation of policy scholars since Kingdon's Multiple Streams theory posited that leaders can help open policy windows to address specific problems of their interest. In their review of adaptive governance scholarship, Folke and colleagues contend that "…leadership is essential in shaping change and reorganization by providing innovation in order to achieve the flexibility needed to deal with ecosystem dynamics" and support this assertion on work on forest and water management (Folke et al. 2005). Armitage et al. (2008), in turn, claim that "key individuals" can help maintain a focus on collaboration and create conditions that are conducive to learning and the avoidance of conflict, while Crona et al. (2011) assert that key players can facilitate a move from unsustainable to more sustainable regimes. In a study of four social-ecological systems in Australia, Sweden, Thailand, and the U.S., Olsson and colleagues examined how key leaders in networks can prepare a system for change by using or creating windows of opportunity to integrate and communicate how actors view a problem, thus helping help the system navigate toward adaptive governance (Olsson et al. 2006).

Most network studies identify the 'leaders' in networks by relying on simple degree centrality measures (see Bodin and Crona 2008; Bono and Anderson 2005; and Friedkin and Slater 1994 for examples). Central actors are more likely to fulfill a coordinating role in networks (Berardo and Scholz 2010), which is a particularly important social function in periods of rapid change that demand adaptive behavior at a systemic level (Bodin, Crona, and Ernstson 2006).[15] Such

[14] The study of bonding and bridging capital in two-mode networks is not restricted to networks concerned with the management of common-pool resources. McAllister, Taylor, and Harman (2015), for instance, analyze the formation of bridging and bonding capital in partnerships networks for urban development in Australia, where stakeholders participate in policy venues where the topic of development is discussed.

[15] Measures of centrality have also been used in International Relations scholarship to study how countries perform environmentally. Ward (2006) examines the network of nations linked to each other through joint participation in

measures can also be employed to identify ‘brokers’ in networks, who serve a similar function (Diani 2003). Scholarship on leadership, brokerage, and bridging capital usually overlap considerably, even if these concepts are not synonymous.[16] Both leaders and bridging actors are seen as key to the successful co-management of natural resources, as they both transmit relevant information and knowledge among actors that operate across different geographies, ideologies, or scales (Berkes 2009; Cohen, Evans, and Mills 2012). Problem-solving and governance in socio-ecological networks rests on the capacity of these actors to learn and share knowledge (Armitage, Marschke et al. 2008; Newig, Günther et al. 2010).

It is important to note, however, that leaders and brokers are not necessarily experts, even though expert knowledge is useful in dealing with environmental problems and has garnered the attention of many students of environmental networks (Haas 1989 and 1992a, 1992b; Sabatier and Jenkins-Smith 1999; Conca 2006; Kamelarczyk and Smith-Hall 2014). Research shows that both expert and non-expert knowledge can play a role in problem identification and analysis contributing to the successful implementation of adaptive co-management (Davidson-Hunt 2006; Berardo, Olivier, and Lavers 2015)

Other work has identified the importance of brokers in institution-building to reach adaptive governance. Jasny and Lubell (2015) explore the complex system of organizations and institutions engaged in water resources management in California, and conclude that brokerage emerges as a result of an evolutionary process in which those who bridge political, geological, and technological divides reap benefits. Interestingly, by extending Gould and Fernandez (1989) classic work on brokerage to two-mode networks, Jasny and Lubell show that brokerage is not only provided by individual actors, but also by the policy venues in which the former interact to advance their agendas. Many of those venues have the goal of spanning various types of boundaries to increase cooperation, bringing together stakeholders that would otherwise be isolated.

We should not assume that actors in position of leadership, or those who can bridge distant parts of the network, automatically exercise a positive influence in the network or even improve their chances of reaching their own goals.[17] In an article that describes the participation of governmental and nongovernmental organizations in a cooperative program implemented by the South West Florida Water Management District, Berardo (2009) shows that project managers

International Governmental Organizations and finds that measures of network centrality positively impact a nation’s performance on different sustainability indicators.

[16] We treat brokers and leaders as similar in nature for the sake of simplicity, though differences between the two concepts exist. See Diani (2003) for a detailed examination of the differences between the concepts.

[17] This contradicts well-ingrained assumptions in the literature on ‘networks as actors’ concerning the more democratic nature of networks (*vis a vis* hierarchical organizations and competitive markets).

that include more collaborative partners in a project increase their chances of getting their projects funded, but that those chances actually decrease when more of those collaborative partners occupy positions of leadership in the network measured by their capacity to reach distant parts of the network through their bridging ties. In other words, organizations perform better by adding more partners as long as this addition does not result in an excessive influx of novel information brought into the project by the bridging partners. Indeed, as the saying goes, too many cooks can spoil the soup.

Even when leaders or brokers are not constrained in their information-processing capacity, they may be more focused on retaining their status and influence than on achieving collective goals. In related work concerning entrepreneurs, Meijernik and Huitema review sixteen case studies around the globe on policy entrepreneurs in water transitions, finding that real-life entrepreneurs are often more interested in institutionalizing their policy ideas than in promoting social learning based on the flow of high-quality information (Meijerink and Huitema 2010). Research with a more explicit focus on social network measurement of leadership finds similar results. For instance, scholars have found that excessive centralization can obstruct learning when the central actor controls information and prevents others from accessing it (Bodin, Crona, and Ernstson 2006; Scholz et al 2008), or when centralization is associated with less deliberation even in the process of undisrupted information flows (Newig, Günther, and Pahl-Wostl 2010).

Directions for Future Research

Our review of the uses of social network analysis in the fields of environmental policy and natural resources management has revealed a keen interest by scholars in linking network analytic tools to the examination of variables that are thought to lead to successful adaptive co-management in complex social-ecological systems. Such adaptive co-management practices are in turn critical to improving social-ecological resilience, and contributing to the use of natural resources in a sustainable manner.

Social network theory and methods have come a long way from the days of relying on small, binary networks and descriptive statistics. In general, until the early 2000s, advances had been tentative in a majority of cases, with a profusion of studies utilizing the term "network" as a metaphor for complex social interactions that are rarely measured exhaustively. But as theoretical perspectives have come to incorporate more explicitly the role that social relationships play in affecting environmental outcomes, network methods have made crucial strides in more accurately capturing this reality. Recent work suggests that researchers are finding innovative ways to examine these relationships (Angst and Hirschi 2016; Berardo and Lubell 2016; Bodin et al. 2014; Kininmonth, Bergsten, and Bodin 2015; Guerrero et al. 2015). We highlight here three particularly compelling directions for future research in this area.

First, scholars need to move more decisively toward the production of research that informs in better detail how activity in social networks impacts specific environmental indicators of interest.

Some teams of researchers are already committed to this vision, and have begun to examine the interaction between ecological and social networks in ways that can inform public policy. For example, Bergsten, Galafassi, and Bodin (2014) study a collaborative wetland management network formed by 26 municipalities in the Stockholm county in Sweden and examine how this collaborative network "fits" with an ecologically defined network of ecologically interconnected wetlands. Using Multiple Regression Quadratic Assignment Procedure (MRQAP), the authors test whether observed collaborations among municipalities are explained by spatial adjacency and/or shared ecological connectivity to wetlands that cross jurisdictional boundaries. Findings show that spatial nearness explains collaboration, but ecological connectivity to wetlands does not. This type of research has important implications for policy practitioners, since it reveals the disconnect between ecological linkages and the collaborative behavior upon which a successful management of the natural resources depends.

Multi-level models may have an important role to play in this area, since they allow for the simultaneous modeling of both social relationship and also the linkages that may take place between human users and certain natural resources of interest. For example, it would be possible to model one network of information exchange among fishermen, a second ecological relationship among the fish themselves (predator-prey relationships, coexistence in habitat niches, dependence on food sources, etc.), along with a bipartite network relating the members of the first to the second (Hollway and Koskinen 2016). Guerrero et al. (2015) provide another example of the use of the modeling of multiplex networks. Using data collected from participants of a biodiversity conservation initiative in Australia, the authors fit Multilevel Exponential Random Graph models and find that individual parcels of native vegetation are the object of more collaborative activities among stakeholders in comparison to parcels that are interconnected from an ecological standpoint. Based on this finding, Guerrero et al. contend that social network analysis can help improve the capacity of stakeholders to assess the obstacles to improved management of natural resources. More work like this is needed if scholars want to make meaningful contributions to the debates on how adaptive management and governance are to be achieved.

Second, many studies in this area explicitly acknowledge a temporal dimension, where governance and socio-ecological outcomes affect one another sequentially. To explicitly examine this topic, we need to model how networks evolve. Modeling network evolution would allow us to tackle critical questions about how governance initiatives affect socio-environmental outcomes and vice versa. Even though work has already been done on network evolution to explain how specific network configurations are formed (see Angst and Hirschi 2016; Berardo and Scholz 2010; Berardo 2014a for examples) and how nodal attributes affect network behavior (Berardo 2013), longitudinal work remains greatly undersupplied. The reasons are obvious. Longitudinal analyses demand the investment of considerable resources (i.e. time and money) on the part of researchers. Yet it is only with this type of work that scholars will be able to fully understand the evolution of many of the variables and processes of interest discuss in this chapter, that are thought to facilitate adaptive management and governance, such as tThe availability of social capital, proper leadership, and a minimum of group cohesion to facilitate collaborative behavior.

Finally, this area of research would benefit from greater availability of explicitly comparative work. As we have mentioned in previous sections, similar network features -- like density and bonding capital – appear to have different levels of importance for how networks operate in different settings. Bonding capital tightly connecting stakeholders in a network, for instance, might yield more positive results in contributing to the sustainable use of natural resources in situations where formal rules to regulate behavior are either absent of ineffective, as it is often the case with developing countries with weak bureaucracies (Berardo and Lubell 2016). Bridging capital, on the other hand, might render more benefits in networks where the actors face a deficit of innovative responses to local problems while still socially embedded in societies where interpersonal trust is high. To reveal the benefits and costs of different network structures for the adaptive management and governance of natural resources and the environment, comparative work is key. Through this approach, researchers can expand the knowledge base regarding which network structures work under specific conditions rather than providing generalizations from findings collected from non-representative cases.

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