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Articles

Does the Social Capital in Networks of "Fish and Fire" Scientists and Managers Suggest Learning?

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Patterns of social interaction influence how knowledge is generated, communicated, and applied. Theories of social capital and organizational learning suggest that interactions within disciplinary or functional groups foster communication of knowledge, whereas interactions across groups foster generation of new knowledge. We used social network analysis to examine patterns of social interaction reported in survey data from scientists and managers who work on fish and fire issues. We found that few fish and fire scientists and managers interact with one another, suggesting low bridging social capital and thus, limited opportunity for generation of new knowledge. We also found that although interaction occurs among scientists—suggesting modest bonding social capital—few managers interact with other managers, indicating limited opportunity for communication of scientific knowledge for the purposes of application. We discuss constraints and opportunities for organizational learning evident in these patterns of social interaction among fish and fire scientists and managers.

Keywords natural resource agencies, organizational learning, riparian and aquatic issues, social capital, social network analysis, wildland fire

It is well recognized that complex ecological problems cannot be solved simply with more scientific information (Ludwig 2001; Holling 1995). Such problems are often characterized by conflicting information, theories, and social values and need to be redefined and approached with new knowledge and insights. In organizational settings, the iterative process of reflecting on, generating, and applying knowledge is called organizational learning (Argyris and Schon 1978). Patterns of social interaction have implications for the capacity of organizations to learn. Embodied in the concept of social capital, interactions that occur within disciplinary or functional groups foster communication of knowledge, whereas interactions across groups foster the generation of new knowledge (Burt 2000). Information about patterns of social interaction within and across groups can therefore be a very important indicator of social capital and the opportunity for organizational learning, and thus the capacity for addressing complex ecological problems.

We examined patterns of social interaction among federal scientists and managers for evidence of social capital and the opportunity for organizational learning regarding the problem of how to manage fish habitat in fire-prone areas. The question we addressed was: Are fish and fire scientists and managers engaged in patterns of interaction that create opportunities for organizational learning? In other words, do scientists and managers interact in ways that the social capital and organizational learning literature suggest lead to the generation, communication, and application of knowledge? We used social network analysis to examine data about patterns of interaction that we gathered through a Web-based survey of federally employed scientists and managers (e.g., U.S. Forest Service, Bureau of Land Management, National Oceanic and Atmospheric Administration) in the U.S. Pacific Northwest, hereafter referred to as the fish and fire network. Social network analysis yields quantitative measures of the distribution of ties among individuals in formal and informal networks. We discuss how patterns of social interaction in the fish and fire network may enable and constrain organizational learning. Although our research focuses on fish and fire, our findings have implications for solving natural resource management problems more broadly.

Background

The Challenge of Fish and Fire Management

A continuing rise in the size and frequency of wildfires in the United States has led decision makers to reconsider management of fire-prone landscapes, broadening the range of acceptable approaches beyond just fire suppression to also include forest thinning to reduce fuel, use of fire as a management tool, and replanting to prevent postfire erosion. Many riparian and aquatic species are adapted to wildfire but are not immune to the effects of uncharacteristically severe fires or fire-related management (Pettit and Naiman 2007; Arkle and Pilliod 2010). Uncertainty exists about how fire management practices affect riparian and aquatic ecosystems; how vegetative conditions in riparian areas contribute to fire risk; and how riparian and aquatic areas should be managed in light of regulatory requirements to protect riparian buffers to protect imperiled species (Richardson, Naiman, and Bisson 2012; Reeves et al. 2006; Arkle and Pilliod 2010; Pettit and Naiman 2007).

Recognizing the need to address complexity and uncertainty associated with fish and fire management, the U.S. Forest Service Pacific Northwest Research Station undertook a research needs assessment in 2007 (USDA Forest Service 2008). Managers and scientists from multiple agencies and organizations met to identify fish and fire research needs and priorities. In addition to calling for more scientific information, participants documented the need to integrate knowledge across scientific disciplines.

Scientists, Managers, and Ecological Knowledge

Communication of scientific knowledge has traditionally followed unidirectional approaches in which scientists generate knowledge and transfer it to managers, or managers request information from scientists (Roux 2006). Scientists have tried to improve the use of science by consulting with managers about their science needs and packaging science to make it more appealing to managers, and managers have tried to improve the usefulness of science by communicating information needs to scientists, providing input on research designs, and developing strategies for searching out and filtering science (Roux et al. 2006; Rogers 1983). However, critics contend that to address complex ecological problems not only must existing knowledge be communicated, but new knowledge must be generated collectively by scientists and managers (Rogers 1983; Walters 1986; Holling 1978; Walters 1998; Roux et al. 2006). This bidirectional model of knowledge generation draws from organizational learning theory, which postulates that learning in organizational settings is a social process in which individuals collectively acquire, create, and transfer knowledge and develop new organizational approaches based on this new knowledge (Garvin 1993; Argyris and Schon 1978; Nonaka 1994).

Organizational learning theory distinguishes between two types of knowledge: tacit knowledge, which is knowledge gained through observation and transferred through shared experience, and explicit knowledge, which is codified knowledge transmitted in formal, systematic language (Polanyi 1966; Nonaka and von Krogh 2009). The process of knowledge creation in organizational settings involves communication of tacit knowledge within communities of practice, conversion of tacit knowledge to explicit knowledge, combination of different bodies of explicit knowledge, and internalization of new explicit knowledge back into tacit knowledge through practice (Nonaka 1994).

In the context of natural resource management, the organizational learning model would have managers and scientists interacting at the outset in the problem definition stage; in the design, implementation, and interpretation of scientific research; and when managers test scientific principles in practical application. Although little research has been conducted about scientist–manager interaction, studies suggest that attitudes and behaviors that indicate organizational learning (Garvin 1993) are not widely found in federal agencies such as the Forest Service and Bureau of Land Management (Brown and Squirrell 2010; Wright 2010).

Social Capital and Organizational Learning

The social capital within and among organizations has bearing on the process of organizational learning. Social capital refers to the stock of informal and institutionalized relationships among people. There are two main types of social capital: bonding and bridging social capital (Burt 2000; Coleman 1990). Bonding social capital refers to connectivity among members of a social group, that is, people who interact frequently or share common socioeconomic characteristics (disciplines, cultural beliefs and values, functional roles, geographic locations). Bonding capital develops out of the natural sociological tendency to associate with others who are similar (homophily), captured in the adage "birds of a feather flock together" (McPherson, Smith-Lovin, and Cook 2001). Bonding capital fosters the creation of common norms and the development of trust and mutual understanding (Burt 2000; Coleman 1990). It also facilitates efficient communication (Borgatti, Jones, and Everett 1998) and transfer of tacit and explicit knowledge (Reagans and McEvily 2003).

Bridging social capital refers to connectivity across social groups. Bridging capital develops in response to resource seeking, the motivation to access novel or rare information and resources (Lin 1999). Interactions across heterogeneous groups create the opportunity for people to air competing ideas, expose themselves to new domains of knowledge, convey their knowledge to others outside their social group, and gain strategic advantage in their work or social relations (Burt 2000; Granovetter 1973). These interactions promote the generation of new knowledge (Reagans and McEvily 2003; Reagans and Zuckerman 2001; Ruef 2002; Rogers 1983).

Balance between bonding and bridging social capital is important to organizational learning. While bridging capital provides access to new knowledge held by other groups, bonding capital is needed to grasp its value (Burt 2000), in part because it is within homogeneous groups that tacit knowledge is most easily acquired and explicit knowledge is internalized back into practice (Reagans and McEvily 2003; Rogers 1983). However, bonding or bridging capital in excess can be crippling for innovation. Too much bonding capital can give rise to homogeneity, jeopardizing an organization or network's ability to maintain a diverse knowledge base, or vulnerability, as when information or decision making is controlled by few individuals; excessive bridging capital may make it difficult to build the trust and norms of reciprocity needed to communicate, process, and act on new ideas (Reagans and McEvily 2003; Ruef 2002; Burt 2004; Borgatti and Cross 2003; Reagans and Zuckerman 2001).

A Social Network Approach to Investigating Social Capital and Organizational Learning Among Scientists and Managers

The term *social network* refers to a set of actors and the ties among them (Wasserman and Faust 1994). Social network analysis is the quantitative method of characterizing the structure of networks based on the distribution of ties. Social network measures can provide evidence of the structural conditions underlying social capital and thus opportunity for organizational learning (Burt 2000; Lin 1999; Borgatti, Jones, and Everett 1998), including in natural resource management contexts (Newig, Günther, and Pahl-Wostl 2010; Bodin, Crona, and Ernstson 2006; Bodin and Crona 2009).

Network density (the percentage of all possible ties among actors that exist in a network) and average degree (the average number of ties held by the actors in a network) are indicators of how interconnected a group is, and thus can be used to measure bonding capital and the opportunity for the communication of knowledge (Borgatti, Jones, and Everett 1998). Centralization describes the extent to which social cohesion is organized around particular focal points (i.e., many ties in the network involve a few main actors), enabling coordination to ensure knowledge is communicated and to control what type of knowledge is communicated (Borgatti, Jones, and Everett 1998). Network measures of bonding capital have been linked to communication of ecological knowledge among fisheries managers (Crona and Bodin 2006) and actors in estuary policy networks (Scholz, Berardo, and Kile 2008). However, the ease of knowledge communication that bonding capital affords has also been linked to maladaptive natural resource management behaviors when the knowledge communicated perpetuates rather than challenges assumptions (Crona and Bodin 2006; Wolf et al. 2010).

Cross-boundary ties (ties between actors with different attributes) reflect opportunity for exposure to new ideas, approaches, or resources, and thus bridging social capital (Reagans and Zuckerman 2001; Sandström and Carlsson 2008; Sandström and Rova 2010). Similarly, brokerage (indirect ties between actors provided by their shared ties to a third party) reflects one's opportunity for accessing new ideas, approaches, or resources as a result of another's connections (Gould and Fernandez 1989). For example, gatekeepers broker the flow of information from an actor in a different group to an actor in the gatekeeper's own group; representatives broker the flow of information from an actor in the representative's own group to an actor in a different group (Gould and Fernandez 1989). Network measures of bridging capital have been linked to the ability of groups and organizations to access information and resources, and increase their ability to engage in natural resource management activities and achieve goals (Floress, Prokopy, and Allred 2011; Rathwell 2012; Mandarano 2009; Sandström and Rova 2010). Additionally, cooperation and consensus building in natural resource management have been explained by measures of bridging capital in organizational networks (Pahl-Wostl et al. 2007; Schneider et al. 2003; Mandarano 2009).

We posit that innovative approaches to the fish and fire problem would be more likely to emerge when scientists and managers interact, creating the opportunity for communication and generation of knowledge. However, in light of other research on organizational learning in the field of natural resource management (Brown and Squirrell 2010; Wright 2010; Walters 1997; Rogers 1998; Roux et al. 2006), we expected to find evidence of an institutional culture among public agencies that does not counter the natural sociological tendency for people to associate with similar others in order to promote organizational learning among scientists and managers. In social capital terms, we expected that the fish and fire network would exhibit moderate bonding capital in groups of scientists and, separately, managers but low bridging capital in the network as a whole. In social network terms, we hypothesized that the fish and fire network would largely consist of separate densely interconnected subgroups of scientists and managers with few links between them provided by bridging actors.

Methods

Using social network analysis we examined the patterns of interaction among federal fish and fire scientists and managers self-reported in a Web-based survey. We defined scientists as individuals who considered research their primary professional activity and managers as individuals who were concerned with day-to-day decisions regarding administration, planning, implementation, and regulation of natural resource activities. An advisory committee of scientists and managers from the key federal agencies that work on fish and fire issues in the Pacific Northwest (U.S. Forest Service, Bureau of Land Management, National Marine Fisheries Service, Fish and Wildlife Service, and U.S. Geological Survey) helped us refine research questions, create the survey sample, and interpret the findings.

Survey

The network data for the analysis came from four questions that prompted survey respondents to list the names and employers of individuals with whom they had interacted on fish and fire research or management issues in the past three years:

1. With whom have you worked (planned, consulted, implemented, or monitored) . . . ?
2. From whom have you sought the information you needed to address commonplace tasks, chores, or duties . . . ?
3. From whom have you sought the information you needed to address uncommon, unexpected, or novel problems . . . ?
4. With whom have you had informal interactions, experiences and discussions (e.g., at the water cooler, in the hall, on field trips) that led to the generation of new ideas, understanding, or knowledge . . . ?

Basic demographic information was also collected in the survey, along with information on other topics that lie outside the scope of this article.

The survey was administered following the tailored design method (Dillman 2009). In May 2011 we sent an invitation e-mail explaining the study and containing a link to the survey website to an initial list of 456 federal scientists and managers who our research team and advisory committee believed worked on fish and fire in the Pacific Northwest. Two weeks later we began sending reminder e-mails, also containing the Web link, and making follow-up phone calls. In August 2011, we sent a second "wave" of the same survey to 129 individuals who were not initially surveyed but were named at least twice in response to the four social network questions in the first wave of the survey. We received 420 valid responses, which, after accounting for the 34 individuals who had retired or moved, yielded a 76.2% response rate.

Sample

For this analysis, we eliminated from the sample of the 365 managers 232 managers who were technical professionals (generally those with a GS grade of 11 or below in the U.S. General Schedule Pay Scale for federal employees) because our advisory committee cautioned that technical professionals would not have the opportunity to interact with scientists. Indeed, we found evidence for this concern in our initial data processing. Also, we eliminated 20 respondents (6 scientists and 17 managers) who did not name and were not named by other scientists or managers (and thus were "isolates"). Table 1 presents descriptive statistics of the sample for this analysis, which consisted of 49 scientists and 116 managers. The sample is dominated by Forest Service employees—not surprising, given that this agency is a large employer of scientists and managers. Scientists and managers were similar with respect to many characteristics (age, gender, years worked in natural resources). However, a large proportion of scientists reported that they worked across regional boundaries compared to managers, which is not surprising given their professional motivations to generalize across cases.

Analysis

We created binary indicators (present [1] or absent [0]) in a matrix of ties between all individuals in the sample (survey respondents and individuals named by survey respondents in response to the four the social network questions). We collapsed all duplicate ties (i.e., when a respondent listed the same individual in response to more than one network question) to produce one set of unique ties between actors. These 507 ties comprise the raw data for the analysis. Although separately examining each of the four sets of ties would be enlightening, for this article we were more interested in patterns of interaction than types of interaction.

We first produced a graphic representation of the network using an algorithm that keeps connected actors near each other and spreads nonconnected actors apart. Then we calculated density, average degree, and centralization to provide descriptive measures of network structure that can reflect bonding social capital (Borgatti, Jones, and Everett 1998), and cross-boundary exchange as a descriptive measure of bridging social capital (Sandström and Carlsson 2008). We then used a block-model approach to assess the extent to which the network comprised separate densely interconnected subgroups of scientists and managers with few links between them as we hypothesized; this consisted of a permutation test to compare the

Table 1. Sample characteristics

Descriptive variables	Scientists ($n = 49$)	Managers ($n = 116$)
Sample (%)	30.5	69.6
Male (%)	75.0	74.5
Age (approx. mean, years)	53.7	50.9
GS level (mode)	13	12
Forest Service employee (%)	67.3	80.9
Bureau of Land Management (%)	2.0	5.2
National Oceanic and Atmospheric Administration (%)	8.2	10.4
Other agencies (e.g., National Park Service, Natural Resource Conservation Service, U.S. Geological Survey)	22.4	3.5
Work focuses in Washington	6.8	22.5
Work focuses in Idaho	18.1	16.2
Work focuses in Oregon	13.6	45
Work across geographic boundaries (%)	61.4	16.2
20 or more years spent working in natural resources (%)	70.8	80.9

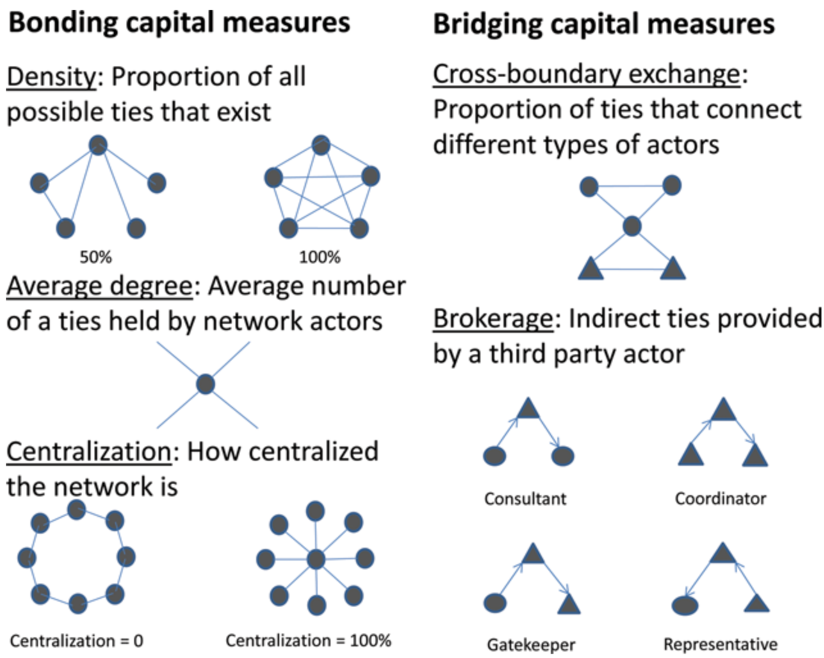

Figure 1. Social network measures used in the analysis of the survey data. (Color figure available online.)

observed ties among scientists and managers to the average number of ties predicted through a large number of randomizations of the data. Finally, we conducted a permutation test on brokerage, including four specific types of brokerage outlined by Gould and Fernandez (1989) (coordinator, consultant, gatekeeper, and representative), to provide further insight on bridging capital in the network.

Although our primary objective was to understand patterns of interaction within and between scientist and manager subgroups that may indicate bonding and bridging capital and opportunities and constraints for learning, we also report network-scale measures for the sake of comparison. The social network variables are defined and depicted in Figure 1. All social network measures and graphic representations of them were calculated in UCINET (Borgatti, Everett, and Freeman 2002) or the SNA package (Butts 2008) of R (R Development Core Team 2010).

Results

Figure 2 depicts patterns of interaction among scientists and managers in the sample based on responses to social network questions in the survey. Scientists are clustered at the center of the network while managers are peripheral (Figure 2a). This pattern suggests that some ties exist between scientists and managers, many ties exist among scientists (Figure 2b) and some ties exist among managers (Figure 2c). Although one scientist is not connected to other scientists and several managers are not connected to other managers (Figures 2b and 2c), they are not isolates because the scientist reported ties with managers and the managers reported ties with scientists.

Density of the overall network of scientists and managers was 1.9%, indicating that a small proportion of all possible ties in the network actually existed, a pattern

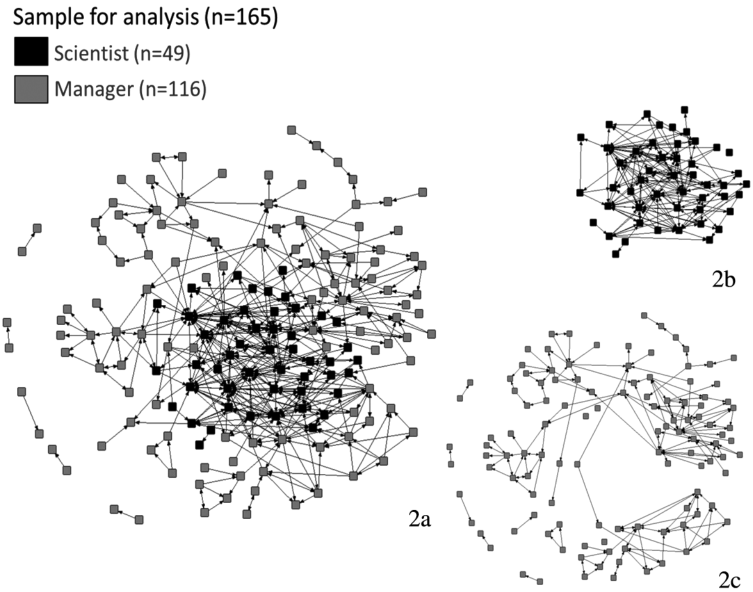

Figure 2. Graphic image of the actors in the fish and fire network and the ties among them in the overall network (2a), scientist-only network (2b), and manager-only network (2c).

that should be expected given that density it is a function of network size (the larger the network, the smaller is the proportion of the total ties that will be held by an actor, because actors can only maintain so many social ties). When examined separately, density among managers was lower than density among scientists (Table 2). Average degree in the network was 3.1, indicating that scientists and managers on average interacted with just a few others (scientists or managers) on fish and fire issues. Managers reported interacting with on average fewer actors than scientists (Table 2). Network centralization was 14.8%, reflecting a network structure that looks more like a circle than a hub and spoke in which all ties go through one person (Figure 1), and indicating that the fish and fire network has little organization around one or a few actors. Scientists were more centralized than managers (Table 2). In other words, many scientists had ties with the same scientists, whereas managers' ties with other managers were more dispersed. Cross-boundary exchange was 22.1%; only about one-fifth of the ties in the network linked scientists and managers, and the rest were among scientists or among managers. The percentage of ties that managers identified with scientists in response to the four network

Table 2. Descriptive network statistics

Descriptive variables	All ($n = 165$)	Scientists ($n = 49$)	Managers ($n = 116$)
Density (%)	1.9	8.8	1.4
Average degree	3.1	4.2	1.6
Centralization (%)	14.8	29.5	6.4
Cross-boundary exchange (%)	22.1	12.7	30.4

questions on the survey was greater than the percentage of ties that scientists identified with managers (Table 2).

Results from the block-model test indicate significantly ($p \leq .05$) more observed scientist-to-scientist ties than expected, and fewer scientist-to-manager and manager-to-scientist ties (Table 3). These findings support, in part, our initial assumption that the fish and fire network would consist of separate subgroups of scientists and managers with few direct links among them provided by bridging actors. Indeed, the frequency with which scientists named managers in response to the four network questions was about one-third of what would be expected given the number of scientists and managers in the sample, and the frequency with which managers named scientists was about four-fifths of what would be expected (Table 3). However, the block-model test results also indicate significantly ($p \leq .05$) fewer manager-to-manager interactions than expected, which does not support our hypothesis that both scientist and manager subgroups would be densely interconnected. Rather, the block-model test results suggest that unlike scientists, who are densely interconnected, managers are sparsely connected.

Brokerage provides further insight into opportunities for interaction created by individuals who mediate the flow of information or resources between two actors who are not directly connected. The number of actors brokering the flow of information among others (total brokerage) was higher ($p < .001$) than would be expected based on the number of ties in the sample (Table 4). However, the vast majority of brokerage occurred in the form of coordinator brokerage among scientists, which does not contribute to bridging capital in the way we conceive of it because it does not link scientists and managers. Rather, coordinators link members of their own group. Consultant brokerage—an actor in one group mediating communication between two actors in another group—occurred much less frequently than would be expected ($p < .001$). This suggests that scientists were not frequently mediating communication among managers, as might be expected considering that the role of science in natural resource agencies is to inform management, and that managers were not mediating communication among scientists. Gatekeeper brokerage—an individual mediating communication from a member of another group to a member of his/her own group—occurred more frequently than would be expected ($p < .01$), due almost entirely to scientists acting as gatekeepers. Actors that function as gatekeepers typically selectively grant outsiders access to members of their own group (Gould and Fernandez 1989); for example, by fielding requests for information. In our case, six scientists contributed the majority of the incidences of gatekeeping. Finally, the frequency of representative brokerage was not significantly different from

Table 3. Block-model permutation test results ($n = 507$)

From	To	Observed ties	Expected ties (mean)	*SD* expected
Scientist	Scientist	207**	43.9	6.3
Scientist	Manager	30**	105.9	9.6
Manager	Scientist	82**	105.5	9.2
Manager	Manager	188*	248.6	11.6

Note. Expected ties are the average of 1,000 random assignments of 507 ties among the 165 scientists and managers reported in Table 1.

$^{***}p \leq .001$. $^{**}p \leq .01$. $^{*}p \leq .05$. Model chi square = 680.750, $p = .0001$.

Table 4. Brokerage permutation test results

	All ($n = 165$)			Scientists ($n = 49$)			Managers ($n = 116$)		
Brokerage variables	Observed	Expected (mean)	*SD* expected	Observed	Expected (mean)	*SD* expected	Observed	Expected (mean)	*SD* expected
Total brokerage	1928**	1519	138	1365*	451	389	563	1068	921
Coordinator	1056***	562	70	796***	38	70	260	524	555
Consultant	90***	319	47	50	225	238	40	94	171
Gatekeeper	412**	319	35	345*	94	134	67	225	320
Representative	370	319	35	174	94	134	196	225	320

Note. Expected brokerage ties are the average of 10,000 random assignments of 507 ties among the 165 scientists and managers reported in Table 1.
***$p \leq .001$. **$p \leq .01$. *$p \leq .05$.

what would be expected, suggesting that members of the fish and fire network are not emphasizing ambassadorship in their interactions.

Discussion

The goal of our research was to determine whether scientists and managers who work on fish and fire issues in the U.S. Pacific Northwest were engaged in patterns of social interaction that reflect social capital conducive to organizational learning. We hypothesized that the fish and fire network would largely consist of separate densely interconnected subgroups of scientists and managers (reflecting high bonding capital) with few direct or indirect links between them provided by bridging actors (reflecting low bridging capital): a structure that would promote communication of knowledge with the scientist and manager subgroups but not generation of knowledge in the network as a whole. Consistent with our expectations, we found little evidence of bridging social capital among fish and fire scientists and managers. We found substantial evidence of bonding capital among scientists. Surprisingly, however, we found little evidence of bonding social capital among managers.

Bridging Social Capital and Implications for Learning

The network was not characterized by the bridging ties that expose people to new information and provide opportunity to generate new knowledge needed for complex problem solving. Cross-boundary exchange did not occur as frequently as expected. Only one out of five ties directly linked scientists and managers and few indirect ties were brokered between scientists and managers. Few scientists functioned as representatives to broker communication of knowledge to managers, or as consultants to broker the communication of knowledge among managers. Instead, scientists assumed the role of gatekeeper more often than expected, suggesting that they are in a position to enable or constrain the flow of information from managers to scientists (Gould and Fernandez 1989). Managers reported ties with scientists more often than scientists with managers, consistent with the traditional role of managers as consumers of scientific information. However, few managers represented other managers to broker communication with scientists, perhaps because managers infrequently interacted with other managers, which we address in the discussion of bonding capital.

Our findings about bridging social capital are consistent with our expectations and what is known about the divisions between scientists and managers in the field of natural resources and in federal agencies in particular. Despite efforts to base natural resource decisions on science and to manage adaptively, progress toward integrating management and science has been limited (Stankey and Shindler 1997; Walters 1997; Brown and Squirrell 2010). This disconnect can be traced to institutional norms that influence how scientists and managers behave and interact (Walters 1997; Rogers 1998). Scientists and managers represent two different communities of practice (Roux et al. 2006), with different operational goals and institutional reward systems. Scientists are driven to produce science of intellectual difficulty and global relevance, whereas managers want science that is accessible and locally relevant (Rogers 1998). In the Forest Service, the largest source of respondents in our study, scientists and managers are further separated by an organizational structure that divides research and management in different administrative branches, and directs managers' activities to particular locations (e.g., national forests, ranger districts). Indeed, a larger proportion of the scientists in our sample worked across regional boundaries than managers (Table 1). Moreover, science communication in Forest Service vernacular is often referred to as "tech transfer," a phrase that suggests that knowledge is a product of scientific inquiry moved from one group, scientists, to another, managers. These institutional norms that divide scientists and managers may be inherent in bureaucracies and other hierarchical organizations, which typically expect subordination by lower levels, limiting the opportunity for shared experience, dialog, and learning (Weber 1947; Thompson 1965).

Although these findings are not surprising, they are nevertheless of concern, and raise a number of questions relating to the practice of natural resource management. The lack of interaction among scientists and managers may limit opportunity for the exchange of explicit knowledge and the generation of new knowledge regarding fish and fire (Roux et al. 2006; Burt 2004; Nonaka 1994). The lack of bridging ties may deny scientists access to the experiential knowledge of fish and fire managers that would provide direction for useful lines of inquiry, and may deny managers access to fundamental information about fish and fire systems to inform on-the-ground decision making. More broadly, low bridging capital in the fish and fire network poses challenges to adaptive management, which is a key strategy of many natural resource agencies (Rogers 1998; Walters 1997). Adaptive management implies learning how to manage an ecosystem through experimentation (Holling 1978). How is adaptive management possible without scientist–manager interaction? Moreover, a lack of interaction may also limit opportunities to reconcile conflicting scientific assumptions and management priorities in the historically separate disciplines of riparian and aquatic ecology and wildland fire protection (Roux et al. 2006; Rogers 1998; Walters 1997).

Despite their importance, bridging ties between scientists and managers are not likely to develop naturally, given the well-founded principle of homophily (McPherson et al. 2001). Ties among heterogeneous actors are slow to develop and are quickly broken down (Molm, Takahashi, and Peterson 2000). The current era of fiscal austerity and government downsizing may discourage the formation of scientist–manager ties. As funding declines and retirees are not replaced, remaining scientists and managers may be compelled to take on more work, leaving less time to invest in extending professional relationships. Indeed, 70.9% of scientists and 60.9% of managers in the sample were 50 years of age or older, nearing the average retirement age for federal employees of 58 years (U.S. Office of Personnel Management 2001). Deliberate institutional commitment will likely be necessary to maintain and create new scientist–manager ties during periods of transition in public agencies.

Bonding Social Capital and Implications for Learning

Our results suggest that bonding capital is much higher among fish and fire scientists compared to managers. Scientists reported on average more ties and a greater proportion of potential ties than managers. The scientist subgroup was also more centralized than the manager subgroup. These findings suggest greater opportunity for communication and coordination among scientists than among managers. Moreover, the relatively high level of coordinator brokerage among scientists suggests scientists in the network may be mediating interactions with one another, perhaps to diffuse or gain access to information from scientists they don't work with directly. An explanation for this may be that scientists share many sociodemographic characteristics (education, professional motivations, and cultural beliefs) and often work in central labs where they have opportunities to interact informally and develop trust. Moreover, their relatively small group size increases the chances of interaction. Managers, on the other hand, are physically dispersed as they focus on the management of specific public land management units. In addition, opportunities for managers' professional advancement often depend on relocating to other regions, which may discourage long-term maintenance of ties with other managers. Other studies have attributed low bonding capital to lack of spatial proximity (Bodin and Crona 2009; Ramirez-Sanchez and Pinkerton 2009). Hierarchical organizational structure in federal agencies, which places managers in a vertical chain of command, may also impede horizontal communication among managers.

The lack of bonding capital among managers is of concern. Social cohesion creates opportunity for communicating tacit knowledge, converting explicit knowledge back into practice and engaging in coordinated action (Oh, Chung, and Labianca 2004; Reagans and McEvily 2003; Reagans and Zuckerman 2001; Burt 2004; Nonaka 1994; Nonaka and von Krogh 2009). Accordingly, other social network studies have found that that small, interconnected networks (low degree, high density) provide the basis for trust, communication, and consensus among actors in natural resource networks and that well-connected central actors foster cooperation (Scholz et al. 2008; Crona and Bodin 2006). Our findings suggest that managers who work on fish and fire issues may lack sufficient relationships among themselves to diffuse information gathered from scientists; they may also lack opportunities for shared experience that could help them internalize this explicit knowledge in order to apply it in practice (Roux et al. 2006; Reagans and McEvily 2003; Reagans and Zuckerman 2001; Burt 2004).

Although the substantial bonding capital among scientists bodes well for coordinated scientific inquiry on the topic of fish and fire, it may also suggest a risk of network constraint: the limitation imposed by many close relationships on one's exposure to other ideas and resources that provide strategic advantage (Burt 2000). Scientists overinvested in their own network may lack social energy to invest in developing the ties with managers that are ultimately important for the ability of the wider community of interest to act in concert (Granovetter 1973), a potentially major hindrance to science-based natural resource management. Another risk that comes with high levels of bonding capital is vulnerability of the network to control by a few individuals (Newig et al. 2010). The relatively high level of bonding capital among scientists may hinder scientists from coordinating their approaches to scientific inquiry on fish and fire with managers. It also may suppress the emergence of new scientific ideas and approaches among scientists.

We emphasize caution in interpreting the findings for several reasons. Although our survey response rate was high (75%), our study likely suffers from the imperfect recall and refusal problems that affect many social network studies. Many respondents did not answer the social network questions or may not have disclosed all their contacts, either because they were unwilling to do so or because they were unable to recall all their contacts while completing the survey. Also, we chose to focus our study on scientists and managers because of the substantial literature that raises concerns about the science–management divide, particularly in the context of aquatic issues. However, we recognize that it would be interesting to explore patterns of interaction between federal employees who address fish and those who address fire, or who are employed by different agencies, or between groupings that emerged through the data analysis rather than groupings that were predetermined. We focused on federal employees to avoid the potentially long approval process required by the Office of Management and Budget when federal personnel or funds are involved in surveying individuals who are not federal employees (Paperwork Reduction Action of 1995). Although respondents were not discouraged from naming non-federal actors, our sampling approach was biased toward federal employees. As a result, our findings may not reflect the opportunities for learning created by scientists and managers at universities and state and local agencies. Although our sample was dominated by Forest Service employees, a large employer of fish and fire scientists and managers, our findings did not differ substantively when the sample was restricted to Forest Service employees compared to when it included all agencies.

Implications for Future Research and Policy

Social network analysis provided insight into patterns of interaction among scientists and managers who work on fish and fire issues in the U.S. Pacific Northwest. Interpreting these patterns through the lens of social capital and organizational learning theory illuminated constraints for communication and innovation in the field of fish and fire. We were dismayed to encounter low bridging capital in the fish and fire network and surprised to discover low bonding capital among managers in particular. Findings from this study raise more questions than provide answers to the challenge of fish and fire management. For example, to what extent is formation of ties among federal fish and fire scientists and managers simply a function of geographic proximity and social similarity, or can ties be better explained by the institutional incentives of federal natural resource agencies? How might the lack of bonding capital among managers and bridging capital between scientists and managers affect the utilization and generation of knowledge about fish and fire? What kinds of policies and organizational changes may encourage more bridging capital in the network and more bonding capital among managers?

To answer these and other questions, we plan to analyze the survey data to investigate social, cultural, and institutional factors in the structure of the fish and fire network. We also plan to investigate how the structure of the network might be improved to increase learning. The organizational learning literature offers ideas for organizational "interventions" to increase communication between scientists and managers: for example, integrating scientists and managers in communities of practice; forming long-term partnerships involving mutual investments of planning, risk, and ownership; and entering into transactional agreements (e.g., management units paying for science) (Rogers 1983; Roux et al. 2006). Walters (1998) and Rogers (1998) propose similar approaches to increasing scientist–manager interaction in the field of riparian management specifically. Striving for balance in social network measures that indicate bridging and bonding social capital may be a useful and tangible goal for such interventions. The theory and methods used in the design of this study can guide the development of these efforts.

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