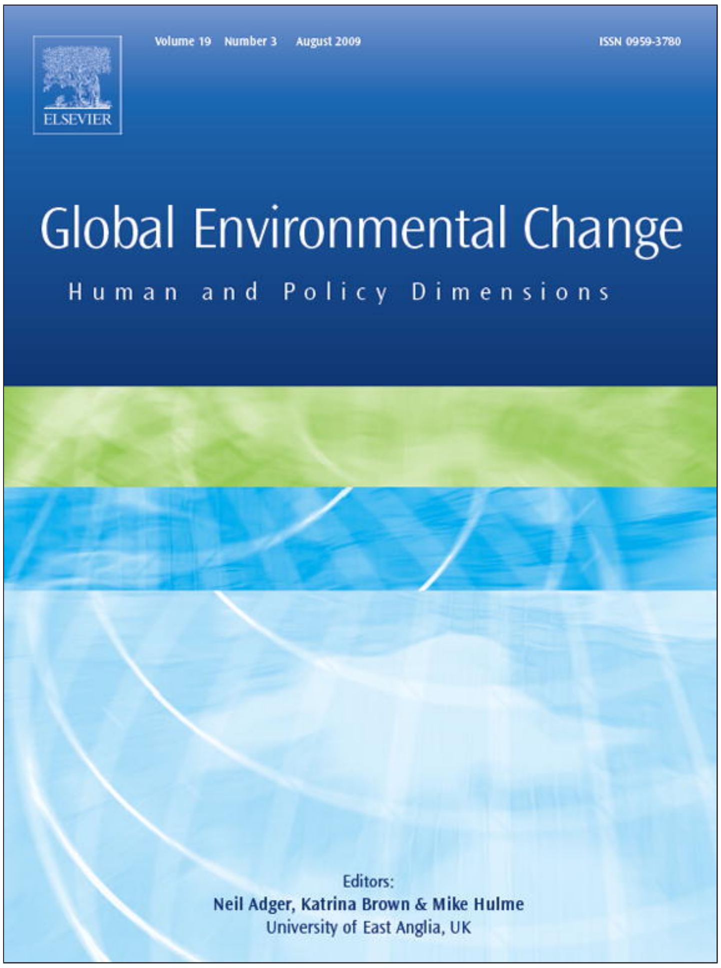
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Review

The role of social networks in natural resource governance: What relational patterns make a difference?

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ABSTRACT

Resent research has identified the existence of social networks as a common and important denominator in cases where different stakeholders have come together to effectively deal with natural resource problems and dilemmas. It has even been shown that social networks can be more important than the existence of formal institutions for effective enforcement and compliance with environmental regulations. However, all social networks are not created equal. On the contrary, the structural pattern of relations (i.e. the topology) of a social network can have significant impact on how actors actually behave. This clearly has implications for actors' abilities to manage environmental challenges. This review aims to add more precision to initial insights and pending hypotheses about the positive impacts of social networks on governance processes and outcomes, by reviewing and synthesizing empirically based literature explicitly studying structural characteristics of social networks in natural resource governance settings. It is shown that significant differences in governance processes and outcomes can be expected among networks experiencing structural differences in terms of density of relations, degree of cohesiveness, subgroup interconnectivity, and degree of network centralization. Furthermore, the review shows that none of these structural characteristics present a monotonically increasing positive effect on processes of importance for resource governance, and that favoring one characteristic likely occurs at the expense of another. Thus, assessing the most favorable level and mix of different network characteristics, where most of the positive governance effects are obtained while undesired effects are minimized, presents a key research and governance challenge.

1. Introduction

Governance[1] of ecosystems is inherently difficult since both the natural environment and human societies are characterized by uncertainties, complex dynamics, natural variations and scale dependencies (e.g. Levin, 1998; Berkes et al., 2003). Furthermore, they do not abide by human-made jurisdictions and administrative borders, and it is not possible to divide them into separate, self-supporting, autonomous components. Many of the services they provide are common pool resources with multiple actors[2] competing for use, often leading to resource depletion or management conflicts (Hardin, 1968). Hence, management of any given resource would benefit from actors agreeing on common rules and practices, coordinating usage, engaging in conflict resolution, negotiating various tradeoffs, sharing information, and building common knowledge (e.g. Folke et al., 2005). Research shows that top-down centralized management is poorly suited for this (Ostrom, 1990; Holling and Meffe, 1996; Gunderson et al., 1995; Berkes and Folke, 1998; Pretty and Ward, 2001). Attention has therefore been directed at governing systems where multiple actors to various degrees are involved in the governing processes. These ideas are captured in the concept of co-management (see, e.g. Carlsson and Berkes, 2005), where the underlying rationale is that by involving different actors in the governing process, the complexities inherent in both ecosystems and the social arrangements constructed around these (i.e. coupled social–ecological systems, see Berkes and Folke, 1998) can be more adequately addressed. Adaptive co-management is a recent expansion of the co-management concept (e.g. Armitage et al., 2009) with explicit focus on the adaptability of the joint management process in response to environmental change and the continuous acquisition of new knowledge (cf. adaptive management, see Holling, 1978).

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[1] By governance we refer to the management of natural resources, as well as the structures and processes that provide the social and institutional environment in which the management can take place.

[2] By actors we refer to all possible stakeholders (e.g. resource users/extractors, state agencies, NGOs, land owners, etc., see Fig. 1).

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However, history, contemporary science and politics all suggest that joint management and governance processes are often difficult, albeit not impossible, to achieve in practice (e.g. Ostrom, 1990; Hahn et al., 2006; McClanahan et al., 2008). To address contemporary natural resource problems ranging from local fish stock depletions to climate change and declining global ecosystem services, it is therefore imperative to better understand how collaborative barriers can be overcome (cf. Dietz et al., 2003). Resent research has identified the existence of social networks (Fig. 1) as a common and important denominator in cases where different stakeholders have come together to effectively deal with natural resource problems and dilemmas (e.g. Gunderson, 1999; Hahn et al., 2006; Folke et al., 2005; Pretty and Ward, 2001; Olsson et al., 2008; Grafton, 2005; Scholz and Wang, 2006). It has even been shown that social networks can be more important than the existence of formal institutions for effective enforcement and compliance with environmental regulations (Scholz and Wang, 2006). Social networks can improve collaborative governance processes by facilitating, (i) the generation, acquisition and diffusion of different types of knowledge and information about the systems under management (Crona and Bodin, 2006; Isaac et al., 2007; Schusler and Decker, 2003), (ii) mobilization and allocation of key resources for effective governance (e.g. Carlsson and Sandström, 2008; Carlsson and Berkes, 2005; Newman and Dale, 2007), (iii) commitment to common rules among actors fostering willingness to engage in monitoring and sanctioning programs (Dietz et al., 2003; Scholz and Wang, 2006), and (iv) resolution of conflicts (Hahn et al., 2006). However, all social networks are *not* created equal (Bodin et al., 2006; Newman and Dale, 2005). On the contrary, the structural pattern of relations (i.e. the topology) of a social network can have significant impact on how actors actually behave (Degenne and Forsé, 1999; Wasserman and Faust, 1994).

Emerging recognition of the importance of social networks for outcomes in natural resource governance has resulted in an increase in empirical studies analyzing the structural characteristics of these networks, and more is under way. This increase is at least partly driven by the recognition that despite an obvious decline in, or degradation of, natural resources, and in spite of the best intentions, many governance initiatives around the world are failing. Analyzing networks of various stakeholders helps tease apart how social structures, created by the pattern of relations, enhance or hinder these initiatives. The profound effect of social networks on social processes in general is well documented by social scientists, and has lead to the development of the field of social network analysis (SNA) (Freeman, 2004). To date, empirical research in natural resource governance applying quantitative analyses of networks characteristics is, however, still limited. Yet valuable insights and hypotheses have started to materialize in this evolving field, and these are synthesized and discussed here. We begin by reviewing how certain structural characteristics of social networks influence the key social processes which are of particular interest for natural resource governance. We also discuss the challenges in addressing the intricate balance between several of these structural network characteristics for governance outcomes. The paper concludes with ideas and perspectives for further research in this area.

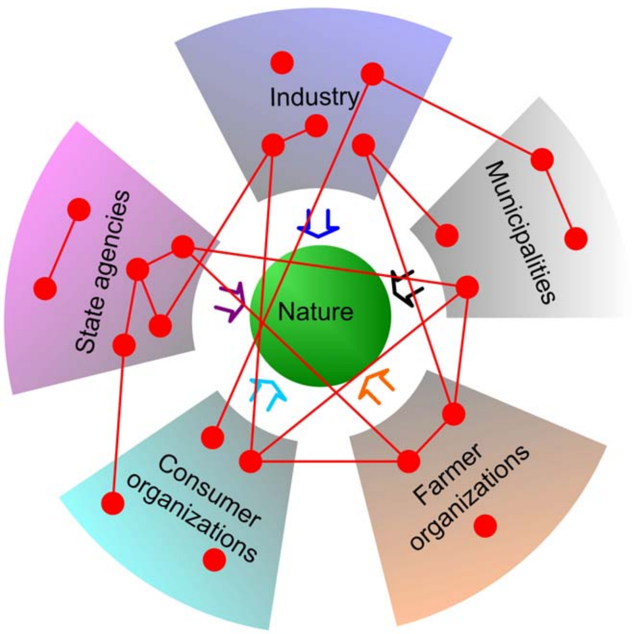

Fig. 1. Different sectors of society involved in the use and management of the natural environment are schematically represented as different triangular slices. The red dots represent individual organizations or persons (i.e. actors) within each sector, and the lines represent relational ties among these. These relational ties can contribute to better natural resource governance by, for example, facilitating coordinated actions among different actors.

2. Relational patterns and processes

To better understand how social networks affect natural resource governance processes, one needs to start by acknowledging some key characteristics which differentiate social networks. First, the pattern of relations will differ depending on which network is in focus, i.e. depending on the type of relations involved. We refer to these different patterns of relational ties as structural characteristics of networks, and the effect they have on social processes such as knowledge transfer, information sharing, consensus building and power relations will be explored here. Secondly, and as eluded to above, the content of the relational ties between actors is fundamentally different in different networks. The ties of a network of close kin will likely convey different resources compared with a network of work colleagues. Similarly, a network for transfer of ecological knowledge is different from a network of relations used for accessing fishing gear. Therefore, when studying social networks, it is important to specify which kind of relations are being studied, and how they relate to the research question and governance issue at hand. To date, however, most empirical studies addressing social networks in natural resource governance have treated them as being either present or absent, and rarely have structural characteristics been explicitly measured and formally analyzed. Although network structure may not be of primary interest by itself, social processes which underpin the outcome of resource governance are enhanced or inhibited by different structures. Likewise, but from another angle, the same social processes can also, over time, lead to changes in the network structures (see, e.g. Borgatti and Foster 2003 for a discussion of how networks can be studied both as explanatory as well as outcome variables). Analyses of the relation between structure and process can thus help us understand the complexities of resource governance. This is the rationale behind this review and in the following sections we will discuss how the number of ties, degree of network cohesion, subgroup interlinkages, network centralization, as well as actor centrality affect resource governance. This categorization of different structural characteristics are typically used in social network analysis (see, e.g. Wasserman and Faust, 1994), and are also reflected in the reviewed studies.

3. Few or many social ties?

Simply speaking, to turn a set of isolated actors into a set of interacting actors, social relations have to be created among them.

Thus, a reasonable starting hypothesis would be that the more social ties, the more possibilities for joint action and other kind of collaborations that would help actors avoid fierce resource conflicts and instead facilitate the development of common resource regulations. Using network terminology, we can express this as the higher the network density (i.e. the number of existing ties divided by the number of possible ties), the more potential for collective action. Increased levels of collective action would thus result from increased possibilities for communication and, over time, by increased levels of reciprocity and mutual trust (e.g. Pretty and Ward, 2001; Janssen and Ostrom, 2006; Axelrod, 1997; Putnam, 1993). Several empirical studies, across different disciplines, support this general hypothesis (see, e.g. Diani, 2003a).

In the natural resource governance literature, the positive relationship between density and joint action is also supported. Qualitatively, it has been demonstrated that by including various stakeholders, and by fostering the development of relations among them, chances for collaborations and joint action increases (Hahn et al., 2006; Bebbington and Perreault, 1999; Olsson et al., 2004; Gunderson, 1999). Using a quantitative approach Sandström showed the impact of density on collective action among different natural resource managers in northern Sweden (Sandström, 2008). She observed that joint action benefited from increased tie density, and that it was especially important that many relational ties existed between actors of different kinds (e.g. between recreational fishermen and governmental officials). Similarly, in a study of fishermen in rural Kenya, King (2000) showed how a group of local fishermen, by interacting with an increasing number of government officials and other influential individuals, and by encouraging them to also interact among themselves, managed to deal with a series of unfavorable developments related to the fishery.

Having social relations does not only lead to increased possibilities for joint action, it may also enhance development of knowledge and understanding through exposure to new ideas and an increased amount of information. In agriculture and agroforestry, it has been shown that important information on new technologies and more sustainable management practices to a large extent flows (or diffuses) through informal social ties (e.g. Isaac et al., 2007; Conley and Udry, 2001). It is important to note that the information which flows through such networks can be of both external origin (e.g. new techniques in using pesticides in agroforestry), as well as generated within the network (e.g. which species are most suitable for the local ecosystem) (Isaac et al., 2007). In addition, the study by Sandström (2008) showed that the positive effects of social networks on knowledge development seems to require less ties compared to what seems to be needed for enabling collective action.

Some caution is warranted however, since there is also evidence that the positive effect of network density in natural resource governance is not necessarily continuously increasing but might in fact decline at high densities. Very high tie density can, in fact, reduce a groups' effectiveness in collective action (Oh et al., 2004). Furthermore, both empirical work and theoretical multi-agent simulations of interacting resource users suggest that excessively high network density can lead to homogenization of information and knowledge which results in less efficient resource use and/or reduced capacities to adapt to changing conditions (Bodin and Norberg, 2005; Little and McDonald, 2007; Ruef, 2002).

This section looked at the effect of the number of social ties *per se* on governance processes. Social ties are, however, rarely distributed equally among actors. In the following sections we will discuss how more complex patterns of tie distribution can affect processes such as consensus building, and knowledge transfer and build-up.

4. Level of network cohesion

One important characteristic of a social network is the level of cohesion, i.e. to what extent the network "hangs together" instead of being divided into separate cohesive subgroups (Wasserman and Faust, 1994). Thus, a network with high structural cohesion lacks a set of clearly distinguishable subgroups (see Fig. 2A and B). The existence of subgroups can pose challenges for joint action aimed at governing a common natural resource, due to the risk of "us-and-them" attitudes among actors (e.g. Borgatti and Foster, 2003). The factors behind the formation of subgroups in networks are many. There might be geographical boundaries that distinguish sets of actors from others (e.g. villages, see, e.g. Ramirez-Sanchez, 2007), division of labor and/or specialization may lead to the formation of subgroups (Frank, 1995; Crona and Bodin, 2006), or it may simply be the result of the inherent limitation of actors to uphold too many concurrent relations (see, e.g. Gladwell, 2002). Thus, subgroups tend to inevitably develop, and this has consequences for governance outcomes.

In network terms a subgroup can be defined as having significantly more ties between its group members than between members and non-members, and various methods exists to identify them (e.g. LS sets, Lambda sets, k-cores, see Borgatti et al., 1990 for an overview). A group can also be identified algorithmically by iteratively removing ties which are situated 'in between' many pair of actors, thus essentially unfolding the underlying subgroup structure by fragmentation (community structure, see Girvan and Newman, 2002). Regardless of how groups are defined and identified, the underlying assumption is that groups distinguish themselves from the rest of the network through their internal tie distribution, i.e. they make up more or less distinguishably islands in the relational landscape. Ties within such cohesive subgroups are also referred to as bonding ties (cf. Newman and Dale, 2007).

Relating this to the previous discussion of the (mostly) positive effect of network density on collaborative processes we can conclude that if a social network is less cohesive, i.e. there are several clearly distinguishable subgroups present, the density of relational ties *between* groups can be regarded as low, and this could have negative effects on the capacity for collaborative processes among subgroups (Granovetter, 1973). However, if actors connecting subgroups have the willingness, capacity and motivations to coordinate subgroup activities towards a common goal, this limitation could be overcome (as will be discussed in the next section). Formation and maintenance of subgroups also have implications for a process deemed important for resource governance, namely generation and transfer of tacit knowledge, including, e.g. understanding of complex ecological linkages.

To develop tacit knowledge of complex systems, such as ecosystems, a high degree of information exchange among more or less specialized actors (such as, e.g. lagoon gillnet fishermen) is beneficial (e.g. Crona and Bodin, 2006; Hamel, 1991). Research suggests continuous and persistent interaction is needed for tacit knowledge transfer. This has been shown in studies of organizational performance (Reagans and McEvily, 2003; Hamel, 1991; Hansen, 1999), and through comparison of local ecological knowledge held by different groups of small-scale fishermen (Crona and Bodin, 2006; Crona, 2006). The cognitive capacity of any one individual is limited, and a constant influx of less relevant information from numerous other actors may in fact hinder the development of specialized knowledge. Thus, the presence of multiple subgroups may enhance both (1) the development of knowledge itself by providing opportunities for high degrees of interaction among similar others, and (2) contribute to the development of a diversity of knowledge by enabling different knowledge to develop in different subgroups. Both of these factors are thought to affect outcomes of natural resource governance in a desirable way (e.g. Walters, 1986; Moller et al., 2004). However, developing isolated sets of specialized knowledge is of limited use in governing complex ecosystems since systemic and boundary-spanning understanding and actions are often needed (Berkes and Folke, 1998). Thus, it is apparent that different subgroups should interact, and that social networks conducive for governance processes therefore need to balance between an overall structural cohesion on the one hand, and allowing for the presence of subgroups on the other. In the next section we examine the structural characteristics of social networks that facilitate or impede such subgroup interactions.

5. Connecting beyond your subgroup

As seen above, cohesive subgroups can be said to consist of bonding ties. Bridging ties, on the other hand, refers to ties connecting different subgroups (see Fig. 2D). The primary argument for this distinction has been that bonding ties promote trust, reciprocity and thus cohesion within communities, which is beneficial for consensus building and conflict resolution, two important prerequisites for natural resource governance (Ostrom, 1990). Bonding ties are also often required for tacit knowledge transfer as discussed above. Bridging ties, on the other hand, provide access to external resources of various kinds, and are often needed to help actors initiate or support collective action (e.g. Granovetter, 1973; Newman and Dale, 2007; Lin, 2002), both of which are vital for resource governance.

The value of bridging ties has been shown in several disciplines. In organizational science, Ruef (2002) explicitly showed that increased connectivity between different subunits in corporations enhanced productivity and innovative capacity. Krishna (2002) used a large dataset of rural villages in India to conclude that a key factor in collective action and economic development was the ability of a village to link up with various external actors and agencies. Warriner and Moul (1992) also showed that farmers who were tied to dense and closed subgroup (i.e. had less bridging ties in favor of more bonding ties), were less inclined to adopt the new conservation tillage practices.

Similar insights have begun to emerge in research of resource governance. In a case study in a semi-urban setting, it was suggested that one of the most influential factors behind the successful establishment of the adaptive co-management process was the existence of trustful bridging relational ties among various different actors and stakeholders in the region (Hahn et al., 2006). This is supported by other studies where the positive impacts of such boundary-spanning network characteristics (i.e. networks rich in bridging ties) on resource governance outcomes have also been assessed (e.g. Pretty and Ward, 2001; Newman and Dale, 2007; Westley and Vredenburg, 1997; Ernstson et al., 2009).

In addition to these studies, where the bridging characteristics of the networks were more qualitatively assessed, quantitative investigations of specific structural characteristics of boundary spanning social networks in natural resource governance have been conducted. A case study of rural fishing villages in Mexico (Ramirez-Sanchez, 2007; Ramirez-Sanchez and Pinkerton, 2009) showed that, in addition to bonding ties, bridging ties were also used for critical information exchange of fish stock abundance and location. Furthermore, Sandström (2008) demonstrated that the presence of bridging ties enhanced the different natural resource managers' collective ability to mobilize various different kinds of know-how for lake fisheries management. Another study showed that a group of fishermen, particularly well connected to a range of other subgroups of fishermen defined by specialized gear use, seems to have been able to utilize those bridging ties to develop a better systemic understanding of ecological processes in the region (Crona and Bodin, 2006).

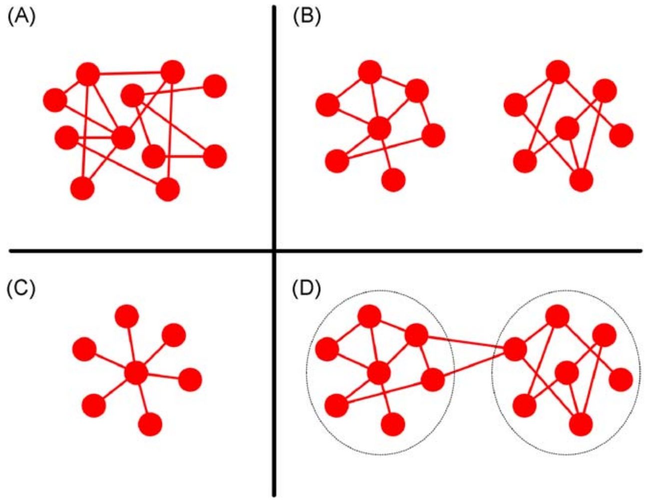

Fig. 2. Schematic presentation of some archetypical network topologies. (A) Represents a network without any clearly distinguishable subgroups (high cohesiveness), whereas (B) presents a network that is divided in two isolated subgroups (low overall cohesiveness, also described as a high level of modularity). (C) Represents a highly centralized network (the node in the middle has much higher degree centrality than the rest of the nodes), and (D) presents a network with two distinguishable groups (dotted lines), which are interconnected via two bridging ties.

The positive effect of bridging ties in natural resource governance extends beyond the exchange of information and knowledge. They can foster trust among previously unconnected groups which facilitates collective actions among different types of actors, such as farmers and governmental officials. This is crucial in natural resources governance which typically affects many different sectors of society. Schneider et al. (2003) explicitly assessed, using a series of case studies in the USA, how some structural characteristics of social networks among various government authorities and other stakeholders affected estuary governance processes. They found that if an increasing number of different types of actors were tied together in boundary spanning networks, there were positive effects on their beliefs in collaborative action, they developed more trust in the governing processes, they were more confident in being able to solve conflicts, and hence conditions for efficient coordination among governmental agencies and others seemed to be significantly improved. Implicitly stated, bridging ties thus help putting heterogeneous actors in contact with each other. The positive effect of such bridging ties in enabling collective action is also tentatively supported by the previously mentioned Mexican case study (Ramirez-Sanchez, 2007). Another example can be found in the study by King (2000), who showed how the establishment of bridging social ties to various external and formally more powerful actors enabled a local group of fishermen to influence decision-making processes in their favor. This particular kind of bridging ties, which vertically connect different hierarchical levels of authority, are often discussed in terms of linking social capital, and are suggested as being particularly relevant in order to leverage resources, ideas and information beyond the level of the community (e.g. Woolcock, 2001). Interestingly, King (2000) showed that real progress in the decision-making processes occurred only when local fishermen were able to involve external authorities beyond those directly involved in natural resource governance. Thus, it appears that bridging ties in some cases need to vertically link several different levels of authorities in order to be really effective.

Organizational and sociological studies show that the inherent diversity of ideas and perspectives that emerge with the presence of bridging ties enhance the capacity for innovations and for finding solutions to complex problems, and thus adaptive capacity (e.g. Page, 2007; Davidson-Hunt, 2006). In his study of Mexican fishing villages, Ramirez-Sanchez (2007) described how bridging ties (i.e. between villages) provided access to fishing grounds in distant fishing villages. These ties, which from a hierarchical perspective of authority can be seen as horizontal, provided access to a resource which could buffer fluctuations in the local fishery, but they also had a beneficial effect on social integration between interacting communities. Thus the net effect was a potentially increased adaptive capacity stemming from facilitation of consensus building and reduced costs of conflict resolution between villages, in combination with shared resources to deal with resource fluctuations spanning spatial and temporal scales.

6. Network position and influence

So far the discussion has focused on structural characteristics at the level of whole networks. However, it is often equally relevant to assess structural characteristics at the level of individual actors (i.e. the nodes of the network) to understand how actors can use their structural position to influence the natural resource governance process. By occupying certain central positions in a social network (Fig. 2C), actors are able to exert influences over others in the network, and are better situated to access valuable information which can put them at an advantage (Burt, 1992, 2004; Degenne and Forsé, 1999). There are various ways to define and measure centrality in social networks. Here we focus on two important and distinct types of centrality: degree and betweenness. The number of ties an actor possesses (degree centrality, Fig. 2C) has been shown to have a positive effect on that actor's influence (Degenne and Forsé, 1999). There are, however, possible drawbacks of having too many ties. An actor may feel obligated to please all, or most, of its numerous network neighbors thus constraining his/her possibilities for action (cf. Frank and Yasumoto, 1998).

Centrality can also be seen as the degree to which an individual actor connects other actors who would otherwise not be linked (Burt, 1992). In SNA the degree to which an actor indirectly connects other actors is often quantified using the metric betweenness centrality (Freeman, 1979). An actor who sits between many other actors in the network is said to have a high betweenness centrality. This implies that the actor could act as a bridge between these others (ties that span between otherwise disconnected sets of actors are by definition bridging ties). It follows from this that high betweenness centrality grants the actor the ability to influence the flow of resources between others, and it also provides him/her with a diversity of resources provided by the bridging ties (Burt, 2004; Granovetter, 1973).

The impact of structural position has been investigated in the literature on natural resource governance. The semi-urban case study mentioned earlier (Hahn et al., 2006) showed, qualitatively, that the critical bridging ties among actors in the region were to a large extent created and maintained by a very small set of key individuals. This shows that the existence of bridging (or bonding) ties *per se* may not be enough to improve governance processes, it is equally important that the central actors use these in ways that benefit other actors in the network (cf. Krishna, 2002; Bebbington and Perreault, 1999). Who occupies these positions, and how they utilize their favorable position will therefore have an impact on governance outcomes. If individuals occupying influential positions in the social networks are unaware of the need for, or unwilling to engage in, collective action they may end up, deliberately or not, blocking initiatives by others. This has been put forth as a possible explanation for the lack of common initiatives among fishermen to effectively deal with fish stock degradations (Crona and Bodin, 2006; Bodin and Crona, 2008), and it also points to the power asymmetries among actors resulting simply from occupying different network positions. On the other hand, an example where a central position is used to improve governance for the whole community is shown by Isaac et al. (2007), where centrally positioned farmers engaged in information acquisition and development of ecological knowledge, while also passing this information on to other farmers in their personal networks.

Possessing a favorable position in a social network may not, however, by itself necessarily lead to higher influence. Furthermore, an individual can very well be influential without necessarily occupying a favorable position (for example, if the individual possesses formal authority). Interestingly, King (2000) showed that the combined effect of network position (degree centrality) *and* formal level of authority coincided with perceived level of actual influence in the decision-making processes, and that individuals that did not have both were ranked lower in terms of influence. In their study of a rural fishing village Bodin and Crona (2008) also illustrated this interplay between structural positions and formal authority. They identified two nodes of power. One was represented by the government official, who was formally recognized by the state but who occupied an only marginally influential position in the village networks. The other was represented by the village chairman, who had no official power vis-à-vis the state but was firmly embedded and very central in the village networks and therefore highly influential in all village matters. Thus, the village as a whole was highly dependent on how and if these two individuals, who's influence was based on very different grounds, chose to collaborate on village matters. Further investigation into the incentives, interests and objectives of such key individuals should therefore be of interest in network research for natural resource governance.

A first step in approaching these questions can be to identify common characteristics, such as age, ethnicity, level of education, occupational/hierarchical position, and wealth, among actors holding influential network positions. Empirical work has shown that by doing this, i.e. analyzing which attributes are shared by central actors, better understanding of factors affecting resource governance issues in small-scale fisheries and agroforestry, such as knowledge generation and transfer, can be achieved (Isaac et al., 2007; Bodin and Crona, 2008). Furthermore, central actors may not well reflect the statistical distribution of member characteristics in the network at large. In fact, they may display quite a skewed, but internally homogenous, representation with effects on natural resource governance and agency at the village level as shown by Bodin and Crona (2008). This shows, once more, the importance of including analysis of actor representation and effects on agency for change in studies of social networks and resource governance. A more elaborative approach to the study of central actors is therefore to look at strategies or methods employed by them. Which strategies appear more or less efficient given an actor's specific position? For example, are there any commonalities between successful leadership strategies, used by key actor upholding positions characterized by high centrality?

6.1. Network centralization

Centrality can also be measured at the level of the whole network. The degree of network centralization assesses the degree to which centralities of constituent actors differ among each other, i.e. the variability in centrality amongst network members (see, e.g. Wasserman and Faust, 1994). Thus, networks including actors with both very high and very low centrality will have a high overall network centrality; i.e. they are highly centralized (Fig. 2C). Early hall-mark studies of small group performance have shown that ability to solve simple problems is positively correlated with high network centralization, while solving more complex problems requires more diverse structures (Leavitt, 1951). It has been tentatively shown that high degrees of network centralization appears positively correlated with collective action in resource governance, mainly through the positive effect on central actors' abilities to prioritize and coordinate activities (Sandström, 2008).

There are, however, several issues of concern with highly centralized networks. The uneven distribution of ties in itself leads to asymmetric relations of influence and power (Ernstson et al., 2009; Diani, 2003b) which means that issues of legitimacy and accurate representation of peripheral actors need to be brought into the analysis. In addition, highly centralized networks may not be appropriate for governing social–ecological systems over time since they are less suited for solving complex tasks. They are also more vulnerable to the removal or dysfunctionality of the few central actors (e.g. reference Frank et al., 2007). As suggested by Bodin et al. (2006), the degree of network centralization most beneficial for natural resource governance may differ depending on the phase of the governance process. For example, mobilizing and coordinating actors at the start of a process may require higher degrees of centralization, while engaging various actors to resolve management of complex ecosystem processes may be favored by less centralized networks.

7. Core–periphery networks

A special kind of centralized network, so-called core–periphery network, results when highly central (core) actors are very densely tied to each other, while actors in the periphery are connected only to the core actors, and not directly to other actors in the periphery (e.g. Borgatti and Everett, 1999) (Fig. 3). This structural characteristic has, as we discuss here, implications for e.g. information diffusion, but also for access to diverse knowledge and for mobilization of support at critical moments in the resource governance process. It has been reported that adoption of new innovations generally tends to trickle-down from highly interconnected core actors to more loosely connected peripheral actors (see Abrahamson and Rosenkopf, 1997 and references therein). Similar effects of core–periphery structures on the exchange of

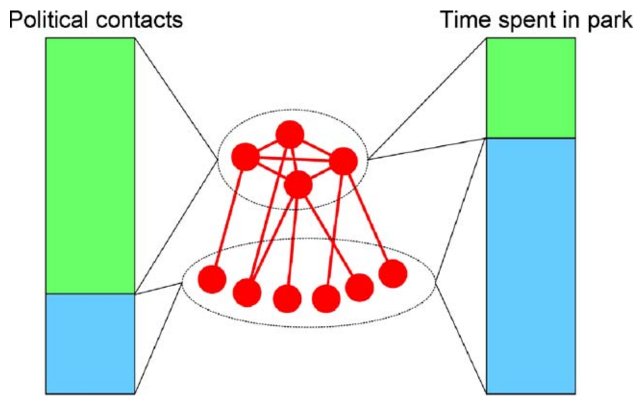

Fig. 3. A schematic representation of the core–periphery network of voluntary organizations in Stockholm (adapted from Ernstson et al., 2009). The core (on the top, encircled with a dotted line) consists of a small set of highly interconnected organizations. The periphery (bottom, encircled with a dotted line) consists of a larger set of organizations typically not linked to each other, but to the core. The core group of organizations posses much more ties to political actors (as shown by the left column) whereas the larger group of peripheral organizations spends more time in the park (right column).

information and knowledge have been specifically reported in resource governance contexts. For example, Isaac et al. (2007) found that the advise networks among farmers in four agroforestry-dominated villages in Ghana exhibited core–periphery structures. Furthermore, the core actors were found to be significantly more engaged in acquisition of new information and knowledge than periphery actors. These core actors acquired information from external sources beyond the local community (e.g. from governmental institutions) but also from other, more peripheral, farmers in their own village. The core actors where thus acting both as (i) bridges; bringing in new information and knowledge to the village, and (ii) communication hubs; disseminating this new information within, but also beyond, the core. There are potentially positive effects of such information dissemination with regard to the adoption of new, more sustainable farming techniques and agricultural output at the village level, and the communication channels, once established between the core and peripheral actors, could be beneficial for other forms of communication of value to resource governance in the future. However, these are hypotheses that have not been explicitly tested.

As mentioned, core–periphery networks may affect not only information and knowledge but also acquisition and dissemination. There is also evidence of effects on collective action in general. This has been explicitly demonstrated in a comprehensive study of governance processes involving green area management and planning in an urban landscape (Ernstson et al., 2009). The study showed how a number of diverse and mostly volunteer based organizations were brought together in an organizational network by their common interest to protect an urban green area from further exploitations. The core–periphery structure of the resulting network coincided with a clearly marked division of labor (Fig. 3). Core organizations had many ties to political, government and administrative agencies, and were using these ties (along with other strategies, such as media exposure) to influence the governance processes by effectively acting as "watch-dogs" for urban exploitation plans. Through their central position they were able to frame the discourse and to a large degree set the decision-making agenda, thus they effectively channeled and exerted the influence of the complete set of 62 volunteer organizations with their approximately 10,000 individual members. The peripheral organizations, on the other hand, spent more time actively using the green areas, and had more introvert and user-oriented activities. They acted as "sensors" of ecological change and/or small-scale exploitations, and they habitually reported what they saw directly to the core organizations who could then bring the issue into the governing processes. This also shows how the increased power often associated with central actors can actually be utilized by peripheral actors in certain situations. There are, however, issues of legitimacy that need to be considered when a set of centrally positioned actors define the agenda on behalf of the majority of network members. For instance, and as suggested by Ernstson et al. (2009), the same core–periphery structure effective for protecting the urban green area may have hampered the emergence of co-management since user groups in the periphery, with local ecological knowledge, have been marginalized on decision-making arenas.

Finally, in comparison with networks with multiple centers or subgroups, core–periphery structures seem less likely to suffer from extensively "us-and-them" attitudes among actors. Although actors in both the core and periphery might sense a social distinction between the two groups, there is only one "centre-of-gravity". This reduces the risk for e.g. conflicts which could hamper collaborative processes (Johnson et al., 2003). However, as mentioned previously, the lack of distinctive subgroups risks leading to homogenization and lack of diversity of, e.g. knowledge and experiences, which, in turn, can reduce the collective capacity of the actors to adapt to changing conditions (Bodin and Norberg, 2005).

8. Summary and outlook

It is clear form this review that structure does make a difference, although the literature on how structural social networks characteristics affect natural resource governance is still limited. Therefore, network studies of successful cases can reveal key network characteristics that benefit governance processes. Below we briefly relate how these insights can inform future transdisciplinary research on the effects of social networks on natural resource governance as well as more practical applications of resource governance.

8.1. Balancing structures

Reflecting on the discussions above, it is apparent that many of the different structural characteristics presented here do not present a monotonically increasing positive effect on processes of importance in the governance of natural resources. For example, if only few ties exist among actors, joint action is hard to achieve, but too many ties can foster actor homogenization and reduce the capacity for effective collective action to deal with changing conditions. Thus, assessing the most favorable level where most of the positive effects are obtained while undesired effects are minimized presents a key research challenge. Furthermore, there is a need to balance several *different* and often opposing structural characteristics of social networks in order for them to be effective and efficient in the governance of natural resources (cf. Prell et al., in press; Bodin et al., 2006; Janssen et al., 2006; Frank et al., 2007). The study by King (2000) serves as an interesting example of the need for both bonding and bridging ties. Local fishermen engaged with several external actors in order to amass support for their cause (bridging). Successful use of such external ties typically requires well-coordinated collective action and agreement among the fishermen themselves. This in turn requires, at least hypothetically, internally well-connected actors (bonding ties). However, how much of each type of tie is needed, and what an optimal ratio of bonding and bridging ties might be needed, also needs further investigation (cf. Bodin and Crona, 2008). Additionally, as stated above, the current phase of the governance process (e.g. initiation, reorganization, consolidation), will dictate which structural characteristics are most likely to be beneficial.

8.2. Network creation and stakeholder participation

Given that social networks and their structural characteristics do make a difference in governing natural resources; can we help build them, and can we simultaneously make sure they develop favorable structural characteristics? Technically, networks can, and are, being created and designed in various forms. Theoretical examples show that changing the configuration of ties between otherwise identical actors could significantly improved the aggregated management outcomes (e.g. Bodin and Norberg, 2005). However, for social network to provide more than just information transfer, and for them to be sustained over time, the relational ties must be voluntary. Human agency will inevitably make actors resist imposed design and they will tend to choose their contacts based on personal preferences, which are often related to how similar the contacts are to the actors themselves (cf. homophily, McPherson et al., 2001). Encouragingly though, Schneider et al. (2003) have shown that facilitating the development of effective boundary-spanning networks among different kinds of actors is feasible. Some of the key issues needed to accomplish this include providing an arena for interaction, encouraging broader participation, and funding for coordinators/facilitators.

From another angle, agencies can use SNA to make sure that the most relevant representatives of different, sometimes even marginalized, subgroups are being invited and engaged in participatory processes (Prell et al., 2008). A study of fishermen in southern US actually showed a poor correlation between the fishermen who were judged as influential by external governmental agencies, and those fishermen who appeared influential based on social network characteristics such as centrality (Maiolo and Johnson, 1989; Maiolo et al., 1992). Social network analysis can thus be used in guiding governing agencies' communication and engagement efforts to maximize efficiency, and/or to target specific subgroups (see also Mertens et al., 2005).

8.3. Social network dynamics and cross-scale interactions

Social networks evolve over time. For example, actors who are ultimately successful in furthering their goals often engage in actively linking up with others in order to pursue their interests (cf. King, 2000). One can therefore expect the structural characteristics to change over time. Maiolo and Johnson (1989) showed that structural characteristics of fishermen's networks differed between cases where the fishery was more or less developed (different societal sectors were more or less represented in the different networks). The study suggests the process of fisheries development may have co-evolved with changes in the network structure. It has been explicitly suggested that a successful management strategy in governing natural resources is one where actors, during periods of stability, develop new relational ties with various other actors and stakeholders which can be drawn upon in times of change (Olsson et al., 2006), see also (Hirschmann, 1984; Gunderson, 1999). This resonates with the proposition that informal networks are especially useful in times of changes (Frank et al., 2007; Ramirez-Sanchez, 2007; Bebbington and Perreault, 1999). In this context, we suggest that, in combination with empirical studies, theoretical models and simulations of various behavioral characteristics of individuals can provide important insights on how different networks structures can emerge, and how the emerging structures might co-evolve with behavioral changes of the individuals (cf. Hanaki et al., 2007; Skyrms and Pemantle, 2000). We also think it is important to point out that not only the structures of a network can evolve, the content of what is transferred through the ties can also change over time. A relational tie that, initially, is used only for the exchange of some specific kind of information, e.g. sustainable farming practices, can evolve into deeper social relationships which in turn can facilitate the development of common norms and values (cf. the discussion on homophily and social ties in McPherson et al., 2001). Furthermore, even in cases when a tie that is used strictly for a specific kind of information exchange does not develop into something deeper, the conveyed information can trigger some change of behavior. Such a behavioral change could, eventually, lead to changes in norms and values which, in turn, also shape governance outcomes.

Viewed from a different perspective, networks which consist of a set of distinguishable subgroups can be seen as networks of subgroups. The networks thus exhibit different hierarchical *levels of scales* (in this case, individual nodes at the lowest scale, and interacting subgroups at a higher scale). Different processes can be dominating at different scales. For example, how individual actors interact within dense subgroups can be quite different from how subgroups interact. This can be seen as different scales providing different functions in the system. However, the different levels of scale are not isolated from each other; they continuously feed back to each other. The need for better understanding of such cross-scale interactions in natural resource governance is put forward by many scholars (e.g. Berkes, 2008; Cash et al., 2006; Ostrom, 2005). Such cross-scale interactions also affect how social networks influence governance processes. As stated by Frank et al. (2007), local resource extractors are increasingly linked to global networks of trade (*large scale*), but the structure of the local social networks (*small scale*) largely determines who gets to participate and under what conditions. A social network perspective holds great potential in enabling analyses of various cross-scale interactions. It could therefore be of great value in researching natural resource governance processes ranging from the local to the global thus enabling understanding of various factors driving global environmental change.

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