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Adaptive institutions in social-ecological systems governance: A synthesis framework

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ABSTRACT

Adaptive governance of social-ecological systems depends on adaptive institutions. Efforts to understand the factors affecting adaptive institutions have identified many variables, but our understanding is constrained by multiple definitions of these concepts. In this article, we synthesize across two decades of studies relating to adaptive institutions. After clarifying some definitional confusion in the literature, we provide a theoretical framework to guide research on purposeful institutional change. While numerous scholars have identified a wide variety of important factors, we find that many of these factors can be traced back to (1) federalism and polycentricity and (2) networks and learning. Our synthesis suggests several avenues for future research centered on these factors. For example, how might the potential negative effects of key facilitating variables such as polycentricity (e.g., racial segregation and income sorting) and heterogeneous networks (e.g., increased coordination costs) hinder adaptive institutions? How can learning through both scientific and time-and-place knowledge promote adaptive institutions? More broadly, social science can play an important role in identifying factors that foster adaptability in different contexts, so that policy makers can promote such adaptability.

1. Introduction

Longstanding approaches to solving ecological and social problems are often insufficient to address complex, highly interactive challenges facing our world today. Climate change, species loss, non-point source pollution, and technological and population pressures on scarce resources are all examples of problems that arise in social-ecological systems (SES). SES are systems that involve both natural/ecological and human/social components that interact to affect system dynamics. Such challenges have led to calls for increasing attention to how societies organize governance and institutions. As an integral component of governance, institutions are of particular interest. Our ability to purposefully change institutions to enhance adaptive governance requires better understanding of how politics, science, and other factors affect institutional change, as addressed in this Special Issue. Our contribution is in the form of a synthesis and research agenda that broadens the concepts of politics and science to include political structures, e.g. federalism and polycentricity, and learning, where science and other factors can promote knowledge. We start by clarifying how institutions are conceptualized in SES studies and conclude with a

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research agenda building on these prior studies and our new theoretical framework.

1.1. *Adaptive governance*

A leading approach to successfully meet the challenges of changes in social-ecological systems is adaptive governance. Adaptive governance has gained widespread support among scholars, who argue that it is responsive to emerging problems and knowledge surrounding complex ecological systems (Heikkila, 2010; Gunderson and Light, 2006). Some find that adaptive governance can foster effective management and use of shared assets such as common pool resources and environmental assets that provide ecosystem services (Hatfield-Dodds et al., 2007). Others emphasize the complementary government and community-based institutional arrangements that work together in adaptive governance to improve natural resource management (Nelson et al., 2008). At its core, adaptive governance aims to provide for collaborative, flexible, and learning-based approaches to managing ecosystems (Olsson et al., 2006).

From a practitioner perspective, adaptive governance has been described as a move from the conventional view of institutions as ''static, rule-based, formal and fixed organizations with clear boundaries'' to a view of institutions as ''more dynamic, adaptive and flexible for coping with future climatic conditions'' (IISD, 2006, p. 6). Adaptive governance is an approach that is expected to generate the desired end goal of adaptive capacity (Cook et al., 2011). As described by Folke et al. (2005, p. 452), ''Systems with high adaptive capacity are able to reconfigure themselves when subject to change without significant declines in crucial functions of the socio-ecological system.''

Despite its popularity, conceptual clarity on the concept of adaptive governance and its precursors is lacking. Some scholars conflate adaptive governance with adaptive institutions. For example, Hatfield-Dodds et al. (2007, p. 4) define adaptive governance as the ''evolution of rules and norms that promote the satisfaction of underlying human needs and preferences given changes in understanding objectives, and the social, environmental, and economic concepts.'' Thus adaptive governance is defined as changing rules and norms (institutions, as defined by Ostrom (1990)). Others describe governance more broadly, such as ''a range of institutions and relationships involved in the process of governing,'' which ''includes both formal institutions such as laws, policies, and organizational structures, and informal institutions: the power relations and practices that have developed and the rules that are followed in practice'' (Huitema et al., 2009, p. 3). One of the likely reasons for this ambiguity in definitions of adaptive governance is that governance prominently includes aspects of rules, norms, and other institutional elements. However, since governance includes elements in addition to institutions (e.g., resources, leadership, etc.), and since governance includes several actions not included in institutions (production, provision, consumption, financing, coordination, dispute resolution, rule-making), the two concepts are distinct. Other scholars have treated the concept of polycentricity (multiple overlapping centers of authority) as a component of adaptive governance, rather than as a precursor to it (e.g., Lee, 2003). Thus there is a need for greater conceptual clarity of key concepts such as adaptive governance, adaptive institutions, and polycentricity.

Considering the many interpretations of adaptive governance, we find clarity in two succinct elements. First, ''adaptive'' has been described as ''recover[ing] or adjust[ing] to change through learning and flexibility, so as to maintain or improve to a desirable state'' (Engle and Lemos, 2010, p. 1 drawing on Nelson 2007 and Folke et al., 2006). Similarly, Cook et al. (2011) refer to responding to or shaping variability or change. Second, ''governance'' has been defined as the ''process by which the repertoire of rules, norms, and strategies that guide behavior within a given realm of policy interactions are formed, applied, interpreted, and reformed'' (McGinnis, 2011b, p. 171). The generic tasks of governance include production, provision, consumption, financing, coordinating, dispute resolution, and rule-making (McGinnis, 2011a, p. 58). Combining these two elements, we define adaptive governance as steering policy interactions to guide management of resources in a manner that is able to recover or adjust to change so as to maintain or improve to a desirable state. The adaptive governance approach is especially relevant for social-ecological systems, whose dynamic nature is not well served by a static approach. These systems occur at a variety of scales and include a wide range of resources, from local fishing economies to global climate change (Ostrom, 2009).

If adaptive governance of social-ecological systems is a desired approach, then we should seek to understand what factors promote it. Several studies in the past two decades have identified a variety of such factors operating in different contexts, including polycentric systems, vertical coordination, informal networks, learning, leadership, evolving rules, information, conflict resolution, rule compliance, infrastructure, institutional preparedness for change, nested institutions, institutional variety, dialog, social capital, memory, knowledge, cross scale interaction, multi-level governance, and organizations. As described below, many of these factors influence adaptive governance through the promotion of adaptive institutions. Below we synthesize across studies to develop a theoretical framework of variables connected to adaptive institutions and adaptive governance. We start with adaptive institutions, then discuss important precursors of adaptive institutions: federalism and polycentricity; learning and networks; and other variables.

2. Methods

This study draws on a wide range of literature relating to adaptive governance, adaptive institutions, adaptable institutions, polycentrism, social learning, networks, and collaboration. Key word searches on these terms, via Google Scholar, provided the basis for identifying appropriate articles and books. Although the field of adaptive governance is broad, we focused on a narrower set of literature, those theoretical and empirical manuscripts describing factors related to adaptive institutions, and precursors to

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those factors. Our review of literature included SES across a variety of locations, types and scales.

The team of investigators spent collectively over 70 h identifying, collecting, and summarizing such manuscripts. We collected over 40 manuscripts in total, and each investigator read his/her manuscripts in search of key factors described therein relating to adaptive institutions. Each investigator coded these into different categories of proximate factors (e.g., leadership, institutional variety, social learning) and then more distal factors affecting these proximate factors (e.g., networks, polycentrism). This approach followed grounded theory, where themes emerged from the data, rather than imposing preconceived categories of variables (Glaser and Strauss, 1967). Weekly and bi-weekly team meetings throughout the academic year provided opportunities to compare individual findings, develop common definitions, and identify emergent themes across the manuscripts. We continued our searching and coding until we reached a point of saturation; that is, no additional factors were discovered in new manuscripts. If a factor was linked by the manuscript author(s) to adaptive institutions directly or via the precursor variables, we included it in our framework; otherwise it was excluded. We developed the structure of our final Adaptive Institutions Framework by synthesizing variables across the collected manuscripts that other authors argued to be causal linkages (see Fig. 1). Each of the boxes (variables) in the diagram is subsequently described in text.

3. Findings

3.1. *Adaptive institutions*

A leading definition of institutions is ''enduring regularities of human action in situations structured by rules, norms, and shared strategies,'' (Crawford and Ostrom, 1995, p. 582). Institutions are created by people and, in turn, institutions organize and structure human behavior towards collective ends (Ostrom, 2005; Bussey et al., 2012). As such, institutions affect choices made in the process of governing, and institutions can promote or hinder individual actions to adapt to changing conditions.

Adaptive institutions are those that actors are able to adjust to encourage individuals to act in ways that maintain or improve to a desirable state. Such adjustment demonstrates flexibility and diversity, where the ''ability of the institution to bend, but not break, and to learn through experience, speaks to its ability to manage crisis effectively and efficiently'' (Engle and Lemos, 2010, p. 8). Adaptive institutions are able to cope with multiple ambiguous objectives inherent in social-ecological systems (Pahl-Wostl, 2009). Scholars have identified numerous characteristics of adaptive institutions, including participatory, inclusive, integrative, risk tolerant, flexible, legitimate, accountable, diverse, creative, learning, iterative, autonomous, resourceful, self-assessing, collaborative, transparent, reflexive, and integrated with broader

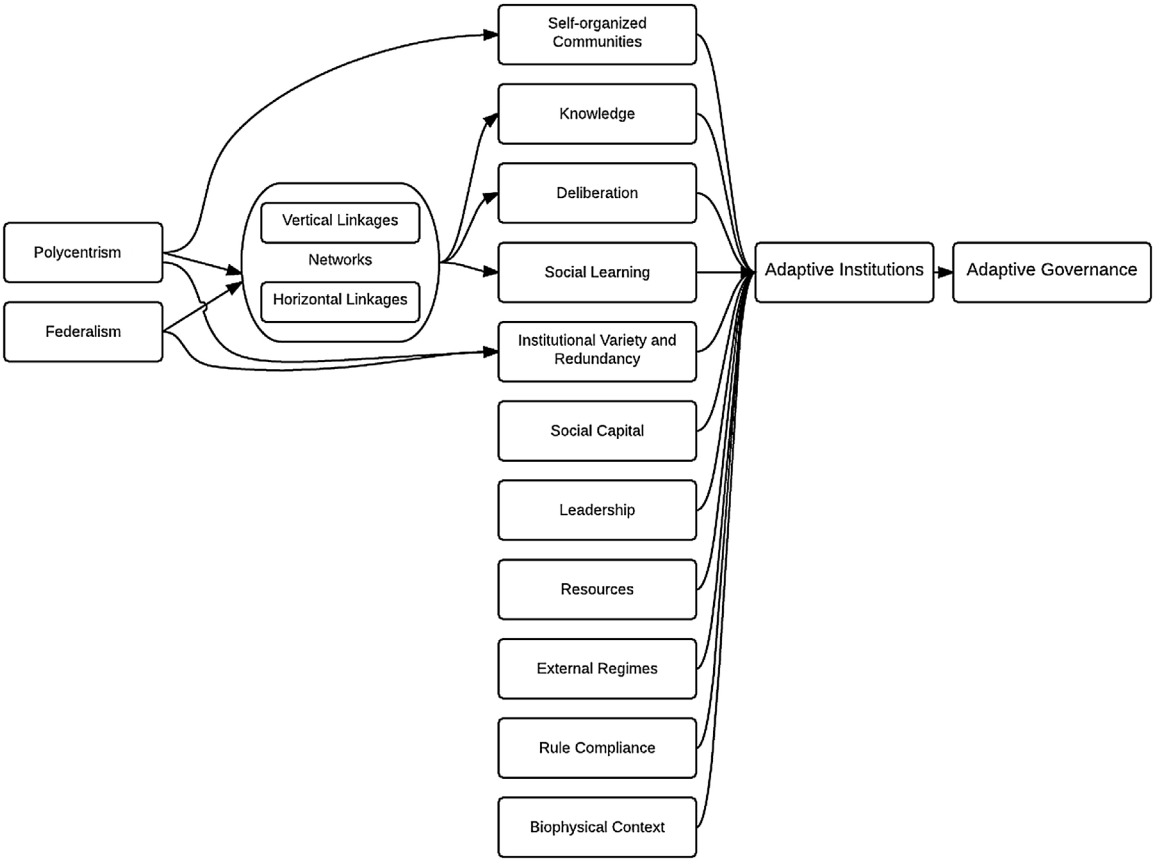

Fig. 1 – Adaptive institutions framework.

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processes (Short and Phelps, submitted for publication; Stankey et al., 2005; Cook et al., 2011; Gupta et al., 2010; Jacobs and Mulvihill, 1995). These characteristics are described as normatively desirable, since they help promote the desired end of more successful problem solving. Thus adaptive institutions are different from the more general concept of institutional change, wherein institutions change but not necessarily in a direction that maintains or improves to a desirable state. For instance, institutional change could make an institution less adaptive or improve an institutional characteristic other than adaptiveness.

Adaptive institutions are important for adaptive governance. Foerster (2011) argues that adaptive institutions are necessary to move towards sustainability outcomes because of their ability to adjust participation from multiple stakeholders with multiple interests that evolve over time. They encourage experimentation with different approaches to respond to challenges that arise, which promotes adjustments to social practices that affect the system (Orlikowski, 1996). Adaptive institutions are thought to help a governance system cope with uncertainty and complexity (Huntjens et al., 2012). In order to adjust systems to environmental issues, and make and implement the right decisions, institutions need to be changed, adjusted, expanded, or created (Short and Phelps, submitted for publication). Adaptive institutions have been highlighted by scholars studying water resource systems, wetlands, climate change, flood infrastructure, and more generally the ''tragedy of the commons'' dilemma facing many social-ecological systems (Méndez et al., 2012; Moench, 2010; Huntjens et al., 2012; Cannibal and Winnard, 2001; Cook et al., 2011).

Birkenholtz (2009) provides one such example. Farmers in Rajasthan, India, traditionally used institutions of property rights that encouraged individual tube wells for crop irrigation and drinking water. However, as ecological conditions changed and water became scarcer, they adapted these institutions to encourage tube well-owning partnerships with each other. These partnerships changed existing institutions and led to new arrangements for coordinating tube well operation and maintenance activities. Existing power relationships in the system also changed. Previously the eldest was the main decision maker and had authority to make his cropping decisions first with others following suit. However, in the new arrangements, if technological knowledge about the tube wells is available to a younger member of the family, that member becomes the decision maker and makes his cropping decisions first. This example illustrates that an improvement towards adaptive institutions might occur either by altering existing institutions so that they are more adaptive, or by creating new ones that are adaptive (or both).

The presence of multiple adaptive institutions promotes adaptive governance. Adaptation suggests that different institutions will evolve in different ways, based on local conditions, which yields a diverse variety of institutions within the system. This variety allows for testing of rules at different scales and contributes to the creation of institutional dynamics important for building adaptive capacity in social-ecological systems (Folke et al., 2002; Ostrom, 2005). This institutional variety also fosters variety in the actors, leading to a greater diversity of ideas, skills and competences to cope with the complexity of natural resource systems (Carlsson and Sandström, 2008). In addition, multiple adaptive institutions promote redundancy of institutional functions, which fosters adaptive governance (Dietz et al., 2003; Rijke et al., 2012; Huitema et al., 2009). Systems are less vulnerable to collapse because if one part of the system fails, another part can take over its functions. Low et al. (2003) suggest that the redundancy of institutions and their overlapping nature across organizational levels plays a central role in absorbing disturbances and spreading risks. Exogenous political and economic (fast moving) institutions need to co-evolve with endogenous traditional and cultural (slow moving) institutions for the survival and adaptation of SES to global market disturbances.

In contrast, non-adaptive institutions are hard to change due to factors such as lack of regular collective choice discussions, inadequate means to incorporate new information to inform institutional changes, and collective-choice decision rules that prevent changes without high levels of agreement (such as consensus). For example, Ostrom (1990) discusses cases of institutional fragility and failure. She describes a Turkish in-shore fisheries case where institutions well-suited to the context of a limited number of fishers appeared to be incapable of adjusting to address increased demand for fishing, since the users did not establish regular arenas for incorporating a larger number of fishers in collective choice discussions. As another example, Dietz et al. (2003) describe a cod fishery in northern Canada which collapsed when rules failed to reflect new factual information about ecological conditions and human actions and values. In addition, Layzer (2008) describes how the use of consensus decision rules prevented the strengthening of regulatory structures that would have better protected terrestrial and aquatic ecosystems in the face of development pressures. She found that consensus made it easy for any single individual to prevent a protective action, and the result was a 'least common denominator' plan instead of a change from the status quo that would solve the environmental problems. In the above examples, more adaptive institutions could have adjusted rules based on new information and fostered strategies to overcome complexity and uncertainty that threatened the systems.

3.2. *Federalism and polycentricity*

3.2.1. *Conceptual clarification*

Of the factors listed above (see Fig. 1) that promote adaptive institutions, many follow from the networks of interactions that arise from federalism or polycentrism. The terms ''federalism'' and ''polycentrism'' are often used together, and indeed they share many features. However, they are distinct concepts, and it is important to clearly define the two before delving into the relationships between federalism and adaptive institutions, and polycentricity and adaptive institutions.

Federalism is a system of governance marked by multiple, nested jurisdictions of multi-purpose authority, where each jurisdiction has some ability to operate independently (Oakerson and Parks, 2011; Riker, 1964; Madison, 1951). Federalism scholar Vincent Ostrom described federalism as a covenantal system where citizens participate in shaping

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rules that govern society via multiple centers of authority (1994). Federalism is typically contrasted with unitary political systems, where power and authority rest in the center, e.g., a national government that takes primary responsibility for policy decisions throughout the nation, unchecked by lower levels of authority.

The concept of federalism is closely aligned with Hooghe and Marks's (2003) ''Type 1'' governance. Type 1 jurisdictions are characterized as multi-purpose governments with general powers over many different policy issues, and which often include legislative, executive, and judicial functions. They are incorporated into a hierarchically structured political system, with mutually exclusive territorial boundaries at a given level (e.g., counties), overlapping nestedness across levels (e.g., counties within a state) and established channels of representation.

The term ''federalism'' is often used to connote national-subnational government relations (e.g., Hooghe and Marks, 2003). For example, much has been written about the U.S. federal system and debates in the Constitution about the role of states versus the national government. In this vein, studies of federalism have often examined power differentials across levels of government. Elected officials and agency personnel at different levels are thought to pursue different types of policies (Peterson, 1995; Koontz, 2002). Another branch of scholarship, intergovernmental relations, has examined how different levels of government share power and resources (for a review see Conlan, 2006).

Polycentricity has been defined as a system of governance featuring multiple, overlapping jurisdictions at different scales, each with some independent authority over particular issues or functional areas. Vincent Ostrom et al. (1999, p. 73) define polycentricity as ''a pattern of organization where many independent elements are capable of mutual agreement for ordering their relationships with one another within a general system of rules.'' In other words, polycentricity describes a governance system of ''qualified independence among interdependent centers of authority'' (Oakerson and Parks, 2011, p. 154).

A key feature of polycentricity is adaptable boundaries. Unlike a federal system, where jurisdictional boundaries are typically wholly contained within a higher level jurisdiction and fixed over long time horizons (e.g., national, state, and county boundaries in the United States), polycentricity features new jurisdictions being created as needs arise. For example, the E.U. Water Framework Directive created river basin jurisdictions for the special purpose of water management spanning existing jurisdictional boundaries of nations and states within nations (Roggero and Fritsch, 2010). These new boundaries can be made to match the scale of the issue at hand, for example a watershed, and not necessarily contained within just one higher level jurisdiction, such as a nation.

Polycentric systems typically exist within federal systems. They often are described as self-organized, arising in a bottom-up fashion, as stakeholders interested in particular goods or services institute arrangements to do so (Pahl-Wostl, 2009). The presence of a variety of special purpose jurisdictions encourages people to create new, self-organized arrangements to tackle common problems. Although polycentric institutions are often associated with federal systems, they can be created outside of federal systems, such as when the French national government (a more unitary system) created regional watershed jurisdictions that overlapped existing local government boundaries (Buller, 1996).

The concept of polycentrism is closely aligned with Hooghe and Marks's (2003) ''Type 2'' governance. The Type 2 jurisdictions are defined as jurisdictions spanning vertically across political organizations and horizontally across public and private sectors, whose boundaries are not mutually exclusive but rather overlap geographically and lack established channels of representation. Similarly, Oakerson and Parks (2011) describe this type as a ''special purpose'' government.

Closely related to polycentricity is collaborative governance. In collaborative governance, governments or non-governmental actors configure and reconfigure networks and organizations related to a particular issue or functional area (Ansell and Gash, 2008). Collaborative governance shares many features with polycentricity. For example, collaborative governance for environmental issues such as watershed management are marked by overlapping boundaries (watersheds that cross political jurisdictions), a focus on a particular issue, and power sharing across multiple jurisdictions (Koontz et al., 2004; Sabatier et al., 2005; Schlager and Blomquist, 2008).

3.2.2. *Federalism and polycentricity promote adaptive institutions and governance*

A key feature of both federalism and polycentricity is the creation of networks of interactions across different scales. Federalism promotes interactions up and down levels, as jurisdictions work out power and resource sharing. For example Scheberle (2004) described how USEPA shares information and oversight with state environmental protection agencies. Federalism also promotes interactions within a level, as when neighboring jurisdictions seek advice from their peers (Wilson, 2002). Polycentricity promotes interactions across scales and at different scales, as a jurisdiction overlaps physical space with multi-purpose government jurisdictions (e.g., a watershed that crosses county or state boundaries) or is itself a subset of a larger scale boundary (e.g., a watershed that is part of a larger water basin) (Imperial, 1999; Wilson, 2002).

Interactions provide several benefits. First, they expose decision makers to a greater diversity of solutions that may be used. This is especially true for interactions that occur across scales (Ostrom, 2005). Second, and related, interactions promote learning. The autonomous decisions made by multiple jurisdictions provide a set of ''natural experiments'', whereby decision makers in one jurisdiction can learn from the successes and failures from others (Pahl-Wostl, 2009; Hooghe and Marks, 2003; Imperial, 1999). This is particularly important across scales, as larger-scale systems can capture some of the feedback that might be lost at the smaller scale; information that ''leaks'' out of one local jurisdiction can still be included within the larger scale jurisdiction (Wilson, 2002). Third, interactions help reduce conflicts that might arise from competing jurisdictions, as decision makers discuss and share their preferences and ideas and discover common ground (Pahl-Wostl, 2009).

Another key feature of federalism and polycentricity is redundancy and overlap. Federalism has been described as

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providing some redundancy built into the system, as neighboring jurisdictions and multilevel adjacent jurisdictions may provide goods and services in case of failure of a particular jurisdiction to provide them. In the environmental arena, for example, many national laws provide state primacy for particular functions (e.g., state implementation plans in the United States under the national Clean Air Act), with the national government as a backstop in case a state does not do so. In a polycentric system, redundancy comes from the existence of multiple and overlapping jurisdictions which might combine and cooperate in new ways as needs arise. The high degree of redundancy and overlap in federal and polycentric arrangements contributes to adaptive governance (Dietz et al., 2003), makes social-ecological systems less vulnerable to collapse, and promotes institutional adaptation (Huitema et al., 2009; Huntjens et al., 2012). For example, in the Netherlands and South Africa, water board and catchment management authorities, respectively, are nested quasi-autonomous decision-making units operating at multiple levels representing polycentric institutional arrangements (Huntjens et al., 2012).

Finally, polycentricity promotes self-organized institutions, because individuals in a polycentric system are empowered to develop collective solutions to local problems as they arise. Ostrom (1990) argues that these institutions may provide more effective solutions to collective action problems than centrally mandated institutions because they foster local knowledge, inclusion of participants, better adapted rules, and lower enforcement costs. In a successful self-organized institution, resource users willingly invest time and energy in managing resources since they consider those resources to be salient to them and have autonomy to devise and change rules. These rules generate a greater legitimacy among participants, who can design levels of flexibility and enforcement. Moreover, successful self-organizing effort can lower the transaction and coordination costs involved in governance and participation (Imperial, 1999). Many variables can affect the success of self-organized institutions in socio-ecological systems; Werthmann (in this issue) found that variables that directly concern the users (number of users, leadership, norms/social capital, knowledge of socio-ecological systems) promote self-organization.

Of course, federalism and polycentrism are not panaceas. Multiple jurisdictions interacting can generate significant transactions costs, including coordination and information sharing costs. This fragmentation of authority can act as a barrier to adaptive strategies in the face of large scale challenges such as climate change (Eisenack et al., 2014). Operation of polycentric governance systems requires repeated expenditure of time and effort for coordinating and sometimes defending turf (Imperial, 1999; Ross et al., 2013). Creating and changing institutional arrangements can be costly (Ostrom, 2005). Polycentric systems often require substantial effort from private and public entrepreneurs (McGinnis, 2011b). The act of establishing a new jurisdiction to address a collective action problem is itself a collective action problem, as individuals must provide effort and resources for the benefit of a larger group (Lubell et al., 2002). This has been called a ''second order'' collective action dilemma. At the same time, if such startup costs can be overcome, the new institution can benefit from the repertoire of general design principles that can be drawn on by resource users at multiple levels to aid in crafting of new institutions that cope with changing situations (Dietz et al., 2003).

Although polycentric systems are adept and flexible in producing and providing municipal services and a variety of interlocal agreements, they can give rise to spillover effects, with potentially undesirable consequences for racial segregation, income sorting, urban sprawl, and environmental degradation (Ross et al., 2013; Howell-Moroney, 2008). Considerable evidence shows that sorting of citizens in metropolitan areas involves more than mere comparison of municipal services, as citizens are also driven by a desire to create bastions of affluence that exclude low-income persons. This sorting manifests in a variety of forms including poverty concentration in central cities and urban sprawl (Howell-Moroney, 2008).

3.3. *Learning and networks*

Researchers have identified learning as one of the crucial factors fostering adaptive institutions and governance. Learning is important for developing adaptation objectives, identifying knowledge gaps, and creatively improvising solutions (Olsson et al., 2006; Folke et al., 2005; Brockhaus et al., 2013). The culture of social and institutional learning is of particular importance for social-ecological systems, as it allows actors within the system to question embedded ideologies, frames, assumptions, claims, rules, roles and procedures (Pahl-Wostl, 2009; Gupta et al., 2010; Cook et al., 2011).

Social learning occurs as people interact with each other, producing knowledge together that is relational and collectively oriented (Schusler et al., 2003; Muro and Jeffrey, 2008). This process includes both information transfer among individuals, as well as an emergent collective property through group interactions that lead to group agreement, trust, and commitment to a shared vision (Ison et al., 2013). Social learning enables people to use their experience with change and successful adaptations to develop appropriate strategies for dealing with ongoing change (Folke et al., 2009). Such strategies can include both individual actions and actions that change institutions.

Learning about institutions occurs when people view policies as ongoing experiments that need to be monitored, evaluated and adapted over time (Ostrom, 2005). Knowledge acquisition is an ongoing, dynamic process that is accumulated in institutions over decades and helps create institutions that promote responses to environmental change and the ability to deal flexibly with new situations (Folke et al., 2005; Huitema et al., 2009). Pahl-Wostl (2009) identifies three types of learning: single loop, where existing institutions are not questioned; double loop, where a reinterpretation of established institutions occurs; and triple loop learning, where established institutions are changed and/or new institutions are created. In the latter, substantial changes are seen in the regulatory framework of formal institutions, new policies are implemented, and flexible and context specific regulations are implemented. New norms, discourse, and practices come into informal institutions.

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A key aim of learning is knowledge gain. Here science can make important contributions to managing social-ecological systems, by informing policy objectives, management models, and standard setting (Robinson et al., 2011). Scientific knowledge at its best is empirically verifiable, transparently generated, reliable, and explicit about levels of uncertainty, serving as a foundation for efforts to address ecological challenges. However, numerous studies have demonstrated the challenges of turning scientific knowledge into usable knowledge that informs institutional change. Scientists usually operate within disciplinary communities that value written information, lengthy papers/articles, specialization, and peer review in pursuit of questions to build theory. In contrast, policy makers and managers operate within communities that tend to emphasize information that is more integrated, concise, and can be put to work quickly to solve problems (Caplan, 1979; Cerveny and Ryan, 2008). Thus scientific knowledge communicated via journals and scholarly conferences may not provide information in form or content that is taken up by decision makers (Lemos and Rood, 2010). Milkoreit et al. (in this issue) also argue that science needs to be moved into the policy sphere in order for it to become useful in decision making.

Beyond better communication from scientists to policy makers, efforts to better integrate science into policy making have centered on collaborative knowledge co-production. For example, deliberative for a feature the sharing of information and ideas and opportunities to work through conflicts (McCay, 2002). Dialogs involving scientists, resource users, and the public can improve trust, build social capital, and allow for institutional changes in times of conflict (Dietz et al., 2003; Olsson et al., 2006). Having face-to-face interactions with stakeholders also can help to change the perceptions of key individuals who may resist transformational change (Olsson et al., 2006). These efforts can better integrate hypothesis-driven scientific information with local time-and-place knowledge (Ostrom, 1990; Wynne, 1996; Fischer, 2002).

In addition to scientific knowledge, experiential knowledge is important. Stakeholders gain important factual knowledge about the world through their lived experiences, and these insights can sometimes increase the validity and reliability of scientific information (Armitage et al., 2011; Allen, 2006). Moreover, experiential knowledge that affects individual preferences and values forms the basis of desires to change institutions. Thus combining both scientific and experiential knowledge is valuable for promoting adaptive institutions (Stivers, 2011).

Institutions can foster the accumulation of knowledge through local experience and scientific knowledge, thus equipping actors to better respond to environmental feedback. If this knowledge is diverse, the range of possible responses is greater, which improves adaptability (Crona and Bodin, 2012; Olsson et al., 2006; Hatfield-Dodds et al., 2007; Pahl-Wostl, 2009). Note that this suggests the dynamic interaction of knowledge and institutions; while knowledge and learning can foster adaptive institutions, such institutions may in turn promote further learning, creating a positive cycle. Since our interest here is to explain which factors promote adaptive institutions, we focus on the arrow from learning to adaptive institutions rather than the other direction.

Knowledge is built through multiple institutional linkages across user groups, communities, government agencies and non-governmental agencies. Interactions across these diverse levels generate knowledge to respond more appropriately to uncertainty and change (Pahl-Wostl, 2009; Folke et al., 2005; Berkes and Folke, 2002). Knowledge produced at one institutional level influences processes at another level (Pahl-Wostl, 2009). If there are institutional gaps, or if the institutional linkages are not well developed, critical knowledge may not be available to make required changes (Olsson et al., 2006). Thus these linkages are important for learning.

Social networks can be described as social structures made up of nodes (people and organizations) which are connected via a multitude of links (e.g., information flows, exchanges of resources, and legal relations) (Carlsson and Sandström, 2008). Social networks have the capacity to form institutional rules and norms that structure the behavior of individuals. The rise, substance, and structure of social networks affect and are affected by the specific institutional arrangements that evolve according to a given problem and a specific context (Carlsson and Sandström, 2008). This means that the interaction between networks and institutions is dynamic, but we are most interested in how networks affect adaptive institutions rather than vice versa. Social networks along with their supporting formal and informal institutions help in distribution of information and resources, and they contribute to the adaptability of a community (Kofinas, 2009).

Networks are closely tied to learning. It is through networks that individuals have opportunities for repeated interactions that are necessary for social learning to occur (Ison et al., 2013; Muro and Jeffrey, 2008; Schusler et al., 2003). Here individuals can learn about a range of SES components, including ecological relationships, what other stakeholders want, what is politically feasible, and how institutions affect planning and decision making (Koontz, 2013). In particular, informal networks are thought to promote learning by providing access to new kinds of knowledge and by supporting multiple ways of interpretation (Pahl-Wostl, 2009). The informality in networks also promotes flexible memberships, actor roles and powers, and connections, which in turn facilitate learning and change (Folke et al., 2009). Such informal networks have been found to promote social-ecological systems' access to novel ideas and ways of governance (Pahl-Wostl, 2009). Empirical evidence suggests that the formation of informal networks prepares a system for change by exploring alternative system configurations and developing strategies for choosing among possible futures (Pahl-Wostl, 2009; Nooteboom, 2006). Networks have the potential to enhance the resilience of social-ecological systems and thereby facilitate their ability to endure, especially under conditions of environmental risk and uncertainty (Carlsson and Sandström, 2008).

However, social networks are also capable of hindering adaptation. A dense network can exclude outsiders, cut off actors from new information, and impose social norms that discourage innovation (Portes, 1998; Newman and Dale, 2005). In addition, individuals occupying central positions in a network may feel obligated to please all, or most, of their numerous network neighbors, which can constrain their possibilities for action and impede the process of institutional

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adaptation (Crona and Bodin, 2012). Finally, although networks with bridging ties have heterogeneous sets of actors that are more likely to allow actors to possess outside information and overcome local social norms against adaptation, heterogeneity makes integration and joint decision making more challenging, which can hinder timely responses to rapidly changing circumstances (Carlsson and Sandström, 2008).

3.4. Other variables

A variety of additional variables have been linked to adaptive institutions, including social capital, leadership, resources, external regimes, self-organization, rule compliance, and biophysical context. *Social capital* refers to relations of trust, reciprocity, and connectedness in networks and institutions (Pretty and Ward, 2001). Social capital increases the flexibility of institutions and promotes innovation that aids in solving complex problems (Folke et al., 2009). It also promotes learning, which enables people to purposefully change institutions to meet new challenges in the face of uncertainty (Folke et al., 2009). Social capital helps to ensure long term resource management by creating incentives and enforcing regulations (Pretty and Ward, 2001). Of course, social capital is not always constructive. Some forms of social capital have a dark side in that they may prevent the emergence of accountability, perpetuate inequity, shape institutions based on the self-interest of certain individuals, and base these institutions upon fear and power (Portes and Landolt, 1996). Sometimes the negative impact of social capital is manifested in the form of powerful, tightly knit social groups, that are not accountable to citizens at large, and practice corruption and cronyism rather than promoting institutional adaptation (Narayan-Parker, 1999).

Leadership plays a key role in creating adaptive institutions and adaptive governance, especially with regards to developing strategies for exploring more adaptable configurations and learning from feedback (Olsson et al., 2006; Cook et al., 2011; Stankey et al., 2005). Folke et al. (2009) argue that leadership is essential in shaping change and reorganization by providing innovation to achieve flexibility in ecosystem dynamics. Leaders help to build trust, make sense, manage conflicts, compile and generate knowledge, communicate information, and mobilize broad support for change (Gupta et al., 2010; Folke et al., 2009; Bussey et al., 2012; Olsson et al., 2006). Gupta et al. (2010) argue that society is unable to respond to long-term, large-scale, complex challenges in the face of uncertainty without leadership because leaders help to promote innovative approaches in an institutions that help the system to adapt to change (Cook et al., 2011). Similarly, Saravana (in this issue) found that inadequate leadership was perceived to be affecting the distribution of water for two-thirds of the households in an irrigation society in India. However, the role of leaders in elite capture of institutions has also been well documented, which can create institutions that encourage resource exploitation (see Blaikie, 2006).

Besides leadership, people provide many important roles in adaptive institutions, which can influence adaptive governance. People fulfill key roles including knowledge carriers, retainers, interpreters, facilitators, visionaries, inspirers, innovators, experimenters, followers, reinforcers, generators, leaders, stewards, and environmental scanners (Folke et al., 2003; Holling, 1981). Individuals who can accept change and modify their personal behavior provide the basis for creating new and adaptive institutions in the face of uncertainty (Fazey et al., 2007).

Resources are an important factor affecting adaptive institutions and governance. Adequate financial, human, and technological resources, and flexibility in how to use them, allow people to craft institutions that are better prepared for unpredictable conditions that arise (Cook et al., 2011). Political and legal resources are also important for promoting adaptive institutions (Gupta et al., 2010).

External regimes such as government and non-government agencies have been found to both help and hinder adaptive institutions. (Note that while federalism, discussed earlier, includes regimes external to a given jurisdiction, here we are talking about not just federalism but any form of government, as well as NGOs.) On the one hand, increased external intervention diminishes autonomy, flexibility and the responsiveness of an institution (Smith, 2004). Mukhtarov et al. (in this issue) found that sometimes institutional designs imposed by external influence are not compatible with specific contexts.

On the other hand, external regimes can provide crucial resources in the form of funding, information, and training that can aid in adjusting institutions. For example, Laerhoven and Barnes (in this issue) examined 20 NGOs working in the field of forest governance in India and concluded that through their awareness building, training and capacity building activities, the NGOs were able to strengthen long-lasting collective action. Sometimes external agencies are also involved in monitoring and evaluation that help in identifying how effective current policies are, which can foster increased accountability and transparency for plans and management strategies in social-ecological systems (Nikolic and Koontz, 2008). An external regime that grants flexibility to institutions without having overlapping and contradictory policies gives the institutions room to adapt as new circumstances arise (Cook et al., 2011).

Rule compliance is a key consideration for successful governance and institutional maintenance. Enforcement involves monitoring and sanctioning to encourage compliance. Studies have demonstrated that user groups are capable of devising and monitoring their own rules, which are adapted to local conditions (Ostrom, 1990). However, even if such rules generate positive collective outcomes, the temptation for individuals to break them increases if they see others breaking them without consequence. Eventually, lack of rule compliance may lead to institutional breakdown and harm to the systems. Thus, enforcement efforts that are sufficiently dynamic to foster compliance with changing rules are critical for the ability of institutions to be adaptive.

Biophysical context impacts the ability of institutions to be adapted. Although adaptive institutions are largely a function of social and institutional factors, the ecological side of social-ecological systems also matters. In particular two characteristics of the biophysical world affect institutional adaptation: visibility and stability.

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In her work on social-ecological systems, Ostrom (2009) describes several ecological characteristics relating to visibility of ecological conditions. Some ecological conditions lend themselves better to accurate and reliable measurements that provide greater certainty of their status. These provide greater opportunity for institutions to adapt as the ecological system changes, as they are more predictable and allow people to understand the impacts of different actions on resource conditions. This feedback loop reduces uncertainty and enhances learning. In contrast, learning is reduced when people are unable to detect the magnitude or even existence of changes in ecological characteristics.

Greater resilience of an ecosystem also promotes institutional adaptation. As scholars have described system resilience, certain states may be stable and thus return after a perturbation, while others are unstable and quickly move away from a state (Carpenter and Kitchell, 1993; Gunderson, 2000; Gunderson and Holling, 2002). Wilson (2002) describes a positive correlation between adaptive institutions and the resilience in an ecological system. For systems that exhibit resilience, experience with them over time gives us a greater ability to gauge which actions and institutional changes are likely to successfully meet challenges. On the other hand, when a system flips to a new state, our prior understanding may mislead us and suggest interventions that would have worked in the previous system state but now fail to achieve desired ends in the new system state.

4. A research agenda

Many studies have identified variables that proximately affect adaptive institutions or adaptive governance. Our synthesis combines such findings in a theoretical framework that links both proximate and underlying variables. In particular, we find that federalism and polycentricity have powerful effects on adaptive institutions, both directly (by fostering institutional variety and redundancy and self-organized communities) and indirectly (by fostering networks, which in turn promote knowledge, social learning, and deliberation). These links suggest several fruitful avenues for future research, especially polycentricity and federalism, science and learning, and proactive adaptation.

The ability to create adaptive institutions is positively associated with polycentrism and federalism. It is likely that institutions within polycentric and federal systems are more adaptive than institutions in more centralized governance systems. At the same time, adaptive institutions can be fostered without polycentrism and federalism, if other arrangements provide networks and other key factors such as resources, rule compliance, social capital, and leadership. In any case, the identification of federalism and especially polycentrism as affecting the ability of institutions to adapt highlights a deeper cause underlying the proximate factors such as social learning and knowledge that are often identified in studies of adaptive governance (e.g., Cook et al., 2011). It also suggests several research questions. The existence of overlapping, nested, and multiple jurisdictions raises questions about who pays the cost of adaptation activities. In addition, since polycentric governance systems have the disadvantage of increasing transaction costs, how can a balance be achieved between efficiency and redundancy to reduce transaction costs? How much redundancy and overlap are optimal? At what point do the costs of duplication outweigh the benefits of redundancy and overlap?

Our theoretical framework suggests an important role for social scientists, as many of the variables are the purview of scholars in political science, public policy, planning, sociology, epistemology, and psychology. Further study is needed to refine the theoretical model and to identify which variable sets are most important in which contexts. Following Ostrom (2009), we recommend research that develops typologies to aid analysis of particular configurations, to understand how adaptive institutions are most readily attained in different types of settings.

More broadly, social and natural scientists can foster purposeful institutional change through networks and learning. As described above, considerable interest and scholarship has focused on information exchange and knowledge creation, particularly how scientists interface with policy makers in social-ecological systems. Much of this research has been in the realm of collaborative environmental management, where scientific and time-and-place information are brought to discussions about managing social-ecological systems (Born and Genskow, 2000; Allen, 2006; Wondolleck and Yaffee, 2000). Studies of collaborative environmental management have examined stakeholders, processes, and outputs (Koontz et al., 2004; Sabatier et al., 2005; Margerum, 2011). Collaborative watershed plans, for example, often recommend behavior change among land managers, or carrying out of project work, but less is known about the degree to which they recommend and foster institutional changes. This line of inquiry might fruitfully be expanded to examine how knowledge, deliberation, and learning affect institutional change. Saravana (in this issue), in his study on understanding institutional change in an irrigation society in India, found that agents responsible for water management gained power through knowledge and social networks as well as from socially embedded and statutory rules, which in turn allowed them to integrate actors and build adaptive institutions. However, due to inadequate information and scope rules, which the agents exploited using their authority rules, the management of water continued to remain inequitable, inefficient, and unsustainable. In addition, one empirical study of institutional responses to flood hazards in Brazil found deliberation and knowledge to be negatively correlated with adaptive institutions, without explaining how this may have occurred (Engle and Lemos, 2010). This result raises questions about the contexts within which deliberation and knowledge promote adaptive institutions.

Since learning plays a critical role in enabling adaptive institutions, important questions about creating, communicating, and acting on knowledge should be addressed. In particular, scientific knowledge is likely to grow in importance as the scale and complexity of social-ecological system challenges grow (Robinson et al., 2011; Heikkila and Gerlak, 2005). In fact, Milkoreit et al. (in this issue) argue that resiliency scientists should develop their own position on their involvement in policy and purposeful institutional change processes. A key question in the creation of scientific knowledge about

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social-ecological systems is. How do social and ecological conditions interact across scales? How might scientific and experiential knowledge together inform our understanding, and how is scientific knowledge incorporated into decision making by those who might change institutions? How do ecological processes and conditions affect variables such as resources, rule compliance, and social capital? As information is shared through networks, emerging techniques for social network analysis could be employed.

Our reading of prior studies revealed a dearth of instances of proactive adaptation. Several authors describe a current state of affairs that does not sufficiently promote adaptive institutions. Rather, where adaptation occurs it is often a result of a crisis that galvanizes attention and resources to promote a response. Such system shocks may provide responses that are more or less adaptive (e.g., after a large flood, do institutions compensate losses and encourage rebuilding on the same sites, or do they tighten flood plain zoning restrictions to reduce future losses?). Further research could examine when these responses are more or less likely.

While our synthesis identifies many variables that foster adaptive institutions, it is unclear how to motivate action before a crisis. This possibility is a key premise of this special journal issue about purposeful institutional change. We recognize this as a critical challenge for successful social-ecological system governance. What motivates and helps actors to proactively create adaptive institutions? For example, polycentricity and federalism enhance the ability to respond to change, but do they also encourage leadership and entrepreneurial activity to create adaptive institutions before a crisis? How might this occur? What mechanisms might promote characteristics, such as redundancy and overlap, that are helpful for adaptive institutions but not favored in economic systems, such as the free market, that promote efficiency? Studying proactive adaptation may require studying a longer time horizon, as cases would be needed where evidence of successful adaptation (or not) can be paired with evidence about how actors previously promoted (or not) adaptive institutions before the change.

5. Conclusion

Adaptive governance and adaptive institutions have spurred much scholarly attention over the past two decades. The accumulation of scholarship has contributed to a large number of variables to which scholars turn in explaining how humans can best promote adaptive governance of social-ecological systems. Our review of the literature indicates challenges in theory building that stem from inconsistent use of terms such as adaptive governance and adaptive institutions. In particular, some authors have treated the two terms as synonymous. Also, concepts that are components of adaptive governance to some scholars have been described as variables promoting adaptive governance by others. This makes it difficult to develop a clear picture of the current state of the knowledge in this arena.

Rather than adding to a lengthy list of variables, we sought to organize findings from prior scholarship into a theoretical framework that identifies key precursor variables that affect subsequent variables that, in turn, link to adaptive institutions and, ultimately, adaptive governance. What emerges is a focus on, first, polycentricity and federalism, and then on networks and learning. We view polycentricity and federalism not as components of adaptive governance, but rather as factors that can promote adaptive governance through adaptive institutions. Along the way, we disentangle polycentrism from federalism. Similarly, we view networks and learning as factors that may promote adaptive institutions – the ability of actors to change institutions in order to maintain or improve to a desirable state.

Our theoretical framework and analysis point to several knowledge gaps that are ripe for further exploration. How can the transaction costs and potential inefficiencies of polycentricity and federalism be balanced with the adaptive benefits of redundancy and overlap? What typologies are useful for predicting which sets of variables are more likely to be important for which contexts? How can scientific and time-and-place information inform institutional change? How do social and ecological conditions interact across scales, and how might biophysical conditions affect key variables such as resources, rule compliance, and social capital?

In addition, competing claims about the effects of particular factors warrant further research. For example, if polycentricity at the local level encourages racial segregation, income sorting, and urban sprawl, how do these effects influence adaptive institutions? In which circumstances might the benefits of heterogenous networks in providing useful information to foster institutional adaptation be outweighed by the increasing coordination costs that may slow it? And how might powerful actors be prevented from hindering institutional adaptation as a result of the ''dark side'' of social capital?

We acknowledge that the large number of intertwined variables identified could be arrayed into numerous constellations. Although we understand there are likely interactions among the proximate variables affecting adaptive institutions (e.g., biophysical context affects learning), our framework emphasizes how a few precursor variables affect sets of proximate variables. Our hope is that by clearly defining our terms and describing links among numerous variables, scholars and practitioners may be better able to test connections among variables and trace causal pathways. Such work will improve understanding of how institutions contribute to adaptive governance of complex social-ecological systems, as well as how polycentricity and federalism, networks, learning, and other factors affect our ability to purposefully change institutions.

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