Environmental Science & Policy 57 (2016) 112–121

Contents lists available at ScienceDirect

Environmental Science & Policy

journal homepage: www.elsevier.com/locate/envsci

Institutional networks and adaptive water governance in the Klamath River Basin, USA

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ARTICLE INFO

Article history:
Received 23 March 2015
Received in revised form 26 September 2015
Accepted 14 November 2015
Available online 9 January 2016

Keywords:
Adaptive governance
Social network analysis (SNA)
Klamath River Basin
Water governance
Institutional analysis

ABSTRACT

Polycentric networks of formal organizations and informal stakeholder groups, as opposed to centralized institutional hierarchies, can be critically important for strengthening the capacity of governance systems to adapt to unexpected social and biophysical change. Adaptive governance is one type of environmental governance characterized by the emergence of networks that stimulate adaptive capacity through increases in social-learning, communication, trust, public participation and adaptive management. However, detecting and analyzing adaptive governance networks remains elusive, especially given contexts of highly contested resource governance such as large-scale negotiations over water use. Research methods such as social network analysis (SNA) are often infeasible as they necessitate collecting in-depth and politically sensitive personal data from a near-complete set of actors or organizations in a network. Here we present a method for resolving this problem by describing the results of an institutional SNA aimed at characterizing the changing governance network in the Klamath River Basin, USA during a period of contested negotiations over water. Through this research, we forward a method of institutional SNA useful when an individual or egocentric approach to SNA is problematic for political, logistical or financial reasons. We focus our analysis on publically available data signaling changes in formal relationships (statutory, regulatory, contractual) between organizations and stakeholder groups. We find that employing this type of SNA is useful for describing potential and actual transitions in governance that yield increases in adaptive capacity to respond to social and biophysical surprises such as increasing water scarcity and changes in water distribution.

1. Introduction

Organizations and actors engaged in environmental governance – processes for making decisions about the use and conservation of natural resources – are often stymied by ecological uncertainty and overwhelmed by the complexity of public and private demands on resources (Allen and Gunderson, 2011). In the Western U.S., for example, the dominant paradigm of centralized and hierarchical water governance has not kept pace with the dynamic social-hydrologic landscape and has instead continued to privilege powerful agricultural interests over rising environmental concerns (e.g., endangered aquatic species) and marginalized water users such as Native American tribes (Bark et al., 2012). Ineffective coordination amongst a myriad of public agencies and private organizations with conflicting mandates and missions for water management have increased conflicts over water use and conservation. In addition, the onset of climate change will bring a change in water supplies and distribution across much of the West, likely further exacerbating current conflicts over water governance. In this respect, water governance in the Western U.S. is representative of the complex challenges that face environmental governance more generally.

As a solution to better accommodate both the uncertainty and complexity surrounding environmental governance in social–ecological systems (SESs), scholars have built upon the concepts of adaptive governance (Brunner et al., 2005; Folke et al., 2005; Chaffin et al., 2014b). Broadly, adaptive governance is an oft cited

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http://dx.doi.org/10.1016/j.envsci.2015.11.008
1462-9011/

'form' of environmental governance with the capacity to adapt to changing social and biophysical circumstances including shocks and surprises such as those induced by climate change (Folke et al., 2005). Approaches cited in the literature as adaptive governance assume a shift away from exclusive control by the hierarchical organization of governments and instead toward a more diffuse governance of resources through the activation of cross-scale and cross-level networks (Olsson et al., 2004; Folke et al., 2005; Crona and Hubacek, 2010). Polycentric networks – networks with multiple sources of power or legitimacy – are essential for spanning multilevel governance systems (local to global) to coordinate the collaboration, trust-building and learning necessary to maintain ecosystem-based management and facilitate decision making in response to disturbance and change (Huitema et al., 2009; Schultz et al., 2015).

Examples of adaptive governance, however, have been difficult to capture and analyze, and published accounts have been limited to a few prominent cases (Schultz et al., 2015). A partial explanation for this is that adaptive governance is difficult to achieve through legislation or mandate and is instead an emergent phenomenon (Chaffin and Gunderson, 2016). Thus, any systematic analysis remains elusive. An additional challenge is detecting governance change over time given the reality of unpredictable time lags. A diversity of examples of adaptive governance may be existent in the world, but it may be years or decades before the social and biophysical outcomes of these governance processes become detectable. The study of adaptive governance must therefore shift to investigating contemporary transitions in governance in an effort to better understand the processes of emergence, and then translate this understanding into policy mechanisms that create space for emergence in other contexts.

One method already employed by scholars to better understand transitions toward adaptive governance is that of social network analysis (SNA). Researchers have employed SNA techniques to correlate changes in structure of governance networks with characteristics of adaptive governance (e.g., Prell et al., 2009; Bodin and Prell, 2011). Network research on emerging adaptive governance remains sparse, however, due to the challenges associated with collecting adequate network data for meaningful analysis. For example, in situations of conflict over natural resource management (e.g., lawsuits or public protests), information on active, informal governance networks may be regarded as sensitive or political, and stakeholders may perceived it as advantageous not to share information with researchers. This renders traditional, egocentric approaches to SNA nearly impossible (Knoke and Yang, 2008).

In this paper, we present research responding to the difficulties in employing SNA to capture and analyze transitions toward adaptive governance. We apply this approach to the contexts of a governance transition in the Klamath River Basin, USA, including a set of recently negotiated agreements between stakeholders in the basin aimed at equitable water allocation and climate change preparedness. Using the tools of SNA, we 'map' changes in legal, financial and other fiduciary relationships over time among water stakeholder organizations in the Klamath basin to determine the potential emergence of adaptive governance. In so doing, we critique the application of SNA for its usefulness in scaled SESs, proposing that: (1) SNA metrics alone are generally insufficient to determine the emergence of adaptive governance; but (2) a focus on institutional SNA as opposed to egocentric SNA, may yield a relatively accessible, rapid assessment tool for scholars and practitioners interested in mapping the architecture of governance change over time to determine where additional capacity is needed to foster the emergence of adaptive governance. Increasingly, contested water governance will be addressed with large, multi-stakeholder agreements much like the Klamath Agreements described herein. Thus, our research has direct policy implications – institutional SNA can be used to evaluate these types of agreements prior to their establishment and funding to determine the potential for fostering the emergence of adaptive governance.

2. Adaptive water governance and social networks

In this section, we first review concepts surrounding adaptive governance. We then introduce literature on SNA of environmental governance networks to determine the characteristics of networks that suggest transitions toward adaptive governance.

2.1. Adaptive governance and water resources

Adaptive governance is an approach to governing the use and protection of natural resources that emerged from research on failures of governments and other organizations to equitably allocate scarce resources amidst overwhelming complexity and uncertainty (Dietz et al., 2003). Adaptive governance has theoretical roots in research on collective action and ecological resilience and has been described as the social contexts necessary to manage resilience in SESs (Folke et al., 2005). In this sense, 'governance' differs from 'government' by expanding social contexts to explicitly include the "range of interactions between actors, networks, organizations, and institutions emerging in pursuit of a desired state" for SESs (Chaffin et al., 2014b). The term 'governance' inherently introduces normative connotations along with tenuous idea that there is a universally desirable path forward to both allocate and conserve environmental resources. While there is no panacea for resource allocation conflicts (Ostrom, 2007), nor is there a utopian path toward resource sustainability, the normative concept of governance is useful as it emphasizes state and non-state processes for negotiating tradeoffs and resolving conflicting demands on resources. Governance is not management, but instead includes the processes for determining what management actions to pursue 'on-the-ground' that directly affect the use, conservation and sustainability of environmental resources (Green et al., 2015). For example, in the U.S. West, water management would include operating plans (and outcomes) for organizations tasked with water distribution, while governance would include the multi-level processes, parties and institutions involved in negotiating the terms of those operation plans.

Research on adaptive governance has commonly discussed water as a focal resource (Huitema et al., 2009; Pahl-Wostl et al., 2007; Cosens et al., 2014). Governance of water is inherently the governance of complexity and uncertainty – complex because water spans boundaries from administrative to biophysical, and uncertain due to the potential impacts of climate change on the distribution of water through changes in both extreme and slow onset events (Vörösmarty et al., 2000). Analysis of the sheer diversity of actors, organizations and institutions involved in water governance has yielded important insights for framing adaptive governance. Of interest here is the role of networks (as opposed to hierarchies or markets) as a mode of governance. Network governance tends to be polycentric – having multiple sources of power or legitimacy – and polycentric governance systems are more likely to learn and adapt following a disturbance (Huitema et al., 2009; Pahl-Wostl, 2009). Network governance increases the capacity for a diversity of actors and/or organizations, both state and non-state, to participate in decision making processes by building trust, increasing communication and initiating collaborations across administrative and political boundaries spanning both vertically and horizontally (Folke et al., 2005; Pahl-Wostl, 2009). Network governance can also promote social learning through increased exposure to information through knowledge brokers and bridging organizations strategically positioned throughout the network (Olsson et al., 2007; Pahl-Wostl et al., 2007; Crona and Parker, 2012).

These characteristics of networks – polycentricity, trust, communication, collaboration, learning, participation – are aspects that contribute to the adaptive capacity of a governance system (Huitema et al., 2009; Pahl-Wostl, 2009). We refer here to adaptive capacity as the ability to experiment and foster innovative solutions to change, crisis or disturbance (Armitage, 2005). Transitions toward adaptive governance are facilitated by high levels of adaptive capacity (Chaffin and Gunderson, 2016), and thus one method to analyze the potential emergence of adaptive governance is to characterize changes in adaptive capacity during governance transitions. Toward this aim, the following section highlights insights from research using SNA to identify adaptive capacity through structural elements of environmental governance networks. From this, we are able to associate changes in SNA metrics as potential indicators of changes in adaptive capacity, and then apply this to a governance transition in the Klamath River Basin to analyze the potential emergence of adaptive water governance.

2.2. Linking adaptive water governance and social networks

Research inquiry into the influence of networks on environmental governance and management has increased in recent years (e.g., Bodin and Crona, 2009; Ernstson et al., 2010; Newig et al., 2010; Bodin and Prell, 2011; Ernstson, 2011). Environmental governance networks can be defined as a set of relatively stable relationships of communication between actors or organizations involved in resource management, and based on degrees of mutual trust, reciprocity and cooperation (Torfing, 2005; Newig et al., 2010).

Empirical research has indicated that certain network structures and patterns of relational ties can increase the likelihood of collective action and collaboration in natural resource management (Schneider et al., 2003; Tompkins and Adger, 2004; Crona and Bodin, 2006; Prell et al., 2009), and thus differences in network structure may signal different amounts and types of adaptive capacity (Newman and Dale, 2005; Bodin et al., 2006). Governance networks can contribute to the adaptive capacity of an SES by increasing the SES's resilience to internal and external disturbances. Increased adaptive capacity in governance networks may include: (1) increased capacity for governance networks to learn and experiment (Newig et al., 2010); (2) strengthened trust, communication and knowledge sharing (Bodin and Crona, 2009); and (3) new connections of disparate subgroups within previously established networks (Bodin et al., 2006).

Researchers often rely on social network analysis (SNA) techniques to characterize network structures and to quantify whole networks or actor positions for descriptive and comparative purposes (Wasserman and Faust, 1994; Knoke and Yang, 2008; Borgatti et al., 2009). SNA techniques provide mathematical tools to create descriptive metrics and graphical depictions of nodes (actors, organizations or events) and ties (connections or linkages between nodes) within a defined network (community, social group or related interest network) that can be used to trace channels of information transfer and other relationships (Wasserman and Faust, 1994; Borgatti et al., 2009). The value of SNA metrics, while subject to qualitative interpretations, is in their ability to assist researchers in assessing relative node position, power, influence and legitimacy among other nodes (e.g., stakeholders) involved in environmental governance (Prell et al., 2009). Recent research using SNA metrics to investigate environmental governance has forged a path for us to further associate specific SNA metrics with characteristics of adaptive capacity in governance networks (Table 1).

Table 1 describes a set of associations between quantifiable SNA metrics and aspects of adaptive capacity necessary to support transitions toward adaptive governance of SESs. Using these relationships, we describe a longitudinal approach to SNA applied to a governance network in the Klamath River Basin, USA during a time of distinct transition in governance (2001–2010). We attempt to detect increases in adaptive capacity, potentially signaling a transition toward adaptive governance, by identifying changes in the network and node-level metrics described in Table 1. The next section is an overview of our methodology and our choice of the Klamath River Basin as a case study.

3. Methods and case study description

3.1. Klamath River Basin study area

Legal, political and even physical contestation over water and associated resources in the Klamath River Basin has been the status

Table 1
The potential of select social network analysis (SNA) metrics to characterize adaptive capacity of governance networks and indicate a transition toward adaptive governance.

SNA metric	Type of network measure	SNA metric description	Adaptive capacity indicators
Density	Whole network measure	Density indicates the total number of ties divided by the total number of possible ties in a network (Granovetter, 1985)	Increased density may indicate increased trust, decreased transaction costs and increased node interaction and network identity (Granovetter, 1985; Coleman, 1990). Dense networks promote communication, information sharing and knowledge production (Crona and Bodin, 2006; Bodin and Crona, 2009; Newig et al., 2010)
Centralization	Whole network measure	Network centralization is the degree of variance (expressed as a percentage) from a perfectly centralized or star-shaped network of the same size (Freeman, 1979)	Increased network centrality reinforces pathways for communication and node interaction (Prell et al., 2009), potentially increasing the likelihood of node participation [in governance] and collaboration between nodes
Betweenness Centrality	Node-level measure	High betweenness values describe nodes that link groups in the network that would not otherwise be directly connected (Freeman, 1979; Burt, 2004)	An increase in nodes with high betweenness centrality indicates an increase in links that serve as connectors between subgroups in the network (Granovetter, 1973). These "brokers" synthesize tacit knowledge from subgroups, promoting trust, learning and innovation (Newman and Dale, 2005; Bodin et al., 2006)
Degree Centrality	Node-level measure	High degree centrality describes the tendency of only a few actors in the network to have many links (Freeman, 1979)	Nodes with high degree centrality are positioned to efficiently mobilize information and resources from the network to respond during times of disturbance and change (Burt, 2004)

quo since the mid-20th century (see Most, 2006; Doremus and Tarlock, 2008). The rural Klamath landscape supports a myriad of land uses, including extractive industries such as irrigated agriculture, commercial salmon harvesting and hydropower. The basin's unique geography (see supplemental material for basin maps) and historic development patterns have increasingly positioned water users against each other in recent years (Chaffin et al., 2014a). Parallel conflicts in the basin include: hydroelectric dams that prevent anadromous fish (e.g., salmon) from migrating to historically critical spawning habitat; agricultural runoff exacerbating toxic algae blooms that degrade fish habitat and limit recreational opportunities; and a fragmented strategy for surface and groundwater management due to multiple sovereigns and a myriad of political, administrative and social boundaries (NRC, 2004; FEIS, 2012). In addition, the basin is home to six federally recognized American Indian tribes, four of which have recently regained political power as co-managers of water, fisheries and natural resources in partnership with state and federal agencies. The basin's tribes have been involved in an ongoing political struggle to gain recognition of legal rights over the land, water and resources of their ancestral homelands – all against the backdrop of overallocated surface water, increasing aridity, and highly contentious, but legally prioritized agricultural water uses (Most, 2006).

In May 2001, over 18,000 protestors lined the streets of the rural community of Klamath Falls, Oregon in public defiance of a shutoff of irrigation water delivered to over 1,400 farms and roughly 210,000 acres of a federal irrigation project (Doremus and Tarlock, 2008). This shutoff was a court-ordered enforcement of the U.S. Endangered Species Act (ESA), leaving adequate water in Upper Klamath Lake and the Klamath River to protect threatened and endangered fish species. In response, a shifting implementation of the ESA in 2002 allowed for reduced flow in the Klamath River during late summer, creating conditions leading to the mortality of over 30,000 Chinook salmon migrating up river toward fall spawning grounds (CDFG, 2004). In addition, commercial ocean harvest of salmon was either drastically reduced or closed altogether in the late 2000s because of declining Klamath River salmon stock numbers (Spain, 2007). Each of these acute resource crises in the basin caused corresponding crises in Klamath communities, threatening the security of livelihoods and cultural identities (Gosnell and Kelly, 2010).

After an exhaustion of adversarial options (e.g., lawsuits, negative media campaigns) to achieve zero-sum outcomes, key leaders of basin stakeholder groups engaged in a variety of formal and informal venues in an attempt to resolve conflicts over water allocation by identifying mutually beneficial goals. One such venue arose from a federal requirement to relicense the Klamath Hydroelectric Project. Under amendments to the U.S. Federal Power Act, the Project's private owner, PacifiCorp, initiated an "alternative relicensing" process with the Federal Energy Regulatory Commission (FERC) that created space for legitimate interests in the basin to collaboratively negotiate a proposal to remove part of the project – four dams on the mainstem Klamath River – and fund a basin-wide restoration effort for endangered species recovery, riparian ecosystem rehabilitation and rural economic stabilization (Spain, 2007).

In 2010, after more than five years of negotiation by a group of local leaders, scientists and federal and state agency representatives under an alternative to FERC hydropower relicensing, the proposed Klamath Basin Restoration Agreement (KBRA, 2010) and companion Klamath Hydroelectric Settlement Agreement (KHSA, 2010) were unveiled as a plan to manage water, maintain agriculture, sustain commercial and recreational fishing and restore ecosystems in the basin (the KBRA and KHSA are herein referred to as the 'Klamath Agreements'). Although most provisions in the suite of Klamath Agreements requires U.S. Congressional authorization and funding to take effect,[1] changes in the governance network underlying the negotiation and agreement process may be indicative of a shift toward adaptive governance of the Klamath SES. Thus, we engaged in a SNA of changing institutional relationships in the Klamath between 2001 and 2010 in an attempt to further analyze this transition in governance.

3.2. Methods

We used the tools of computerized SNA to analyze data on governance networks collected during field and archival research performed in the Klamath River Basin between 2011 and 2014. The methods presented here are part of a larger qualitative case study approach, bounded physically by the Klamath hydrologic basin, and designed to retain "holistic and meaningful characteristics" (Yin, 2009, p. 4) of an ongoing transition in water governance in the Klamath River Basin beginning with acute conflict in 2001 and leading to the Klamath Agreements in 2010.

Our initial task was to collect data describing the pattern of formal relationships defining the water governance network in the Klamath Basin during the study time period. We identified the nodes of the governance network first from a public list of parties (organizations) to the Klamath Agreements, and then worked backward through public records data to identify all organizations and stakeholder groups with formal relationships to these parties between 2001 and 2010 (Table 2). We defined 'formal' relationships between these organizations and groups as either: (1) a statutory obligation (e.g., U.S. Bureau of Reclamation's (USBR) requirement to consult with the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) under the ESA); (2) a jurisdictional hierarchy (e.g., Modoc County is connected to California, which is connected to the U.S. federal government); (3) membership in another organization (such as individual Tribes connected to the Klamath River Intertribal Fish and Water Commission (KRITFWC)); (4) a contractual link (e.g., water delivery contracts between the USBR and the Klamath Water Users Association); or (5) a litigation alliance (e.g., there are ties between all plaintiffs and between all defendants in the *Kandra v. United States* (2001) and *Pacific Coast Federation of Fisherman's Associations* (2001) litigation that was ongoing in the basin during the "conflict" period (2001–2004)).[2]

To reconstruct these formal relationships, we reviewed public documents including agency operation plans, management and monitoring studies, Biological Assessments and Opinions, research reports, court cases, planning documents, peer-reviewed research and the Klamath Agreements themselves, to determine connections between resource governance organizations in the basin at

[1] Legislation (S.2379, Klamath Basin Water Recovery and Economic Restoration Act of 2014) was introduced May 21st, 2014 to the Senate of the 113th Congress by Senator Ron Wyden (D-OR). The Bill was amended by the Senate Committee on Energy and Natural Resources in December 2014, but did not receive a full Senate vote.

[2] It is important to note that we view the nodes in the Klamath network under investigation here as groups and organizations, not individuals. In many SNA investigations this assumption has been shown to be problematic, because individuals representing groups in resource negotiations may change over time and the beliefs or actions of the leaders representing stakeholder groups can stray from 'party lines' (Newig et al., 2010). In the context of the Klamath negotiations, however, we are comfortable with analyzing a network of groups and organizations as opposed to individuals for three reasons: (1) the relationships we have mapped (links between organizations) are not generally subject to individual agency as would be a relationship based on communication or frequency of contact; (2) individual agency is not as concerning given the broader context that organizational representatives were charged with negotiating the best interest for the group or interest represented; and (3) according to interview data, generally, the representatives of each group or organization remained the same throughout the time period analyzed.

Table 2
Formal organizations and informal stakeholder groups engaged in environmental governance in the Klamath Basin 2001–2010.

Organization type	Formal environmental governance organizations in the Klamath Basin
Federal Government	United States (Departments of Commerce, Interior, and Justice); U.S. Bureau of Reclamation; U.S. Environmental Protection Agency; Federal Energy Regulatory Commission; U.S. Fish and Wildlife Service; U.S. Geological Survey; National Marine Fisheries Service
State Government	State of California; State of Oregon; California Department of Fish and Game; California Natural Resources Agency; California North Coast Regional Water Quality Control Board; Oregon Department of Environmental Quality; Oregon Department of Fish and Wildlife; Oregon Water Resources Department
Local Government	City of Klamath Falls, OR; Del Norte County, CA; Humboldt County, CA; Klamath County, OR; Modoc County, CA; Siskiyou County, CA
Tribes/Tribal Organizations	Hoopa Valley Tribe; Karuk Tribe; The Klamath Tribes; Quartz Valley Indian Reservation; Resighini Rancheria; Yurok Tribe; Klamath River Intertribal Fish and Water Commission; Klamath Tribal Water Quality Work Group
Conservation and Environmental NGOs	American Rivers; Audubon Society; California Trout; Defenders of Wildlife; Earthjustice; Friends of the River; Institute for Fisheries Resources; Friends of the River; Klamath Forest Alliance; Klamath Riverkeeper; National Center for Conservation Science and Policy; Northcoast Environmental Center; Oregon Wild (formerly Oregon Natural Resources Council); Sustainable Northwest; Salmon River Restoration Council; The Sierra Club; Trout Unlimited; WaterWatch of Oregon; The Wilderness Society
Trade or Industry Groups, Intergovernmental Organizations, Corporations	Klamath Water and Power Agency; Klamath Off Project Water Users Association; Klamath Water Users Association; Northern California Council Federation of Fly Fishers; Pacific Coast Federation of Fisherman's Associations; PacifiCorp; Upper Klamath Water Users Association

three distinct time periods: (1) conflict (2001–2004); (2) negotiation (2005–2008); and (3) agreements (2009–2010). In addition, we used a review of the Klamath Agreements to construct a fourth, hypothetical time period, a period in which the Klamath Agreements are authorized, funded and enforced as law. Using this pattern of relationships between organizations and groups during these time periods, we then employed UCINET SNA software package to 'map' the network of formal relationships between governance organizations in the Klamath Basin (Borgatti et al., 2002).[3] SNA software uses a computerized multivariate approach called a general linear algorithm (GLA) that mathematically arranges nodes in space so that nodes are closer to each other if the degrees of separation between nodes are small, and nodes are farther away if they are large (based on the distance of travel between nodes through established connections or ties) (Knoke and Yang, 2008). GLA also positions more connected nodes toward the center of the resultant network graphs (Knoke and Yang, 2008). These resultant social network maps can be used to visually infer information about the position of specific nodes (e.g., individuals or organizations) relative to the entire network. Given our approach of mapping only formal governance relationships, we were able to construct a relatively whole picture of network governance organizations and stakeholder groups in the Klamath during the time periods under investigation. Employing SNA allowed us to calculate a series of network metrics to compare changes in whole network configuration across four time periods, as well as to compare shifts in relative positions of individual organizations and groups within the network.

4. Results

Fig. 1a depicts a social network map of the water governance network in the Klamath Basin during the period of acute public conflict over water (2001–2004).[4] The map represents the pattern of existing relationships between formal organizations and informal stakeholder groups listed in Table 2. When compared to similar network maps for time periods best characterizing negotiations over water in the basin (Fig. 1b) and the signing of the Klamath Agreements (Fig. 1c), a change in institutional relationships is visually detectable as a change in network organization or pattern of node relationships (e.g., how nodes are grouped in the network).

For example, Fig. 1a–c shows a temporal trajectory from the beginning of which (conflict period) the Klamath environmental governance network was predominantly hierarchical with the United States and state governments as the most central actors. Two lawsuits ongoing during part of this period reinforce this hierarchy by further dividing network subgroups along local and national governance lines (e.g., in Fig. 1a local and state government and industry nodes are relatively close in proximity as are federal government and NGO nodes of regional and national interest). As contexts in the Basin shifted – through the emergence of the FERC alterative to relicensing negotiations and the public release of the KBRA and KHSA settlement agreements – the structure of the governance network also shifted to reveal networks grouped by interest and identity as opposed to structured only hierarchically (e.g., see tribal cluster in the lower portion of Fig. 1b, and the general bifurcation of the network into environmental NGOs and non-NGO organizations in Fig. 1b and c).

In an effort to quantitatively describe the changing relationships between formal organizations and informal stakeholder groups in the Klamath Basin water governance network from 2001 to 2010, we calculated a series of network metrics using SNA software that included whole network density and measures of network- and node-level centrality (Table 3). An increase was observed in both network-level metrics (density and network centralization) from the conflict to negotiation time period. During the following time periods describing negotiation and agreement, however, network density remained the same and there was a measureable decrease in network centralization. Lastly, density measurements were stagnant and network centrality decreased between the negotiation and period of releasing the Klamath Agreements.

We also calculated two measures of node-level centrality: node betweenness and degree centrality. These metrics offer a more detailed description of changes in the Klamath governance network over time by describing mobility of individual nodes within the network. Our results indicate that organizations shifted position in both betweenness and degree centrality through the three mapped time periods of governance change in the Klamath Basin between 2001 and 2010. The most central actor in each case

[3] This "map" is a type of sociogram pioneered by the sociologist Moreno (1934).

[4] The sociograms or social network maps (a more contemporary reference) displayed in Figs. 1a-c and Fig. 2 depict non-directional, complete networks (i.e., unconnected nodes were not analyzed as part of the networks during the specified time periods). Depicted links between nodes simply indicates an existent relationship between nodes as opposed to defining a specific flow from one node to another.

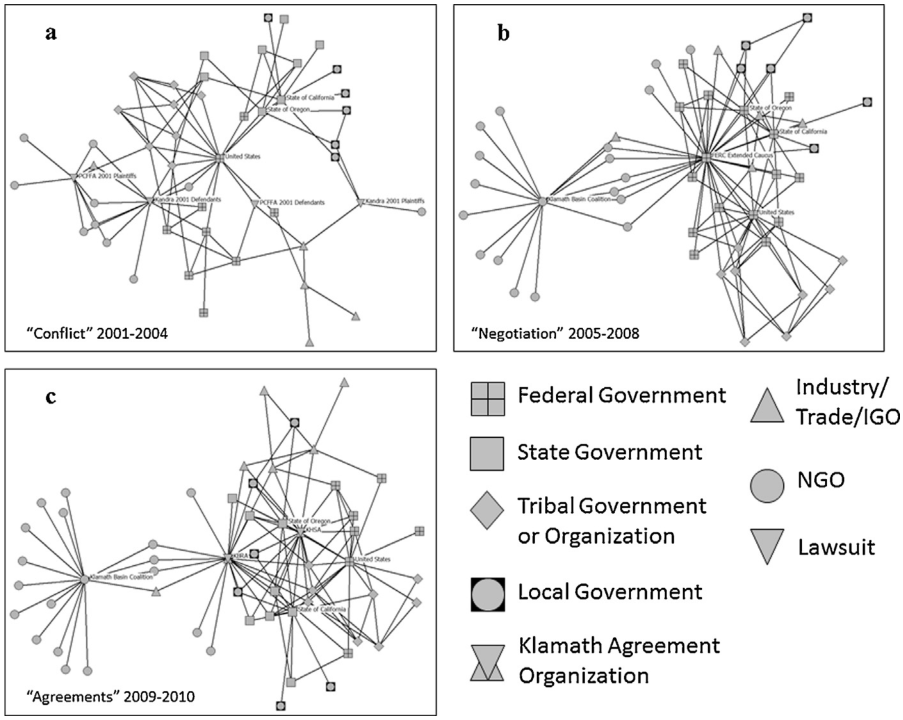

Fig. 1. Sociograms of formal relationships between water governance organizations in the Klamath River Basin over time periods of conflict (a), negotiation (b) and agreement (c).

shifted from the federal government during the period of conflict, to the negotiating caucus during the negotiation phase, to the parties to the Klamath Agreements during the agreement phase.

5. Discussion

5.1. Network metrics and a transition toward adaptive governance in the Klamath River Basin

Based on our review of literature and subsequent association of network structures with aspects of adaptive capacity (Table 1), we brought several assumptions to this analysis. First, we incorrectly assumed that an increase in network density and network centralization in the Klamath water governance network over time would correlate with relationship changes in the basin from conflict to negotiation to agreement. We assumed that density would steadily increase, but the minimally observed change and plateau in light of the obvious shift in network structure between time periods (Fig. 1) calls into question the usefulness of density as an indicator of changes in adaptive capacity and as a potential predictor of a transition toward adaptive governance. While increases in density and centrality often indicate an increase in communication and the ease of information transfer, increased density can also lead to homogenous perceptions and attitudes and can be indicative of hierarchical pathways for communication (Oh et al., 2004; Bodin and Crona, 2009). This lack of diversity can inadvertently maintain the status quo within governance networks, decreasing the potential for innovation that comes with increased knowledge sharing and experimentation, and decreasing adaptive capacity within the governance network. Dense, centralized networks, while enjoying a wider network reach and more efficiency in completing simple tasks, can also fail to effectively govern in the face of complexity or unexpected disturbance (Bodin et al., 2006). These ideas may begin to explain the plateau in density between the negotiation and agreement phases in the Klamath water governance network.

Increases in network centralization (and density) often indicate increases in trust, communication, information sharing and knowledge production (Crona and Bodin, 2006; Newig et al., 2010; Prell et al., 2009), all aspects of adaptive capacity that qualitatively increased in Klamath governance networks between 2001 and 2010 (Gosnell and Kelly, 2010; Chaffin et al., 2014a). Our failure to detect a steady increase in network centralization consistently across the three time periods, however, is likely explainable by the nature of the changes in institutional relationships over these time periods. The failure of lawsuits during the conflict period to solidify lasting governance reform in the basin and the sudden willingness of stakeholder groups and organizations to support a new process in the basin (a negotiated settlement as opposed to relicensing the Klamath Hydroelectric Project) during the negotiation phase, supports the measured increase in centralization between these first two time periods. During the negotiation phase, organizations and stakeholder groups self-organized into two centralized subgroups in the basin (see Fig. 1b): (1) stakeholders legitimately recognized in the FERC alternative relicensing process; and (2) a group of environmental NGOs united in the interest of advocating for the ecological integrity of the basin, collectively identifying as the Klamath Basin Coalition (2007). The negotiation phase saw a mass concentration of groups and organizations interested in having their voices heard and their needs met in a reformed approach to governance (Chaffin et al., 2014a). The agreement phase represents the political outcomes of this process, partially institutionalizing the centralization of some organizations, coalitions and shared responsibilities based on the negotiation process. The network itself is less centralized than during the negotiation phase, but reorganized to include new relationships and new information sharing pathways that are lasting and meaningful.

Node-level centrality measures (degree and betweenness centrality) tell a story of shifting influence in the Klamath Basin between 2001 and 2010. In our reconstruction of the Klamath governance network, the more connections a node has likely indicates the more organizations or groups that rely on that node

Table 3
SNA metrics with the potential to indicate an increase in adaptability of environmental governance in the Klamath Basin (2001–2010).

	Conflict (2001–2004)	Negotiation (2005–2008)	Agreement (2009–2010)
Nodes (ties)	43 (170)	54 (212)	56 (228)
Average degree	3.4	3.93	4.07
Network density	0.069	0.074	0.074
Network centralization[a]	52.16%	73.35%	53.19%
Node betweenness centrality[b]	1. U.S. (55.39) 2. *Kandra 2001* Defendants (24.63) 3. CA (23.06) 4. OR (15.29) 5. Hoopa Tribe (12.36)	1. FERC Ext Caucus (75.07) 2. Klamath Basin Coalition (32.11) 3. U.S. (11.39) 4. CA (5.34) 5. American Rivers, Institute for Fisheries Research, Klamath Forest Alliance, Oregon Wild, Pacific Coast Federation of Fisherman's Associations, Trout Unlimited, WaterWatch of OR (3.84)	1. KBRA (56.04) 2. Klamath Basin Coalition (39.39) 3. U.S. (15.54) 4. KHSA (13.83) 5. CA (11.3)
	6. *PCFFA 2001* Plaintiffs (10. 76)		6. American Rivers, Institute for Fisheries Research, Pacific Coast Federation of Fisherman's Associations, Trout Unlimited (8.54)
	7. FERC (9.06) 8. PacifiCorp (8.36)		
Degree centrality[c]	1. U.S. (15) 2. *Kandra 2001* Defendants (12) 3. CA, *PCFFA 2001* Plaintiffs (9) 4. OR (7) 5. Hoopa Tribe (6)	1. FERC Ext Caucus (36) 2. KB Coalition (16) 3. U.S. (15) 4. CA (10) 5. OR (8) 6. Hoopa Tribe (6)	1. KBRA (22) 2. KHSA (20) 3. KB Coalition (16) 4. U.S. (15) 5. CA (11) 6. OR (9) 7. Yurok Tribe (7) 8. CA Dept. of Fish & Game, Karuk Tribe, Klamath Tribes, PacifiCorp (6)

[a] Freeman graph centralization measure: the degree of inequality or variance measured as a percentage of the observed network that is similar to a perfectly centralized network.
[b] Numerical values reflect normalized betweenness calculations: betweenness expressed as a percentage of the maximum possible betweenness for that particular node.
[c] Numerical values equal total number of ties for the listed nodes.

for administrative direction, legal authorization and other support such as funding. Network researchers have used measures of degree-centrality to indicate the importance of these well-connected actors as brokers of information, communication and trust between potentially disparate subgroups of a larger network (Granovetter, 1973; Bodin et al., 2006). A visual example of the power of these actors is illustrated by the group of nodes that connect the Klamath Basin Coalition of environmental NGOs with the larger network in Fig. 1b and c.

During the conflict period, the most central actor in the Klamath water governance network was the U.S. federal government. This fact is not surprising given the nature of resource governance contestations at play in the basin: federal irrigation project operation plans; endangered species litigation; Clean Water Act violations; settling tribal water rights claims; and the federal-tribal trust nexus. Litigation over water allocation also played a large role during the conflict period as a connector of organizations for information sharing, trust building and resource allocation with an adversarial aim. Litigation roughly divided the basin into two camps, the most connected camp represented by both the defendants of *Kandra v. United States* (2001) and the plaintiffs in *PCFFA* vs. *U.S. Bureau of Reclamation* (2001).

Over time, however, the nature of approaches to resolving resource conflict and adjusting resource governance in the basin changed, as indicated by a shift in the most central and influential groups in the basin – new nodes formed as coalitions of organizations and stakeholder groups (e.g., the Klamath Basin Coalition of environmental NGOs and the FERC alternative settlement negotiation "Extended Caucus"). The creation of these groups also symbolized a designed increase in communication for the transparency of negotiating a vision for governance; this increase in stakeholder communication ultimately manifested as increased trust and knowledge sharing – key elements of adaptive capacity that support transitions toward adaptive governance (Folke et al., 2005; Chaffin et al., 2014b). As the governance network progressed from negotiation to agreement, some of these network changes were formalized with the commitment of certain parties to the Klamath Agreements. In addition, the influence of specific groups and organizations on the processes of governance change became increasingly apparent through their emergence as key brokers in the network (e.g., see organizations listed under "node betweenness, 2009–2010, #6" in Table 3). Node-level measures of betweenness and degree centrality, while they cannot be used as exclusive predictors of the emergence of adaptive governance, can be valuable to determine changes in a governance network indicative of increased interaction, trust, communication, collaboration and influence. Alternatively, the absence of change in node-level metrics may indicate space where the creation of new, connected focal nodes (organizations, coalitions) might be necessary to enhance adaptive capacity and catalyze a governance transition.

5.2. Broader policy implications of institutional SNA

It is clear that SNA metrics interpreted in isolation of more contextualized information on governance transitions are not enough to indicate a transition toward adaptive governance. But what is also clear is that SNA represents a powerful tool for qualitatively (visually and graphically) representing changes in governance networks over time, both collectively in terms of a whole network and via the change in position of individual nodes. This act in itself is valuable, especially as water policymakers look toward the model of large-scale negotiated agreements like those proposed in the Klamath Basin to solve other complex water

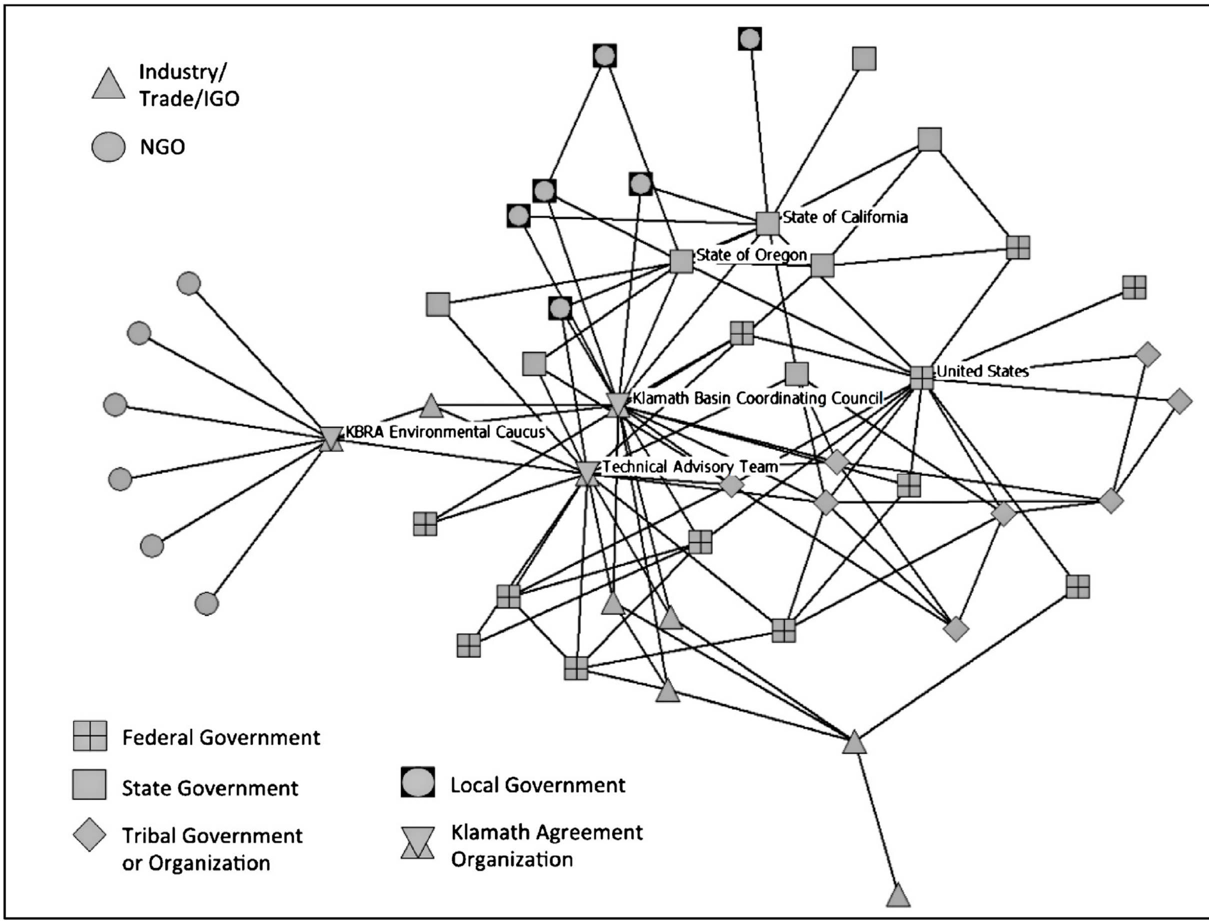

Fig. 2. Projected sociogram of organizational relationships between environmental governance organizations in the Klamath River Basin given U.S. Congressional approval and funding of the Klamath Agreements.

conflicts (e.g., California Bay Delta). To demonstrate this idea, we have hypothetically 'mapped' the Klamath Agreements as they would function if ratified and funded by the U.S. Congress (Fig. 2). What we find is that the Klamath Agreements create new permanent nodes in the altered governance network. These nodes, based on their responsibilities detailed in the Agreements, would be centralized in positions as information brokers and conflict resolvers (Fig. 2). Based on our map, the created nodes would serve a points of centralization for subgroups of similar organizations and stakeholder groups to receive information and participate in larger network governance – decreasing the hypothetical network 'distance' that many nodes would have to 'travel' to participate in meaningful water governance decision making. At the same time, these new nodes do not displace the centralization of important actors such as the U.S. government, states, tribes and the caucus of environmental NGOs. Instead of a mostly hierarchical network (e.g., Fig. 1a), the governance network under the Klamath Agreements would be distinctly polycentric, with multiple and overlapping centers of decision making, political, organizational and communicative power.

The institutional SNA described herein can be employed to proactively analyze proposed formal governance changes similar to those proposed in the Klamath Agreements, as well as at different scales. The technique relies on publically available information and avoids the necessity and expense of collecting politically sensitive information for actors involved in governance change. Using a comparison of network metrics and more qualitative contextual information, this method presents a relatively approachable way to analyze changes in key aspects adaptive capacity in governance networks (e.g., trust, communication, polycentricity, participation and collaboration), over time periods that include potential futures. The methodology presented here is also not limiting. Additional characterization of nodes and ties within the network by collecting data on type and strength of certain relationships (Ernstson, 2011) could add a layer of political analysis to institutional SNA, potentially more likely to predict obstacles and opportunities for building adaptive capacity and supporting transitions toward adaptive governance.

6. Conclusions

Beyond the methodological advances discussed above, our conclusions from this research are twofold. First, specific network- and node-level metrics calculated using quantitative SNA procedures are inconclusive for identifying structural increases in adaptive capacity, and thus this approach alone is inadequate to signal transitions toward adaptive governance. However, taken together with a more nuanced qualitative analysis of contemporary and historical governance contexts, the resulting cumulative analysis of SNA metrics have the potential to illuminate how structural network change supports transitions toward adaptive governance. This type of analysis addresses a persistent void in environmental governance research: how and when should governance actors willfully initiate transitions toward adaptive governance? Understanding the adaptive capacity built and deployed through institutional networks during times of transition may yield insights for actors and organizations interested in creating policies that foster similar changes in other systems and across differing contexts.

Secondly, institutional SNA can provide benchmarks for tracing the continued evolution of governance networks of SESs in transition. In the Klamath Basin, for example, legal developments have continued (beyond the temporal bounds of our case study) to influence governance network developments, which in turn have continued to shape adaptive governance responses. In 2013, the Oregon Water Resources Department completed an adjudication of surface water rights in the Oregon portion of the Klamath River Basin, for the first time quantifying and prioritizing water rights of The Klamath Tribes. The court determined that the Tribes (through their trustee the United States) hold a substantial quantity of senior (dated from 'time immemorial') water rights in the headwaters of the Klamath system, a finding which altered political and social dynamics in the basin yet again. Just months after the court decision, the Klamath Tribes 'called the river,' effectively asserting their water rights to see that water be left in the river as flows for migrating salmon. This action brought several peripheral groups who had refused to sign the Klamath Agreements (and were negatively affected by this 'call') back to the negotiating table to become integrated into the terms of the Klamath Agreements. When analyzed, however, these network shifts will be more meaningful in light of the multi-phased institutional SNAs that we have already completed for the basin.

The institutional SNA methods presented herein should be considered in the early stages of development. We suggest that the technique be built upon by other scholars in an effort to increase the amount and type of data that can be easily gathered and employed to characterize and analyze relationships between institutions and organizations and to expand the use of network metrics to create signals that indicate shifts toward adaptive governance.

Acknowledgements

This research was partially supported by a U.S. Environmental Protection Agency (EPA) STAR Graduate Fellowship (#917277); scholarship funding from the Association of California Water Agencies; and a National Research Council Research Associateship Award administered at the National Risk Management Research Laboratory, U.S. EPA, Cincinnati, OH.

Appendix A. Supplemental material

1. Klamath River Basin (map). U.S. Department of the Interior, Bureau of Reclamation. USBR Klamath Basin Area Office. Compiled by M. Neuman, September 1999. URL: http://klamathrestoration.gov/sites/klamathrestoration.gov/files/Maps/Klamath-Basinmap-from-Reclamation.pdf.

2. The Klamath River Hydroelectric Project Facilities (map). U.S. Department of the Interior, Fish and Wildlife Service. Klamath Falls Office, Klamath Falls, OR. Revised by B.J. Brush, 12 April 2006. URL: http://klamathrestoration.gov/sites/klamathrestoration.gov/files/Maps/PacifiCorp-Facilities-map.pdf.

3. The Klamath River Basin (topography and rivers map). U.S. Department of the Interior, Fish and Wildlife Service. Klamath Falls Office, Klamath Falls, OR. Prepared by B.J. Brush, 3 March 2004. URL: http://www.fws.gov/yreka/Maps/KlamathRvBasinDEM.jpg.

4. The Klamath River Basin (land ownership map). U.S. Department of the Interior, Fish and Wildlife Service. Klamath Falls Office, Klamath Falls, OR. Revised by B.J. Brush, 25 August 2003. URL: http://www.fws.gov/yreka/Maps/KlamathRvBasinV4.jpg.

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