HUMAN ECOLOGY REVIEW

Special Issue: Generating Sustainability-Supporting Knowledge on Social Networks in the Governance and Management of Social–Ecological Systems

Volume 26, Number 2, 2020

RESEARCH AND THEORY IN HUMAN ECOLOGY

BOOK REVIEW

Research and Theory
in Human Ecology

Generating Knowledge on Networks in Environmental Governance

Marion Glaser

Social–Ecological Systems Analysis Working Group, Social Science Department, Leibniz Centre for Tropical Marine Research, Bremen, Germany

Barbara Schröter[1]

Governance of Ecosystem Services Working Group, Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany; Lund University, Centre for Sustainability Studies (LUCSUS), Sweden

Abstract

This paper introduces the special issue on "Generating Sustainability-Supporting Knowledge on Social Networks in the Governance and Management of Social–Ecological Systems." Understanding the interactions of actors and institutions is important for successful governance of human–nature relations. Social network analysis is able to capture and analyze these governance and management interactions, and there is a range of existing tools for collecting, visualizing, and modeling data on social and social–ecological networks. This introductory paper aims to give an overview of the collected papers as well as an outlook of new arising topics in the field. After presenting the single contributions to this special issue, we share our thoughts on network types and performance, network states and dynamics, limits of network studies, new conceptual focuses in network analysis, and methodological innovations (mixed methods and new tools). We conclude with a reflection of the contribution of this special issue to environmental governance.

Keywords: environmental management, social–ecological network analysis, social–ecological systems, social network analysis

Introduction

For several decades now, sustainability research and environmental governance policies, along with diverse tools for environmental research and management, have advocated for—and undertaken—the integration of diverse actors from multiple system levels in systems analysis (Grimble & Wellard, 1997; Phillipson et al., 2012; Reed, 2008; and a recent example, the global Future Earth project[2]).

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1   Corresponding author: barbara.schroeter@zalf.de.
2   futureearth.org/2020/12/08/transition-update-1-scaling-up-global-sustainability-science/.

Implicit in these efforts is a growing focus on social and social–ecological networks. Understanding the interactions of actors and/or organizations with each other and with their natural environment is an increasingly crucial ingredient for the effective governance of human–nature relations. This is a major challenge for academia—in particular, for the fast-growing field of transdisciplinary sustainability science. There has been progress in methods such as agent-based modeling and network analysis but the scarcity of methods for the analysis of social–ecological systems, which was recognized over a decade ago (Glaeser et al., 2009), continues today. In view of increasing sustainability challenges, in particular the analysis of social–ecological systems and their governance needs, it is essential to further engage with methodological innovations.

New methods for collecting, visualizing, and modeling data on social and social–ecological networks in environmental governance and management are emerging, in particular quantitative, qualitative, and mixed methods that foster stakeholder participation and synergistic knowledge generation. In order to depict a spectrum of these innovations, this special issue focuses on the rapidly developing field of methods for network analysis (Kluger et al., 2020; Schwenke & Holzkämper, this issue), which offers a range of innovative options across disciplines for the analysis of environmental governance.

The contributions to this special issue explore different methodological approaches for analyzing social and social–ecological networks relevant to the governance and management of social–ecological systems and present related exemplary results for environmental governance.

María Mancilla García and Örjan Bodin set out to differentiate to what extent power resides within network structures and whether it is rooted in actor attributes such as class and wealth. Through its methodologically innovative combination of social network analysis (SNA) with structural equation modeling and the qualitative analysis of open-ended interview data, this study informs the classic sociological debate, and Giddens's structuration theory in particular, on the roles of structure and agency. The authors focus on differences between the influence and the centrality of actors in an information exchange network for the governance of the East Brazilian Paraíba do Sul River, a network that spans three Brazilian states. The study explores correspondences and causal links between different statistical measures of centrality and measures of influence and popularity by using SNA.

Central findings are that high influence does not necessarily coincide with high social network centrality of a governance actor, and that influential actors with very different attributes can emerge. Neither formal position nor financial resources are found to entirely determine actors' influence, but the authors detect some scope for agency to change networks and influence levels. They conclude that since multiple forums with overlapping environmental governance competencies exist in their

case study region, not only the relations within a network need to be analyzed, but also those between networks. The article offers a path toward a fine-grained, differentiated methodological approach for identifying the causal relations between network structures and positions and actors' influence. By testing a set of hypotheses with empirical data from a Brazilian regional case study on water governance, the article demonstrates the strategic use of networks while being well anchored in theoretical debates. This type of analysis has important potential for policy and practice in the emerging field of environmental governance.

Marco Scotti, Daniel Pereira, and Antonio Bodini offer an entirely method-focused article that presents loop analysis as a qualitative tool for linking disciplinary domains in integrated analyses of the natural and social science variables that are central for environmental governance and ecosystem-based management. Citing diverse case examples, they argue that loop analysis is particularly powerful for analyzing social–ecological systems for which data availability is poor. Adopting an interdisciplinary network perspective that includes ecology, economy, and society, the authors demonstrate that with its simple signed directed graphs, loop analysis is able to show the paths along which perturbations travel through a social–ecological system and identify the associated feedback structures and causal mechanisms in these complex systems. This helps, in their own words, to "make the arcane obvious" while the simple graph format of loop analysis also facilitates the participation of non-academic stakeholders in social–ecological systems model building. Given these important strengths, major remaining limitations of loop analysis concern nonlinearity, problems with the selection of temporal and spatial system levels, as well as with the timing of diverse system changes.

Marina Ribeiro Corrêa, Luciana Xavier, Eike Holzkämper, Mariana de Andrade, Alexander Turra, and Marion Glaser offer an applied study of social networks, examining the role and potential of public sector beach managers for advancing the ecosystem service-oriented management of the social–ecological systems associated with sandy beaches. The authors apply the Net-Map tool to the construction of both current and desired future beach governance networks from the perceptions of local beach managers in four municipalities on the northern coast of São Paulo State, Brazil. They then apply quantitative SNA methods to analyze their Net-Map data and obtain a set of quantitative metrics on beach managers' governance network perceptions. They find that local beach managers envision governance network transformation toward ecosystem-based beach management, and that they may act as effective and motivated leaders in this if supported in the development of skills and of a wider regional identity. The focus on the perceptions of local environmental managers that this study adopts is identified as a new way of fostering collaborative environmental governance to support the successful design and implementation of environmental governance.

Philipp Gorris and Marion Glaser focus on the information transmission capacity and the robustness of actor networks in different approaches to collaborative governance of coastal and marine natural resources. Two contrasting archetypal regional cases of coral reef governance are used as case studies. Both operate in similar institutional and sustainability contexts: a centrally coordinated marine protected area (MPA) in a northeastern Brazilian coastal region and a polycentric form of coastal and marine governance in an island archipelago in East Indonesia, both functioning in the context of governance decentralization. The article investigates how the social network characteristics associated with these contrasting forms of governance affect the respective governance networks' information transmission capacities and the robustness of their information transmission capacity under conditions of sociopolitical change. Stakeholder rosters (which are compiled from gray literature), meeting protocols, and interviews are used for a structured survey of MPA governance interactions among all identified parties. To compensate for missing data from about 20 percent of identified network actors, statements of other network actors on the network relations of the missing interviewees were included. The authors use the idea of reachability within the governance network to examine information transmission capacity. Network robustness is assessed by simulating the speed by which information transmission capacity decreases when the network actors with the highest closeness centrality are consecutively removed. The results show that the polycentric Indonesian governance network performed better than the centrally coordinated Brazilian MPA network in terms of both information transmission capacity and on robustness. The authors discuss the implications of this surprising result for the vulnerability of collaborative governance, combining theoretical deliberations with an analysis of their empirical data, in particular on differences in reachability. The presented approach of simulating the consecutive removal of central actors from the network and analyzing the impact of this on central network functions holds further promise for the analysis of environmental governance dynamics.

Theresa Schwenke and Eike Holzkämper present a bibliometric analysis of publications that address both environmental governance and social (–ecological) network analysis. Using a bibliometric network analysis approach, the authors identify a relatively small but rapidly growing set of publications that address both fields of study and identify the "intellectual linkages" between the identified subsets of publications. They describe in detail how they constructed both a citation network and a similarity network for the identified set of publications and explain, calculate, and interpret key metrics for both chosen network types. The presented analysis identifies the highest ranked articles within the citation network in terms of metrics for source, storage, and bridge functions. The analysis of the similarity network indicates the composition, frequency, clustering and similarity of different thematic focuses within the identified sets of publications on environmental governance and social (–ecological) network analysis. As a central underlying theme

across all identified thematic focuses, the authors identify information, influence, and knowledge, all of which are manifestations of differences in power and knowledge production. Finding a prevalence of locally focused studies, they foresee more global level analysis for the future.

This article carefully explains how an innovative set of techniques—similarity network analysis and citation network analysis—was developed and applied and shows the complementarity of the chosen mix of methods. Pinpointing remaining shortfalls of their pilot study, such as its limited data base, the authors display how their approach increases future options for producing a more differentiated analysis of network types in environmental governance.

Ben Nagel presents a coastal case study from one of the most climate change vulnerable countries on earth, Bangladesh. In a rural community exposed to advancing soil salinity, he investigates the role of social networks in enabling households to use innovative production technologies to adapt to these new environmental conditions. The author examines how the character of relevant social networks, the position of a household within those networks, and a household's characteristics affect its adoption of innovative production techniques to adapt to more saline conditions. Contextualizing the case study via key informant interviews, focus discussion groups, and participatory wealth and poverty ranking exercises, the study uses a whole network household survey to characterize network actors and their connections in an explicitly locally grounded approach. With technology adoption as the dependent variable, the article maps information, labor, and money exchange networks and analyzes the network positions of actors of different demographic and wealth categories. This article includes a candid discussion of methodological biases and implementation hurdles relevant for those planning SNA interviews.

Adam Henry focuses on sustainability learning at the organizational level, addressing to what extent an organization's position in a larger environmental policy network determines learning outcomes. The author examines four hypotheses on the relations between bonding and bridging social capital, network segregation, and network expansiveness (degree centrality) with organizational learning outcomes in three regional land use and transportation policy networks in California. Policy network members are identified through archival research and a survey ($n = 514$), in which stakeholders (34 percent response rate) nominated collaborators and classified their own relations to them. Learning outcomes are assessed through stakeholder perceptions. With this data, three network types relevant to governance are constructed per study region: a trust, collaboration, and information exchange network. Regression modeling analyses, which treat organizations' network positions as independent and organizational learning as the dependent variable, are then implemented. Diverse and sometimes surprising results are discussed. While bonding social capital, belief segregation, and vertical segregation increased learning outcomes, functional domain segregation and brokerage (bridging capital

measured by betweenness centrality) decreased learning. This pioneer paper on the effects of networks and network position opens the path to methodologically innovative, empirically based research on arguably one of the central preconditions for sustainable and effective environmental governance with the needed adaptive and transformative potentials: the learning outcomes for diverse decision-makers. Counterintuitive results such as those reported on the inhibitive effects of diversity and brokerage on learning call for more examples of carefully contextualized work to support network design that supports sustainability enhancing learning outcomes.

Outlook

We conclude with some thoughts arising from our reading of all the papers in this special issue.

Network types and performance

Networks are an analytical tool. In research, each network is a heuristic device, conceptualized and bounded for a particular purpose. The networks analyzed in the contributions to this special issue focus on diverse aspects of environmental governance including innovation adoption in agriculture, influence and power characteristics of social networks in water governance, social–ecological network research, and knowledge production. With the exception of Schwenke and Holzkämper (who focus on authors and publications in citation networks), all contributions analyze governance networks at a subnational regional or local level, with a medium number of involved actors. Work on multilevel local to global environmental governance networks is, with few exceptions (e.g., Gerhardinger et al., 2018), as yet not well developed.

Social network types, and how their features might be conditioned by the characteristics of surrounding system environments, needs to be further explored. Not only the social realm (i.e., differing approaches to governance) but also some of the geo-bio-physical features of the system to be governed are likely to affect the character and performance of a governance network. Gorris and Glaser (this issue) find, perhaps not accidentally, polycentric governance for an MPA that stretches across a physically rather loosely and incompletely connected island archipelago (in Indonesia), but centrally coordinated governance for an MPA that spans along a 150 km stretch of (Brazilian) coast connected by a good road. Better physical communication options may have led to more centralization in the Brazilian MPA and may affect information transmission capacities. Whether and under which circumstances such geophysical or social circumstances affect governance outcomes and/or the structure and organization of associated governance networks requires further explicitly interdisciplinary social–ecological research.

Interviewees in social network studies are often unable or unwilling to discuss obstructive relations (e.g., Nagel, this issue). This may be a feature of their culture or due to the power or dependency relations interviewees see themselves as embedded in. Social network analyses are therefore likely to be better at identifying network functions and features that enhance desirable outcomes, but are likely to underrepresent social network features that reduce or obstruct them. Particularly in the environmental governance field, research designs will need to take this into account.

Network states and dynamics

The great majority of studies present the structure or state of a social network with point-in-time data (e.g., Nagel, this issue). Such "snapshot" representations of social networks that relate to specific time periods or points in time are useful for presenting network structures and comparing their characteristics via an increasing number of SNA metrics. This field of investigation has generated important new knowledge for environmental governance over the past two decades. Thus, for instance, Gorris et al. (2019) and Gorris and Glaser (this issue) present a comparative analysis on different governance network structures and discuss the resulting capacities of governance networks. What such work on network states has generally lacked to date is the temporal dimension. Some of the important questions for environmental governance that require knowledge of change over time are: Are there classical cycles in environmental governance network development and what drives them? How do networks change in response to crisis and how can this be influenced? What role does leadership change play in governance networks and how can this be affected?

Mancilla García and Bodin (this issue) and a number of other authors interested in research on social–ecological systems processes argue that there are only a few longitudinal studies that cover governance structures at different moments in time (Mancilla García et al., 2020).

More studies with an explicitly temporal dimension are needed. Longitudinal social network studies require much time and money, however, and to our knowledge, few if any have been published. Beyond the important work on network characteristics, the ability to analyze and envisage network change over time therefore needs to be enhanced to inform environmental governance and management. Authors in this special issue such as Corrêa et al. engage with this. Future work might include:

1. Connecting a series of point-in-time studies on the state and characteristics of networks to generate a temporal dimension.
2. Identifying network features that indicate the character and or the direction of network change processes. A concentration on network processes and their effects, rather than on the characteristics of networks at a point in time, has the potential to add the required temporal dimension. In line with Glaser et al. (2012), a set of generic indicators on network processes might be developed for this purpose.

SNA has provided information on the character and structure of interactions between actors in environmental governance and management at particular points in time, or for short periods (e.g., Gorris, 2015). This enables the empirical investigation of theoretical concepts, such as multilevel governance or network robustness, and of related questions, for instance on the role of intermediaries, brokers, or institutional entrepreneurs in environmental governance and associated social learning. Classical SNA uses questionnaires that generate standardized network data for the calculation of quantitative metrics. SNA can either assess the relations of single actors, in ego networks, or of all actors to all others in a conceptualized closed universe. The approach finds its limits when larger periods of time (more than one or two years) are the focus of attention.

Another as yet only partly addressed question is how and under which circumstances agency is able to alter networks and thus affect both the influence of individual network actors and the actual environmental outcomes of governance and management efforts. Mancilla García and Bodin (this issue) provide important inputs here.

Limits of network studies

Network surveys are important tools for exploring and improving communication, coordination, and knowledge exchange. With larger networks, surveys meet their limits in terms of the attention span and time required by both interviewer and interviewee, and the number of interviews that need to be agreed to by network members and actually conducted tends to exceed the capacities of all but very large and well-staffed projects. Additionally, with rising network size, reporting errors and omissions increase. Recent fieldwork (Gorris et al., 2019; Nagel, this issue) indicates that beyond a certain network size, a total network survey will suffer unacceptable data quality problems as the attention span and capacities of both interviewer and participants are increasingly overstretched. In small networks, on the other hand, ethical problems arise with the difficulties of guaranteeing anonymity to interviewees. Networks with a medium number of actors (about 100) therefore hold the highest potential for generating reliable data in an ethically sound manner.

Active participation of non-academic stakeholders in the formulation of research questions, in the design of research methods, and in the discussion of results is important in environmental governance network analysis, as in other sustainability fields: given the importance of informed consent and trust between researchers and other participants, such participation will improve research implementation and use of results, perhaps more so in the collaboration-focused field of SNA than in other research fields.

New conceptual focuses in network analysis

Homophily holds potential as an umbrella concept in the debate on governance for sustainable human–nature relations. It describes the tendency of those that share certain traits (such as education, race, or beliefs) to engage in relations with each other. In contrast to its opposite (heterophily), homophily has popularly been described as the propensity of "birds of a feather to flock together" and has been found to foster internal collaboration but also to inhibit wider consensus-building. Two articles in this special issue employ the homophily concept. Henry cites numerous sources that find belief homophily to be a strong force in generating segregated networks, which are reinforced by cognitive biases that support the (re)interpretation of any evidence to confirm prior convictions. Various studies (cited in Henry, this issue) find the resulting self-reinforcing belief-specific networks to inhibit learning. Contemporary belief-specific "communication bubbles" on the internet may be interpreted to demonstrate learning capacities for belief-specific networks. In the paper presented here, however, Henry presents results that show belief-oriented segregation in collaboration networks increases learning outcomes while greater belief diversity actually decreases it. The context in which this was found clearly matters, not least for policy design. We refer readers to the article for details on this interesting and surprising finding. Corrêa et al. (this issue) also employ the homophily concept. They distinguish self-organized and self-directed homophilic and heterophilic network visions of key local environmental managers and discuss the implications of these visions for diverse aspects of network performance. Here, the use of the homophily concept helps to identify the potential of local environmental managers as leaders and shapers of governance and management. Overall, the homophily concept in the environmental governance field emerges as a useful tool for exploring how diversity and homogeneity between network actors along various lines affect governance outcomes.

Various contributions stress the importance of linking the social and the ecological dimensions in environmental governance research and, of course, network approaches offer possibilities here. Scotti et al. (this issue) show that interactions which link variables of the human and the ecological domains have to be considered and that a balanced integration of both variable types is possible in loop analysis modeling.

Social–ecological networks is a concept that extends the purely social science focus of SNA into the natural science realm and vice versa. Schwenke and Holzkämper (this issue) show the emergence of network analysis in the environmental governance field. Kluger et al. (2020) differentiate three types of social–ecological network that are integrated in different ways and to different degrees and show how each is suited for a particular set of purposes. A novel approach, namely that of considering ecosystems and ecosystem components as actors in otherwise social networks

(proposed by T. Schwenke, several personal communications, 2020), opens up new potential for using the network lens in the co-analysis of interrelated social and ecological dynamics.

Methodological innovations

Mixed methods

Mixed method approaches that use a network lens for the analysis of social–ecological systems and their governance have synergy potentials that merit attention. Recent methods and tools that complement classical SNA tools are agent-based modeling of social or social–ecological networks, participatory modeling, net-mapping, and social–ecological network modeling based on the building block approach. In its more radically system-based approach, loop analysis (Scotti et al., this issue) enables a fairly rapid identification of connections between drastically different variables in openly conceptualized complex system models. Structural equation modeling offers further potentials for a fine-grained analysis of causality in multidimensional complex dynamic systems. SNA, on the other hand, is firmly rooted within the social realm: it is therefore weaker on broader system-wide analysis, while strong in pinpointing the particular features and impacts of different network types on governance outcomes.

Mixing methods can also enable triangulation. SNA combined with net-mapping can highlight the differences between self-reported networks and stakeholder-specific perceptions of such networks. New options for the quantification of intrinsically qualitative net-mapping data can avoid the often immense time and effort required to implement full SNA surveys, especially in larger networks, and to develop novel approaches to whole network analysis. New avenues to unravel causality in network analysis, such as between network position, household traits, and engagement with new climate change adaptation techniques (Nagel, this issue) may benefit from further triangulation, such as on network data with data from social experiment work (e.g., Schlüter & Vollan, 2015).

New tools

Diverse software has been used by the authors in this special issue. For analyzing SNA metrics, all authors (Nagel, Gorris & Glaser, García & Bodin, Corrêa et al.) used UCINET, which is probably the most complete tool for SNA measures and is relatively cheap (from about USD40). For visualizing the networks, Nagel, and also Gorris and Glaser, used Gephi, a free tool whose network design is often thought more appealing than NetDraw, which comes in the UCINET package. Due to their specific networks, Schwenke and Holzkämper used the free CitNet Explorer,

which was developed for visualizing and analyzing citation networks of scientific publications, and the data mining software RapidMiner Studio. Henry used the statistical software R for data management and descriptive analysis, including network visualization, and Stata 12 for regression models. Scotti et al. conducted a pure qualitative analysis for modeling relations between factors. Although most authors stress the importance of the analysis of additional qualitative data for their work, be it qualitative interview data, focus group discussions, or similar, these are not given the same importance in describing the analysis, methods, and software tools used, and in the presentation of results. This may be due to the fact that SNA is originally a quantitative method, but the relative importance attributed to qualitative and quantitative data in network analysis could be more balanced in future research.

Contribution of this special issue to environmental governance

The contributions to this special issue are highly diverse in their methods and in the aspects of social–ecological systems they examine. Trends in the development of methods for environmental governance are not apparent. We do, however, present a number of ideas to inspire innovative method development for environmental governance research.

Adaptive management has proven a key approach for sustainability-focused environmental governance (Armitage et al., 2009; Berkes, 2009; Folke et al., 2005). The analytical approaches and associated methods presented here can help to further develop and adapt governance structures and processes in this endeavor: for instance, by examining the importance of specific actors (e.g., nongovernmental organizations) as leaders for change and innovation, or the importance of diverse ties for knowledge distribution and sharing. Insights on information flows that trigger social learning and influence can support social–ecological transformation: for instance, through fostering innovations or resilience in the face of adverse social, political, or environmental change. The case studies presented here focus on the local or regional governance level, but they also indicate how to expand analysis toward addressing multilevel governance. All this may lead to practical insights for policy-makers.

Also, while networks tend to concentrate on actors and their relations, it is time to move beyond "internally focused" analysis and go a step further, by looking at the effects of structures and agency on environmental governance, as well as at causalities. This could be done by, for example, combining methods, like SNA with choice or economic experiments.

Network research tends to focus on either the social or the ecological side (Kluger et al., 2020); for instance, SNA on social actors. Some of the approaches presented here, mainly social–ecological network analysis and loop analysis, enable a better integration of ecological with social system dynamics. Network concepts in the governance field include the concept of a functionally oriented or sector-specific— usually informal and closed—policy network, which contrasts with the more inclusive, democratic slant of the governance network concept (Blanco et al., 2011). Clearly both network types need to be distinguished and analyzed in the environmental governance field. Recent research further stresses the importance of informal network structures for policy-making (Suyo et al., 2020).

The methods presented here open opportunities for the integration of different views, thought styles, and knowledge, as they include participatory elements. These, however, may still be deepened and extended. Through their integration potential across boundaries of different kinds, social–ecological network analysis methods in particular may also serve to connect different scientific fields both with each other and with the science–policy interface, and thus to coproduce knowledge in a more integrative manner (Mollinga, 2010; Star, 2010).

This special issue provides knowledge on different methods in environmental governance. We hope that it inspires researchers to think outside their own disciplinary boxes, to cross methodological boundaries, and last, but not least, to engage in combining and further developing some of the diverse methodological options discussed here.

Acknowledgments

Finally, we thank *Human Ecology Review*, Robert Dyball, Ngaire Kinnear, and the whole team for their continuous support and kind collaboration.

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Uncovering Relationships between Being Influential, Participating in Multiple Forums, and having Many Social Ties in Water Governance in Brazil

María Mancilla García[1]
Stockholm Resilience Centre, Stockholm University, Sweden

Örjan Bodin
Stockholm Resilience Centre, Stockholm University, Sweden

Abstract

Social network analysis has long been used to explore the networks actors build around collaborative institutional arrangements, and to uncover factors explaining why certain actors are more central than others. Being central in a social network is often treated as interchangeable with being influential. We critically investigate this common assumption by drawing inspiration from structuration theory. We use the management forum of the river Paraíba do Sul in Brazil as our empirical case study, and deploy social network analysis and structural equation modeling to disentangle influence ratings and social network centrality. We analyze direct and indirect factors that potentially explain centrality in information exchange and high influence ratings, and how they relate to each other. Our results show that centrality and influence are highly correlated, but also that they are not the same. We draw on interviews to suggest why some actors are influential without being central and vice versa.

Keywords: qualitative data, social structuration theory, structural equation modeling, water basin governance

Introduction

Social network analysis has long been used to explore the networks actors build around collaborative institutional schemes and to uncover the factors that explain why certain actors are more central than others (i.e., have more social ties than others). In the literature using social network analysis, being central in a social network is often treated as interchangeable with being influential. In this paper, we

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1   Corresponding author: maria.mgarcia@su.se.

take a perspective inspired by social structuration theory in trying to disentangle if there is a difference—and what could explain it—between centrality and influence in a particular case of water governance in Brazil, the water basin committee with jurisdiction over the river Paraíba do Sul. Social structuration theory argues that both structure and agency are crucial to understanding social dynamics—or, said otherwise, that structure is dual: It sets both the conditions for agency and the outcome of agents' behavior. Social structuration theory also provides an interesting conceptualization of actors as knowledgeable and powerful, at least to a certain extent. While acknowledging that actors do not know everything and that their acting might produce unintentional outcomes, social structuration theory argues that actors know, at least to some extent, what they do and why they do it, which is what allows them to change existing structures instead of being predestined to certain structural positions with associated behaviors. Structuration theory is a useful perspective for studies on power and influence in that it provides a middle ground between the literature that asserts that power is largely formed and shaped by actors who intentionally or unintentionally create alliances with others (i.e., create and dissolve social ties with others), and the literature that dismisses the effects of such networks to argue that power resides in deeper preexisting structures or attributes (culture, class, wealth, etc.). In this paper we try to disentangle influence ratings and social network centrality (which derives from actors' networking activities) to investigate links between influence and information exchange on a peer-to-peer basis (the social ties).

For this purpose, we combine social network analysis with two other methods: qualitative analysis of open-ended interview data, and structural equation modeling. Our mixed methods approach helps us explore direct and indirect factors that could explain centrality in information exchange and high influence, as well as if and how they relate to each other. Semi-structured interviews, in particular, help us put forward explanations as to why some actors are influential without being central and vice versa. We investigate these issues for the case of the river Paraíba do Sul management system in Brazil, and we particularly focus on the network of information exchange among actors involved in CEIVAP ("Comitê para Integração da Bacia Hidrográfica do Rio Paraíba do Sul," or "Integration Committee of the Paraíba do Sul River"), the basin-based forum for the management of the river.

Theoretical framework

An extensive body of research on power and influence in governance has investigated to what degree agency plays a more prominent role than structure (or vice versa) in explaining power dynamics. Following Lister, agency can be defined as characteristic of "autonomous, purposive and creative actors, capable of a degree of choice" (Lister, 2004, p. 125). The literature on leadership, for example, tends to put

a stronger emphasis on agency than on structures, exploring possibilities for social change dependent on the behavior of key actors (e.g., Ardoin et al., 2014). Much of the literature in political ecology, by contrast, calls attention to the structures—access to resources or discursive framings (e.g., Bakker, 2013; Budds & Hinojosa, 2012) that condition and limit the possibilities for individual choice.

The literature has extensively investigated what explains who are the most influential actors in a given governance arena. Some of the literature considers that the most influential actors will come from a specific group—the group of the powerful—which translates into the exclusion of historically less powerful actors (Dür & de Bièvre, 2007; Few et al., 2007). We find this underlying hypothesis in different literature streams, such as in the institutionalist tradition that holds formal authority as the main way to become influential (Dahl, 1994), or the literature on interest groups that calls attention to the importance of financial resources to become influential (Yackee & Yackee, 2006). From this perspective, whether an actor is central or not is simply a by-product of them being influential (i.e., if the powerful actors are central in the network, they are central because they are powerful). Therefore, the relations that actors cultivate do not play a significant role in determining their influence, since there isn't much any given actor can do in this regard to become influential. This can be read as a form of structuralism, since existing structures—in terms of current distributions of resources—determine influence and current power distributions. This indeed resonates with the structuralist idea that actors are embedded in social structures that they cannot change by themselves, or, in a milder version, that are extremely difficult to change and where changes would typically be systemic—that is, the structures themselves might change over time, and these changes might then lead to a redistribution of influence.

Other perspectives defend the position that power is to a significant extent constituted through the relations established in networks (i.e., being "well-connected" makes you influential). Some studies have, for example, discussed whether actors become more central because they already occupy quite a central position in the studied network—that is, because other actors want to link up with those who are central. In the social network analysis literature, being central in a social network is often treated as interchangeable with being influential (e.g., Burt, 2003), because centrality is associated with influence (Berardo, 2013; Gebara et al., 2014). However, in this paper we seek to investigate if centrality in the information exchange network and high influence can be teased apart, as well as the causal mechanisms that possibly link influence and centrality in the information exchange network. With this in mind, we investigate the extent to which being influential, on the one hand, and being central, on the other hand, can be explained by attributes and/or by actors' networking activities. We find inspiration in Giddens's (1984) structuration theory, which asserts that individuals through their actions confirm or weaken social structures. Individuals always act within social structures, but they can change them either unintentionally while they act or by being actively reflective upon them. For example,

they might disapprove of current structures—in terms of fairness or distribution of benefits—and explicitly seek to change them (Ostrom, 2005). On the other hand, individual actions can also reproduce social structures unintentionally (by repeating habits, for example) or intentionally (such as by maintaining traditions). To sum up, both structure and agency play a role in structuration theory through recurrent and continuous action (Giddens, 1984). As Morse et al. (2013, p. 59), following Stones (2005), put it; "by focusing on the interaction of structures and agents, structuration theory avoids the oversimplification of purely objective or subjectivist approaches." This interplay between agency and structure—as co-constitutive—is what Giddens calls "the duality of structure" which is both an outcome of and a condition for action.

Giddens, and others after him such as Lister (2004), put forward a definition of agency that goes beyond intentional choice. Instead they link agency (or "political agency" in Lister's case) to the outcome of actions, and particularly to the possibility of changing a given state of affairs; that is, the possibility of affecting structures. As Long and Long (1992, p. 23) describe:

> agency (and power) depend crucially upon the emergence of a network of actors who become partially, though hardly ever completely, enrolled in the projects and practices of some other person or persons. Effective agency then requires the strategic generation/manipulation of a network of social relations.

This provides a much more nuanced perspective on structures, in which structures not only condition actions but are actively engaged in action. As Morse et al. (2013, p. 60) explain: "An agent's capabilities, in part, come from their ability to utilize elements of structure (rules and resources) to achieve their goals". Networks provide a concrete, useful tool to conceptualize the constant coevolution between agency and structure. Networks are the product of repeated interactions, and while they happen within social structures, they are also structures in themselves that can change as actors act.

Building on the underlying assumption that influence and information exchange are sufficiently different (i.e., not just two measures of exactly the same thing), we develop a set of hypotheses that allow us to explore the relations between the two. We start by investigating whether influence and information exchange are strongly associated in the context of water governance in our study area. If these factors are sufficiently separated (i.e., not too strongly correlated), it means there is leverage for investigating causal mechanisms explaining how these factors potentially relate to each other. We firstly investigate if and how being centrally positioned in the information exchange network relates to being influential and formulate the following hypothesis:

> Hypothesis 1 (H1): Centrality in the information exchange network is strongly associated with influence.

Recent work by Fischer and Sciarini (2016) tests whether actors tend to link up to exchange information with those who are perceived as more influential, considering that perceived influence would render actors attractive to others. Inspired by this work, we formulate two contrasting hypotheses about the causal direction:

Hypothesis 2A (H2A): The more influential an actor is, the more central they are in the information exchange network.

Hypothesis 2B (H2B): The more central an actor is in the information exchange network, the more influential they are.

Additionally, recent work on the ecology of games suggests that issues of influence and centrality in environmental governance networks need to be re-explored in the face of institutional systems where actors can choose to participate in a multitude of forums (Lubell et al., 2010). Specifically, some of these works have investigated which variables explain high influence in this particular empirical case: In Mancilla García and Bodin (2018), it was found that the number of forums attended was significant in explaining high influence. If high influence and information degree centrality derive from a common cause—in this case, actors building influence (at least partly) by exerting their agency through networking activities (captured by multiple forum participation)—then we might expect that the number of forums attended will also be significant in explaining information degree centrality. In order to account for the effect of forum participation on the two variables of interest, we formulated another hypothesis.

Hypothesis 3 (H3): The number of forums attended has a direct effect on both influence and information exchange centrality.

If this hypothesis was confirmed, then it would mean that influence and degree centrality are—at least to a certain extent—caused by networking activities rather than by structural phenomena, assuming that forum participation is the result of deliberate action and not of inherited attributes of power. Finally, to try and further disentangle the links between information degree centrality and influence, we formulated our last two hypotheses:

Hypothesis 4A (H4A): The effect of forum participation on information exchange centrality is to a large extent meditated through its effect on influence.

Hypothesis 4B (H4B): The effect of forum participation on influence is to a large extent meditated through its effect on information exchange centrality.

These hypotheses build on the assumption that forum participation affects both factors of centrality in the information exchange network and influence, but that each of these effects largely occurs through mediation by the other factor. In essence, the hypotheses on the indirect effects of forum participation on influence and information exchange, respectively, accommodate the hypotheses on the effect

of perceived influence on information exchange centrality (H2A) and vice versa (i.e., that information exchange has an effect on perceived influence [H2B]). These hypotheses specify a direct relationship between information exchange centrality and influence, albeit with different directionality. The last two hypotheses (H4A/B) on the mediated effects of forum participation allow us to investigate whether participating in multiple forums provides an opportunity to build network ties and whether these ties are what make actors influential. Overall, these hypotheses build on the assumption that there are several ways to gain influence, and, therefore, multiple causal relationships that can help explain why certain actors are more influential than others. Assuming that these causal links are directional, we triangulate the use of structural equation modeling (hereafter SEM) with our qualitative insights to support our claims on causal directionality. SEM is a modeling approach, building from path analysis, that allows the analyst to explicate and test a series of causal assumptions between a set of variables in one coherent model (Kaplan, 2009).

Finally, we acknowledge that there might be other factors that explain information centrality. In particular, the more time and energy an actor dedicates to their participation in the forum under study, the more opportunities to interact with other participants and establish relationships with them (Hileman & Bodin, 2018). Hence, we used "degree of involvement" as a control variable when investigating centrality in the information exchange network.

Case study

We chose the case of the governance system of the river Paraíba do Sul to test these hypotheses for three reasons: (1) a multiplicity of actors from diverse backgrounds participates in the forum set up to manage the river, which provides ample opportunities to investigate the question of whether centrality in the information exchange network and influence are solely related to actors' attributes or to their networking activities; (2) this forum has existed for more than 20 years, and some actors have participated in it since its foundation, which implies that any transient effects deriving from the establishment of the forum have disappeared; and (3) besides the forum on which we focus here, multiple participatory forums for water management coexist at both the same and different levels (basin, sub-basin, state levels), which constitutes an interesting setting to explore the effect of multiple forum participation on influence and centrality in the information exchange network.

The Paraíba do Sul river flows through the states of Rio de Janeiro, Minas Gerais, and São Paulo (see Figure 1) and covers a basin area of 56,500 km^2, providing water for 17.5 million people. The main water uses are provision for human consumption (drinking, cooking, washing, etc.), sewerage (dilution of used waters), irrigation, and hydroelectricity generation.

Figure 1. Water basin of river Paraíba do Sul.

Source: Mancilla García & Bodin (2018).

The federal basin committee of the Paraíba do Sul river, CEIVAP,[2] has overarching responsibility for the management of the system. The committee's main responsibilities encompass: determinations for the rights of use and the values of payment for water use; the definition of the quality of the river's water; and approval and implementation of the Water Resources Plan for the basin. CEIVAP was created in 1996. Its statutes define that 40 percent of plenary members represent the private users (industries, hydroelectric companies, agriculture, provision companies, etc.); 35 percent represent governmental entities at the federal, state, and municipal levels; and 25 percent represent civil organizations (associations, nongovernmental organizations [NGOs], universities). The representatives of these three categories are equally distributed between the three states. Besides the plenary, CEIVAP includes a technical chamber—composed of six members per state, two from each category (private users, government entities, civil society)—and several working groups. Additionally, the plenary elects a three-member directorate for two years with one representative from each category (private, government, civil), and each of those from a different state. Representatives of government entities hold the presidency, which rotates between the three states.

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2   Comitê para Integração da Bacia Hidrográfica do Rio Paraíba do Sul (Integration Committee of the Paraíba do Sul River).

The water resources management legislation currently in force in Brazil was approved in 1997, through law 9433. This law is founded on the principles of Integrated Water Resources Management and creates water resources councils at the state and national levels.[3] Brazilian basin committees are embedded within a web of participatory organizations for water management (see also Mancilla García & Bodin, 2018, 2019).

Methods

The sample included in our quantitative analysis consists of the participants in the water basin committee CEIVAP's plenary, provided that they fulfilled one condition: having attended at least two of the last six plenary meetings. This resulted in a sample of 45 people, three of whom declined to participate in the study—a response rate of 93 percent.

We presented respondents with the list of participants in CEIVAP's plenary and asked them to evaluate each participant following two criteria: whether they shared information with them and whether they saw them as influential over the management system of the river Paraíba do Sul. The first question was rated on a four-point scale, where 1 means "rarely or never," 2 means "sometimes," 3 means "often," and 4 means "constantly." Based on responses to this first question, we created the network of information exchange. While we acknowledge there are many types of centrality measures, we focused on in-degree centrality, which is the simplest measure and typically correlates strongly with other measures of centrality such as betweenness centrality.

The other question evaluated perceived influence on a five-point scale, where 1 was "not at all" and 5 "completely." For both scales, 0 indicated a participant unknown to the interviewee. We used influence perception as a measure of reputational power following Fischer and Sciarini (2016); perceived influence was assessed based on the average rating from all other actors responding with a 1 or above. We used a normalized measurement in which all 0 responses were disregarded, since 0 indicated that the actor was unknown to the interviewee, who, therefore, could not assess their level of influence.

Additionally, we asked actors a series of descriptive questions about their own participation in the water management system that allowed us to develop a set of attributes and variables to further explore actors' behavior and strategies.

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3   Integrated water resources management is one of the most broadly implemented approaches to water management and is supported by multilateral agencies and governments across the globe. It was developed by engineers in the 1940s but was broadly institutionalised in the 1990s (Mancilla García, 2015). It proposes to align management with the watershed through the creation of water basin councils at that state and national scales. It proposes a participatory approach, although it has been extensively criticised for doing so uncritically (Mancilla García, Hileman & Bodin, 2019).

We asked participants to list other forums in which they participated to discuss water management issues. We also asked participants the degree to which they were involved in CEIVAP (on a 1-to-4 scale where 1 is "not at all" and 4 is "a fundamental aspect of my work"), which we used in the analysis as a control variable.

To complete these data, we ran extensive semi-structured interviews with participants in the CEIVAP plenary during which they could speak about their general views on the system of management. Finally, we attended and took notes on plenary committee meetings, those of the technical chamber, and some meetings of other forums involving CEIVAP participants. The qualitative data were analyzed following a thematic analysis in which different themes were identified based on actors' responses to the questions as well as on other themes that emerged from reading and summarizing the data. This allowed us to create codes around the discussion of power issues, strategies to improve the system, actors' specific agendas, and broader issues relating to difficulties with ensuring meaningful participation. These thematic codes served to retrieve useful data for the analysis provided here.

The quantitative data were analyzed through descriptive statistics, network regression, and structural equation modeling (SEM). We acknowledge that standard regression techniques are often problematic when analyzing network data due to potential data interdependencies. In this case, the potentially most problematic network-based variable would be the social ties in the information exchange network. Perceived influence is constructed in a similar way (a network-centric data structure), but is, as we argue, a less problematic variable since it does not represent "working" relationships among actors (that could imply autocorrelation—i.e., if you work together you could develop similar traits, and/or you might choose to work with others because they have similar traits). Rather, it represents individuals' independent perceptions of other actors' level of influence. Nonetheless, when testing whether centrality in the information exchange network is strongly associated with influence (H1) we used a quadratic assignment procedure (QAP), a network regression model (Krackhardt, 1988) implemented in the software UCINET (Borgatti et al., 2002) where significance levels are estimated based on a large number of permutations. This allowed us to overcome the possible problems posed by data interdependency (autocorrelation), a feature that standard statistical analysis struggles with.

Although we acknowledge the potential difficulties with the network data primarily related to information exchange, the potential effect of autocorrelation on the residuals would be reduced when modeling each node's total degree centrality, since that measure represents an aggregate measure drawn from the entire network. Assuming that a direct tie between two actors also implies that the data associated with these actors are interdependent to some extent, the level of interdependency would then decrease since the node-level variable degree centrality, for each and every node (actor), is typically composed of many different direct relationships.

For all other hypotheses (H2–H4) we used SEM. We used the Akaike information criterion (AIC), the root mean square error of approximation (RMSEA), and comparative fit index (CFI) to compare the level of fit for different SEMs. In order to compute all these measures of model fit, we had to use normal standard error estimates. Nonetheless, we also ran these models using robust standard errors, and no noteworthy differences between estimated effect sizes and significance levels were observed.

Throughout the quantitative analysis we used our qualitative data to further investigate our hypotheses and particularly tried to disentangle the reasons behind observed patterns of relationships among different variables. This allowed us to get a better understanding of the particularities of the case and to propose avenues for future research.

Results of the quantitative analysis

We started our analysis by evaluating the correlation between centrality in the information exchange network and influence ratings through a dyadic QAP (see Borgatti et al., 2002). The correlation between influence and centrality gave a Pearson's coefficient of 0.762 ($p<0.000$). This demonstrates that although influence and centrality in the information exchange network are significantly correlated (as expected), there is still substantial variability between the two. Indeed, if there was no difference at all, Pearson's coefficient would be equal to 1. The differences between influence and centrality are substantial enough to merit further investigation, since this first result shows that although influence and information centrality are associated, they are not the same thing (H1).

When evaluating the centrality in the information exchange network, we observed that central actors came from all sectors and states. Among the six most central actors in terms of information exchange, two came from civil society, two from the private users category, and two from a government entity. Moreover, the three different states are represented through these actors. This suggests that actors exchange information with others from a variety of backgrounds. It is important to clarify that among civil society representatives in the committee, there were no large NGOs with budgets comparable to those of the private user representatives. Additionally, although one of the two government entity representatives from the six most central actors was a representative of a state-level organization, the other represented a small municipality. These observations together suggest that a variety of reasons, not solely explained by actors' access to financial resources or to formal authority, might explain why actors exchange information with others. In other words, actors' positions in social structures (resources, formal authority) preceding

their interaction with others in the forum do not seem to be the sole guiding factor in the way actors exchange information. Otherwise we would observe that the most central actors are mostly resource-rich actors or actors with access to formal authority. Additionally, our previous study showed that the actors rated as the most highly influential also came from a diversity of backgrounds: Two of them were representatives of private users, two were representatives of civil society, and two others of government entities (Mancilla García & Bodin, 2018). While some of the most central actors in the information exchange network are among the most influential, not all of them are.

We used SEM to evaluate whether attending different forums produced a significant direct effect in terms of augmenting influence and information degree centrality or whether the effect on information degree centrality was mediated through the level of influence (Fischer & Sciarini, 2016).

Table 1. Structural equation modeling (SEM1) to explore effect of influence on information (using standardized coefficients).

	Coefficient	*p* value
Information in-degree ←		
Normalized influence rating	0.6328536	0.000
Degree of involvement	0.2072994	0.018
Number of forums	0.2365686	0.015
Normalized influence rating ←		
Number of forums	0.5017706	0.000

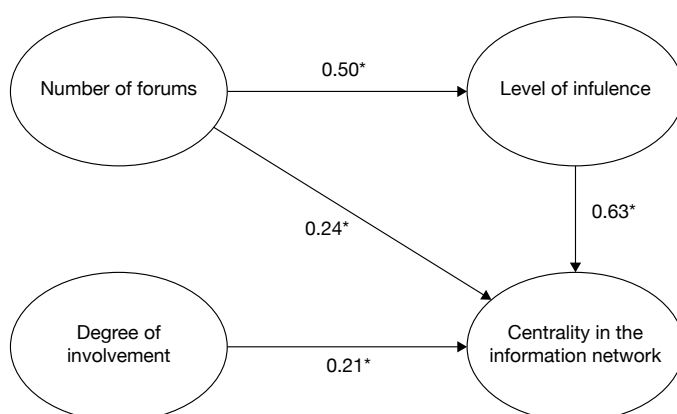Source: Authors' summary of results.

Figure 2. Summary of SEM1.

Source: Authors' summary of results.

SEM1 shows that the direct effect of the number of forums attended on information exchange network centrality is significant but limited, while it is key in explaining influence (Table 1, Figure 2). This confirms the hypothesis that the number of forums attended has a direct effect on both influence and information degree centrality (H3). It also provides support for the hypothesis that the more influential an actor is, the more central they are in the information exchange network (H2A).

We then reversed the assumed causal directionality between level of influence and information exchange centrality (Table 2, Figure 3), to test whether centrality in the information exchange network explained high influence.

Table 2. Structural equation modeling (SEM2) to explore effect of information on influence (using standardized coefficients).

	Coefficient	*p* value
Normalized influence rating ←		
Information in-degree	0.7512243	0.000
Number of forums	0.057579	0.626
Information in-degree ←		
Number of forums	0.531643	0.000
Degree of involvement	0.2732413	0.017

Source: Authors' summary of results.
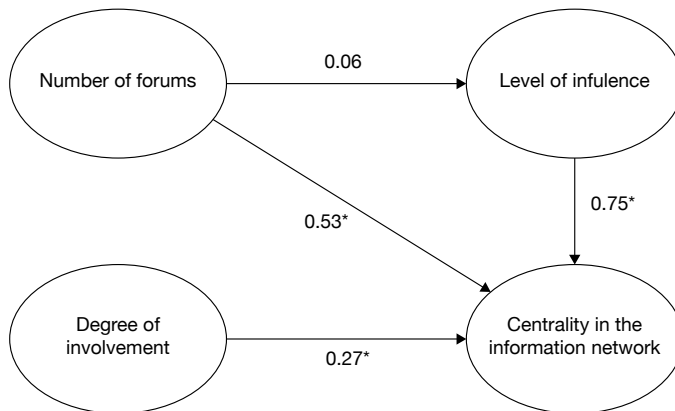
Figure 3. Summary of SEM2.
Source: Authors' summary of results.

In this case, SEM2 shows that the direct effect of the number of forums attended on the influence rating is not significant, while its effect is significant on information centrality. Thus, in this case, the hypothesis that the number of forums attended has a direct effect on both influence and information degree centrality (H3) is only partially true (Table 2). We also observe that information has a strong and significant effect in explaining influence (H2B).

This second model (SEM2) gave reasonably good fit (RMSEA = 0.044; CFI = 0.999), however not as good as the first model SEM1 (RMSEA = 0.000; CFI = 1.000). Hence, in comparing these different models, our results gave stronger support for the following hypotheses: (1) the more influential an actor is, the more central they are in the information exchange network (H2A); and (2) the effect of forum participation on centrality in the information exchange network is to a large extent mediated by its effect on influence (H4A). Our results gave weaker support for the following hypotheses: (1) the more central an actor is in the information exchange network, the more influential they are (H2B); and (2) the effect of forum participation on influence is to a large extent mediated by its effect on information exchange (H4B). Our results also support the hypothesis that forum participation has a direct effect on influence and on information exchange (H3).

Discussion

Our results show that central actors, in terms of information exchange, and actors perceived as highly influential, might emerge from any of the sectors. These results need to be read against the historical background of the region, in which civil society actors, peasant communities, and small municipalities have largely been excluded from management (Abers & Keck, 2009; Mancilla García & Bodin, 2018; Mancilla Garcia, Hileman, Bodin, et al., 2019). Among our interviewees, those who had participated in the design and creation of the committees pointed out that the inclusion of actors from civil society was perceived as a key challenge at the time of designing the committees. The fact that we find actors from civil society actively engaged in the network of information exchange and perceived as highly influential shows that including civil society actors in the process of management has been at least partly achieved. Moreover, our interviewees from small NGOs indicated that, notwithstanding the challenges (such as the necessary fluency in technical discourses to be able to meaningfully contribute to discussions: see Mancilla García & Bodin, 2019, for more details), their participation in the committees allowed them to have a say in the governance of the basin.

Previous literature has argued that government entities in the Global South do not always hold sufficient authority and can be dominated by resource-rich private actors (Abers & Keck, 2009), which challenges institutionalist perspectives. In our particular case, we observed different degrees of authority among government entities. In particular, municipalities, and even more so small municipalities, did not seem to have access to sufficient resources to comply with their responsibilities, let alone to determine the political agenda (for more details, see Mancilla Garcia, Hileman, Bodin, et al., 2019). This is why it is particularly significant that small

municipalities are one of the two government entities among the most influential and the most central actors in terms of information exchange, suggesting that, at least to a certain extent, this type of actor can also play an active role in the committee.

The quantitative results, supported by our qualitative data, seem to go against the idea that differences in preexisting structures (such as resources and formal authority) always lead to the same actors being central and influential and that such structures would be impossible to change. Indeed, actors among the most central and the most influential were from a variety of group origins, including civil society, a key group that the designers of the councils sought to include. This resonates with recent studies' findings (Ingold & Leifeld, 2016; Sciarini et al., 2015), and contributes to challenging the institutionalist hypotheses that formal authority (of the kind certain government representatives hold) is typically the main way to become influential (Dahl, 1994), as well as to challenging the literature on interest groups that argues on the importance of financial resources in becoming influential (Yackee & Yackee, 2006). This provides support for Giddens's definition of agency, since we do not observe a pure reproduction of structures as one would expect to find from a structuralist perspective. Instead, we find influential actors from a diversity of backgrounds and particularly from those groups that were historically excluded from management.

However, during our interviews some actors were critical of the deliberative system and specifically complained that the committees had unintended negative effects. According to these interviewees, by leading to the development of good relationships between representatives from civil society and from private users, civil society representatives refrained from pushing for a rise in the rates of payment for water use, to maintain their good relationships with the users' representatives and thus engaged in a "consensus game" (Whelan & Lyons, 2005). Moreover, some of our interviewees pinpointed that in cases of crisis—such as the management of the drought crisis in São Paulo in 2014—the positions of the committee were disregarded and bypassed by traditional power-holders such as the governors of the states. Our interpretation is that although the committee as a whole seem to have come a long way in implementing a participatory system, this should not be taken for granted. Indeed, there are exterior structures that still matter for the management of the system and that might become dominant at certain times.

It is also important to note that CEIVAP is free to use the resources collected from private users in the basin—through the payment for water use scheme implemented in the basin (Abers & Keck, 2006; Ioris, 2009)—as the plenary considers appropriate. This means that if actors manage to advance their agendas in the forum, this will have an impact on the management system. For example, our interviews suggest that the work within the committee—making proposals and substantiating them with diagnoses on the system state—of previously excluded actors such as environmentalists has had an effect on the kind of projects approved. CEIVAP has

successfully developed a set of projects since it was created in 1997, among which 13 programs of environmental education. Between 2013 and 2016, nearly 55 percent of the money spent—USD22 million—was spent in projects of environmental quality recovery, which involved setting sanitation programs as a priority. Almost USD4 million—>9 percent of the total amount spent—was spent on protection and use of water resources. Projects in this component include a project on payment for ecosystem services, recovery and protection of permanent preservation areas, and the creation of a database from which maps can be built (AGEVAP[4], 2016). The creation of maps is part of the tasks related to the diffusion of information, which has also involved the holding of courses and workshops in diverse areas of the basin.

Our results suggest that in order to become influential or central in the information exchange network, actors should try and invest in attending multiple forums. These findings directly speak to the idea put forward by Giddens, and Long and Long, that structures—in this case the formal institutional network of governance—should actively be used by actors to achieve their goals (Giddens, 1984; Long & Long, 1992). Our results show that the opportunity for actors to increase their influence by participating in multiple formal forums is not restricted to traditionally powerful actors with access to resources, and responds to deliberate action by all actors. Thus, this suggests that the committees provide a platform wherein actors can do something to improve their influence, such as attending other forums.

These results also provide lessons for scholars adopting a perspective inspired on political ecology or those working on leadership studies. Indeed, while those perspectives can help to guide the questions asked on power dynamics and on the role of particular actors, respectively, our results show that they would gain from incorporating insights from structuration theory. Network analysis provides a concrete way to investigate both the effects of structure and agency that can be useful for these perspectives.

It is important to specify that being very involved in one forum, considering it fundamental for one's work, is not the same as participating in many forums. If actors want to increase their influence, they should invest their limited time and resources in participating across multiple forums, not only one forum. It is furthermore interesting to note that the variable "degree of involvement" serves to explain information centrality, which means that actors who invest themselves in the committee work become more central in the information exchange network. Increased involvement might improve an actor's reputation as knowledgeable and thus increase their centrality in the information exchange network, but not necessarily their influence (see also Mancilla García & Bodin, 2018). By participating heavily in the committee, actors seem to be building networks, but not necessarily influence.

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4   Associação Pró-Gestão das Águas da Bacia Hidrográfica do Rio Paraíba do Sul (Association for the Management of the Waters of the Paraíba Do Sul River Basin).

While the analysis above indicates that influence ratings and information degree centrality seem to respond to similar dynamics, our analysis also showed that both measures are separate. Although actors might behave in ways that increase both their influence ranking and their information exchange network centrality, some strategies might benefit only one of those two. For example, we observed that certain actors were very present in online media such as WhatsApp groups on water governance, which they used to communicate all sorts of information on the state of the rivers. While these actors were well known to others, they were not necessarily perceived as influential. Indeed, the information they communicated might serve to feed the management system (such as information on water levels, ecosystem health measures, etc.) but not necessarily determine the agenda. In our qualitative data, we also find cases of actors who were quite central in the information exchange network but who were considered by others as having little influence. For example, one actor—representative of the users—had participated in the committee for several years and had been brought to the committee through a personal connection to a member. The actor enjoyed participating in the committees because they learned about water governance and particularly about basin-perspectives. The sustained participation over time, as well as their willingness to engage with diverse issues, had made them well known among committee participants. However, they rarely expressed strong opinions on the issues discussed or defended any particular position strongly enough to be considered influential.

Conversely, we find examples of actors who were influential but not central in the information exchange network. For example, an actor might be considered influential because they hold a particularly powerful formal position within the committee, but that does not mean that they will be actively engaged in networks of information exchange. According to our interviewees, this tends to happen with actors occupying a high-ranking administrative position in the committee. These actors are considered highly influential during the time of their mandate; however, they frequently are very busy and tend, for example, not to stay until the end of plenary meetings and not to attend other events (such as environmental education activities, etc.), which means that they are rarely available for others. Therefore, our qualitative data provide cases in which influence and information exchange centrality are clearly separate, and as we saw from the quantitative analysis.

Limitations

The main limitation of our study is the lack of longitudinal quantitative data. Without such data, assessing causal directionally empirically is inherently difficult. The SEM results gave more support for the model that reflected the hypotheses that (1) the more influential an actor is, the more central they are in the information exchange network (H2A), and (2) the effect of forum participation on centrality in the information exchange network is to a large extent mediated by its effect on influence (H4A). However, we cannot rule out the hypotheses that (1) the more

central an actor is in the information exchange network, the more influential they are (H2B), and (2) the effect of forum participation on influence is to a large extent mediated by its effect on information exchange (H4B). We also cannot rule out the hypothesis that forum participation has a direct effect on influence and on information exchange (H3), which is only partially excluded.

Importantly, our qualitative data corroborated the ways we interpreted our quantitative results. Hence, in sum, although we acknowledge the limitation deriving from lack of longitudinal data, we maintain that our results provide empirical support favoring certain causal pathways over others. However, we wish to emphasize that although our focus has been on disentangling causal directions, we nonetheless acknowledge that directionality likely goes in both ways (i.e., feeds back), although we maintain that our results demonstrate that certain directions are stronger than others.

Additionally, the study did not consider the effect of participating in one or several of CEIVAP's sub-forums (such as the technical chamber, the directorate, or working groups) on influence or information degree centrality. We did not consider these data to be reliable since the effect of someone participating in one of these subgroups, and it being known and acknowledged by participants in the plenary, seemed to suffer from time lapses. Indeed, in the interviews, participants remembered others being part of the technical chamber in previous years, but did not necessarily know who was part of it at the time of the interview. Moreover, in the specific case of the technical chamber and working groups, organizations represented in the plenary did not necessarily send their plenary representative to the technical chamber; they could send someone else from the organization. This meant that actors who had newly joined the plenary did not know these other actors. For these reasons, we preferred to exclude this attribute.

Finally, in this study we focused on information exchange. Networks made up of other types of social relationships could have led to different results. However, we argue that information exchange is a broadly spanning type of relationship, which often comes together with other types of relationships (e.g., trust). Hence, we in part consider it being a proxy for other kinds of relationships the actors associate with a positive social relationship.

Conclusion

In this paper we have explored the ways in which centrality in the information exchange network and influence are causally connected and how they can be explained by analyzing actors' actions and the structures in which they are embedded. We have seen that high influence and centrality in the information exchange network are related. Attending multiple forums seems to explain influence and information

degree centrality. Moreover, we have seen that influence has a strong impact in determining information degree centrality, although we also found support for the reverse directionality, albeit with a lower model fit.

We have also seen, through the use of our qualitative data, that there are activities and structures that have an impact on information degree centrality but not on influence, and vice versa. On the one hand, being deeply involved in CEIVAP's work is beneficial in terms of information degree centrality, but not necessarily in terms of achieving high influence. On the other hand, occupying a position of high responsibility in the committee—for example, being the president of the directorate—leads to being perceived as highly influential, but this has no all-encompassing impact on an actor's centrality in the social network. These different elements seem to suggest that actors have opportunities to use the available formal institutional structures to act in ways that benefit them. For example, an actor can choose to participate in many forums—which is made possible by the formal creation of such participatory forums in the Brazilian system of water governance—and thus exert their agency to become influential by putting existing structures to good use.

Future research should investigate with longitudinal studies how different events—such as political changes or water availability crisis—impact the perception of influence and the capacity of actors participating in the committees to effectively use their power to steer the system. Additionally, future studies should try to further explore how actors strategically use different structures at their disposal to advance their positions in different networks and forums than the ones studied here—such as project collaboration, alignment of voting behavior, or strategies of participation across forums—and how that relates to their perceived influence.

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Understanding Social–Ecological Systems using Loop Analysis

Marco Scotti[1]
GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

Daniel Filipe da Silva Pereira[2]
GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

Antonio Bodini
Department of Chemistry, Life Sciences and Environmental Sustainability,
University of Parma, Italy

Abstract

The sustainable management of social–ecological systems (SESs) requires that we understand the complex structure of relationships and feedbacks among ecosystem components and socioeconomic entities. Therefore, the construction and analysis of models integrating ecological and human actors is crucial for describing the functioning of SESs, and qualitative modeling represents an ideal tool since it allows studying dependencies among variables of diverse types. In particular, the qualitative technique of loop analysis yields predictions about how a system's variables respond to stress factors. Different interaction types, scarce information about functional relationships among variables, and uncertainties in the values of the parameters are the rule rather than exceptions when studying SESs. Accordingly, loop analysis seems to be perfectly suitable to investigate them. Here, we introduce the key aspects of loop analysis, discuss its applications to SESs, and suggest it enables making the first steps toward the integration of the three dimensions of sustainability.

Keywords: complex systems, networks, qualitative modeling, social–ecological systems; sustainability

Introduction

Human societies and their well-being depend on the provision of goods and services from ecosystems (Haines-Young & Potschin, 2010). Healthy ecosystems respond to human needs by maintaining structure and functioning over time (Costanza & Mageau, 1999), and the conservation of biodiversity is crucial for preserving

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1 Corresponding author: marcoscot@gmail.com.
2 Daniel Felipe da Silva Pereira conducted this study at the Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Italy.

stability and productivity of natural systems (Stachowicz et al., 2002; Worm et al., 2006). However, biodiversity is declining worldwide, a trend that raises concerns on the sustainable supply of goods and services from ecosystems (Lotze et al., 2006). The increasing level of human-induced impacts (e.g., overexploitation of resources, introduction of alien species into native environments, chemical pollution, nutrient enrichment, and climate change) threatens biodiversity in both aquatic and terrestrial systems and calls for the formulation of effective conservation practices. Ecological changes are often associated with social and economic transformations that, in turn, reflect their effects back on ecological functions and processes. Discovering and bringing to light these interdependencies requires a shift in focus: from a "within-domain approach" to a global strategy in which the ecosystem as unit of investigation is part of a larger system that embeds socioeconomic dynamics (Hilborn, 2007). Long et al. (2015) identified 15 key principles for implementing ecosystem-based management (EBM). Among these principles, they included the modeling of interconnections between ecological, social, and governance systems, which implies that social–ecological systems (SESs) are networks and that EBM implementation can benefit from the application of the methodologies that network analysis offers.

The network perspective requires that the interactions that link variables belonging to the human and ecological domains are concurrently taken into account, so that the SES as a whole becomes the unit of management. The challenge is the identification of relationships at different hierarchical levels, which occur at various spatial and temporal scales. To facilitate integration, Ostrom (2009) proposed a classificatory framework that describes the four essential dimensions of SESs: resource users, governance system, resource units, and resource system. The relationships among these four dimensions occur at various geographical and temporal scales, within the rules defined by the SES's ecological, social, economic, and political settings. The choice of the suitable scales and the proper identification of the variables that constitute the SES, and their connections, are essential to assess under what conditions sustainability can be enhanced. Moreover, the concept of sustainability is multidimensional and the spatial heterogeneity of SES variables can cause a mismatch between objectives that belong to either the social or ecological domain. This complexity is exemplified by the study of small-scale fisheries in the Mexican state of Baja California Sur, which showed the lack of association between different dimensions of sustainability (Leslie et al., 2015). Policies for the sustainable use of ecosystem goods and services require policy-makers to take into account the set of interactions linking ecological resilience (i.e., the adaptive capacity to withstand recurrent perturbations) to the society, the economy, and the governance rules (Hughes et al., 2005). The integration of these dimensions is challenging and this difficulty is inflated by the adoption of strictly sectoral approaches. Most studies on the social dimension of resources and environmental management focus on social dynamics and treat the ecosystem as a black box; in parallel, the ecological approach

to sustainability considers the social aspects only at the boundaries of the natural system (Binder et al., 2013; Folke, 2006; Partelow et al., 2019). The balanced integration of social and ecological variables within the same modeling scheme is often precluded by two factors: (1) there are difficulties in the identification of the most important interactions linking the variables; and (2) the mathematical form of interactions is often unknown. Qualitative modeling represents a possible solution to these difficulties. In particular, loop analysis (Levins, 1968, 1974), through its simple application requirements (i.e., describing the presence of links and their signs), can be used to consider the interactions among variables across different domains.

Loop analysis was developed to model the equilibrium levels of a system when growth rates of specific variables are altered by environmental variability. Loop analysis requires that only the sign of the relationship between the variables is specified—that is, whether a variable positively or negatively affects another one. This simplicity overcomes the lack of quantitative information and simplifies the semantic conversion of the concepts related to the processes in which variables take part when belonging to different domains. Most of the works on SESs published so far have focused on ecosystems and considered the human component a source of external perturbations. For example, Bodini et al. (2018) showed how overfishing affected the internal dynamics of the Black Sea, but did not consider how socioeconomic drivers inflated overfishing. Applications of loop analysis to SESs are gaining ground (Dambacher et al., 2007; Martone et al., 2017). Here we show the potential of loop analysis for the integrative modeling of SESs. First, we introduce the methodological aspects behind the tool. Second, we discuss merits and limitations of loop analysis in studying the dynamical behavior of SESs. Then, we compare loop analysis with other qualitative methods that can be applied to SESs. Finally, we present ideas of possible developments that could favor the diffusion of loop analysis in the context of SESs.

Loop analysis: Methodological aspects

Loop analysis is a qualitative technique for modeling complex systems as signed, directed graphs. Interactions are depicted as either positive or negative effects but their strength is not specified (Figure 1A). Positive interactions are illustrated by arrow-headed links, while negative interactions are visualized with circle-headed links. Any signed digraph has a matrix counterpart (interaction matrix) in which positive (arrowheads) and negative (circle heads) interactions are represented by the coefficients +1 and –1, respectively. Zeroes in the matrix stand for null direct relationships between any two variables (Figure 1B). The elements along the main diagonal of the interaction matrix are self-effects on the variables and correspond to self-links in the graph (i.e., an arrowhead or circle-head link connecting a variable

to itself). Loop analysis allows predictions on how the variables will respond to press perturbations that target specific variables. Press perturbations are forces that modify parameters in the rate of change of the variables (Bender et al., 1984), such as environmental warming that enhances the reproductive rate of jellyfish, or ecolabels that increase the rate at which the income of fishing cooperatives is produced. There are as many targets of press perturbations as the number of variables in the system (i.e., any variable can represent the entry point for press perturbations). The effect of press perturbations can be predicted by analyzing the structural properties of the graph (Levins, 1974, 1975).
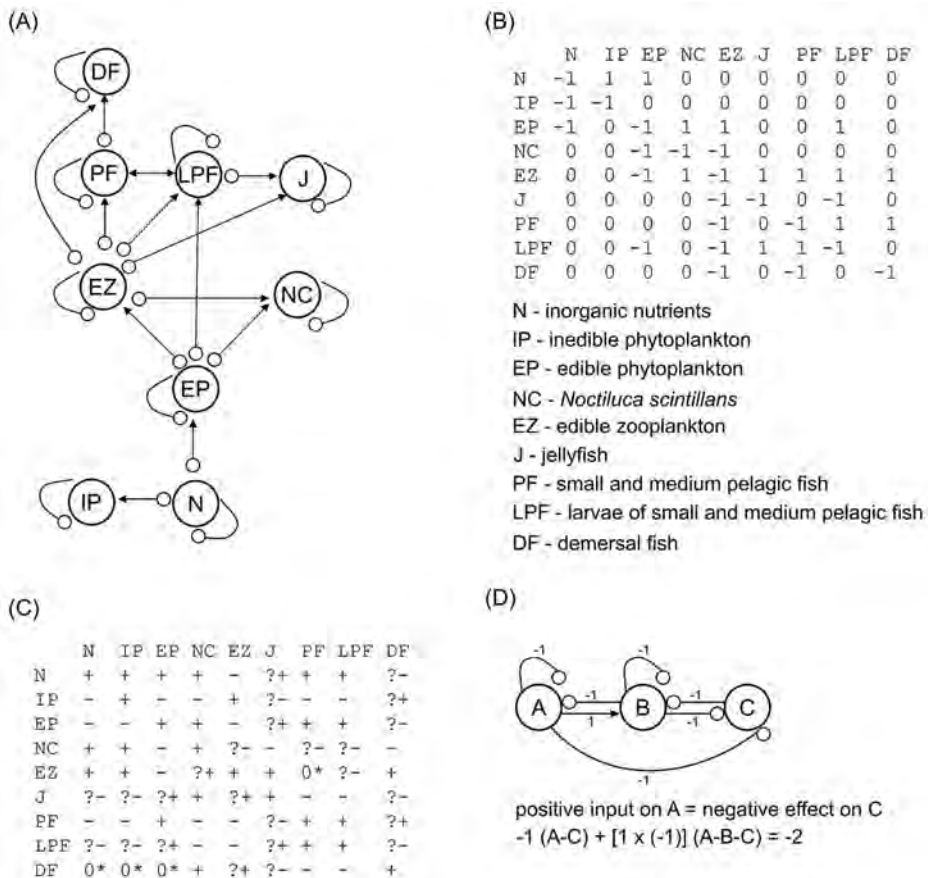

(B)

	N	IP	EP	NC	EZ	J	PF	LPF	DF
N	-1	1	1	0	0	0	0	0	0
IP	-1	-1	0	0	0	0	0	0	0
EP	-1	0	-1	1	1	0	0	0	1
NC	0	0	-1	-1	-1	0	0	0	0
EZ	0	0	-1	1	-1	1	1	1	1
J	0	0	0	0	-1	-1	0	-1	0
PF	0	0	0	0	-1	0	-1	1	1
LPF	0	0	-1	0	-1	1	1	-1	0
DF	0	0	0	0	-1	0	-1	0	-1

N - inorganic nutrients
IP - inedible phytoplankton
EP - edible phytoplankton
NC - *Noctiluca scintillans*
EZ - edible zooplankton
J - jellyfish
PF - small and medium pelagic fish
LPF - larvae of small and medium pelagic fish
DF - demersal fish

(C)

	N	IP	EP	NC	EZ	J	PF	LPF	DF
N	+	+	+	+	-	?+	+	+	?-
IP	-	+	-	-	+	?-	-	-	?+
EP	-	-	+	+	-	?+	+	+	?-
NC	+	+	-	+	?-	-	?-	?-	-
EZ	+	+	-	?+	+	+	0*	?-	+
J	?-	?-	?+	+	?+	+	-	-	?-
PF	-	-	+	-	-	?-	+	+	?+
LPF	?-	?-	?+	-	-	?+	+	+	?-
DF	0*	0*	0*	+	?+	?-	-	-	+

(D)

positive input on A = negative effect on C
-1 (A-C) + [1 × (-1)] (A-B-C) = -2

Figure 1. Signed directed graph describing (A) the Black Sea food web and (B) the corresponding matrix of interactions.

Note: In the graph, positive interactions are denoted with arrow-headed links while negative interactions are visualized with circle-headed links. Names of all variables (i.e., nodes in the graph) are below the matrix of interactions. Loop analysis results for the Black Sea in the period 1960–1989 are summarized in the table of predictions (C). Additive and multiplicative rules are considered for predictions (the example here refers to a theoretical system with three variables) (D).

Source: Bodini et al. (2018).

The links in signed digraphs carry a direction (e.g., where the arrow and the circle point to). By following this direction one can identify paths so that variables that stand far apart from one another in the system can be functionally connected. With reference to Figure 1A, nutrients (N) are connected to demersal fish (DF) by several paths, one of which is: N→EP→EZ→PF→DF. Paths are the routes along which effects of press perturbations travel through the system. Each path carries an effect that is either positive or negative, depending on the product of the signs of the links that compose the path.

Next there is feedback, which can be negative or positive. The former is a process in which an initial change in a variable is reflected back so that its original value is restored. A negative feedback, for example, occurs in agriculture when an increased agricultural yield reduces prices: investments are cut, so that yield is reduced. A positive feedback occurs when an initial change gives rise to a chain of events that amplify the original change. For instance, during the civil war in Colombia the level of violence displaced people from their land, and this contributed to further increases in the level of violence. Since the feedback is a "return effect," it originates when variables are linked by closed paths (i.e., circuits or loops) and its sign is negative or positive depending on the product of the signs of the links that form the loop (see Puccia & Levins, 1985 for a rigorous method for computing the feedback sign). For example, in Figure 1D the arrow from A to B, and the circle-head link from B to A, form a closed path, or loop, with negative feedback, because the product of the two links is negative. There can be circuits of different length depending on the number of variables linked together in a closed path. With these definitions we can express conceptually the algorithm of loop analysis (Puccia & Levins, 1985). The sensitivity of a variable to a press perturbation depends on: (1) whether the perturbation increases (+ sign) or decreases (– sign) the rate of change of the variable through which it enters the system; (2) the sign of the path connecting the variable targeted by the press perturbation to the effect variable (the variable one wants to predict the response of); (3) the sign of the feedback of the subsystem that remains when all variables on the path are ideally removed from the system (this is called complementary feedback); and (4) the overall feedback—that is, the feedback of the circuits that connect all the variables in the system. The algorithm can be summarized in the following formula:

$$\frac{\partial x_j}{\partial c} = \frac{\sum_{i,k} \left[\frac{\partial f_i}{\partial c}\right] \times \left[p_{ji}^{(k)}\right] \times \left[F_{n-k}^{(comp)}\right]}{F_n}$$

in which $[\partial f_i/\partial c]$ expresses whether the rate of change of the target variable x_i increases or decreases because of the changing parameter c; $[p_{ji}^{(k)}]$ is the pathway from the target to the response variable; $[F_{n-k}^{(comp)}]$ is the complementary feedback and $[F_n]$ is the overall feedback. Summation ($\sum_{i,k}$) occurs along all paths from the target

variable x_i to the effect variable x_j. The complementary feedback can be envisioned as a reflecting barrier; if it is negative and strong, the more an impact is reflected back to the effect variable. If it is positive, then the effect variable changes in the opposite direction from the sign of the path. The overall feedback, the denominator of the formula, measures the resistance of the whole system to change. The responses predicted can be positive (+, increase), negative (–, decrease), or null (0, no change), and are summarized in the table of predictions (Figure 1C). The convention is that effects generated by positive perturbations (those increasing the rate of change of the target variables) on row variables can be read along the columns. Consequences of negative perturbations are obtained by reversing the signs of the predictions. Consider a positive press perturbation ($[\partial f/\partial c] > 0$) on node A in Figure 1D: If the focus is on the consequences that the press perturbation has on node B, then the path is the positive link from A to B and the complementary subsystem is node C alone; this latter variable does not form any circuit and the complementary feedback is null (i.e., equal to 0). The overall feedback is the feedback produced by the circuit that connects all the variables in the system (see Puccia & Levins, 1985 for further details). In the digraph of Figure 1D there is one single circuit that starts and ends with node A and connects all variables. This circuit includes one positive and two negative interactions: A→C–○B–○A; its sign is the product of one positive and two negative links and thus it is positive.

In graphs with many variables and interactions, the number of paths between variables often increases, which leads to several ambiguous predictions (i.e., the positive paths counteract negative paths so that a clear sign of the direction of change cannot be identified). To deal with such ambiguities, a simulation approach can be adopted based on a random assignment of strength to each and every link coefficient. To make simulations possible, the signed digraph is transformed in a matrix using +1 to represent positive (arrowhead) links and –1 to indicate negative (circle-head) links. During simulations the coefficient intensities are taken from a uniform distribution in the interval (0,1]. This means that the +1 and –1 values in the matrix are substituted by randomly assigned values between 10^{-6} (the lower boundary equal to 0 is not included) and 1 while the sign is maintained. Not all the matrices obtained can be used to compute the predictions but only those that satisfy criteria for stability (see Logofet, 1993, for stability conditions matrices must satisfy). According to Bender et al. (1984), the net effect that press perturbations targeting the row variable x_i have on the column variable x_j are expressed by the elements of the inverse of the matrix that is obtained from the signed digraph (for details see Levins, 1975). After n simulations, an overall table of predictions is constructed by combining the z matrices that are stable and allow matrix inversion. For each stable matrix assembled using simulated interaction strengths, unambiguous responses in the table of predictions are generated (i.e., the signs are certain). The overall table of predictions is composed of symbols that depend on the percentages of signs from the various simulation runs. Hence, if the same entry in the tables of predictions

from all z (stable) matrices yields the same sign (+ or –) then the expected direction of change is unambiguous. However, during simulations there are cases for which divergent predictions are recorded (i.e., depending on the random arrangement of interaction strengths, the same element in the table of predictions can show either positive or negative sign). The conversion of the outcomes from each simulation run to symbols in the overall table of predictions depends on the percentages of positive (+) and negative (–) signs. The rules to move from simulations results to the overall table of predictions are summarized in Table 1.

Table 1. Rules to convert differences between percentages of signs obtained with simulations ("% of +" – "% of –") into predictions (i.e., signs in the overall table of predictions).

"% of +" – "% of –"	Corresponding sign in the table
[–100, –50]	–
(–50, -20)	?– (tendency to –)
[–20, 20]	0*
(20, 50)	?+ (tendency to +)
[50, 100]	+
0 = 100%	0

Notes: Round brackets indicate that the extremes are excluded. 0* is not a real zero, meaning no changes in the biomass/abundance of variables, but represents neutral results due to relatively balanced amounts of negative and positive effects. When after the complete set of simulations there are entries for which the absence of any effect was always recorded then the symbol in the overall table of predictions is 0, indicating proper absence of effect (see the last row of the table: 0 = 100%).

Source: Authors' summary.

Merits and limitations of loop analysis to model SESs

Loop analysis is particularly suitable to investigate SESs. First, interconnections extend beyond the single domains of ecology, economy, and society to create complex networks. For instance, after the Nile perch invaded Lake Victoria a dramatic restructuring of the ecological community took place, which, in turn, cascaded into deep societal and economic changes (Downing et al., 2014). To disentangle drivers and dynamics of change in such a complex scenario, Downing and coworkers designed an eco-social qualitative model that traced connections across disciplinary boundaries. Second, loop analysis educates intuition to cope with complexity. Often, complex systems defy our predictions and effects of policies or management interventions are at best ineffective if not damaging (Levins, 1995). Failure of policies depends on the feedbacks that are produced by the linkages between the variables and that remain hidden to our comprehension if complexity does not become our central intellectual issue. Cinner (2011),

in discussing problems of reef fishery, emphasizes that the feedback between social and ecological variables may create social–ecological traps (e.g., situations when feedbacks between social and ecological systems lead toward an undesirable state that may be difficult or impossible to reverse). It is extremely interesting to explore these phenomena by loop analysis which, by disentangling feedback loops, helps make the arcane obvious. This capability, however, cannot be fully exploited if the feedback structure of the systems is not adequately represented and the relationships between the variables remain mostly unidirectional; the potential may instead emerge when social and environmental variables are incorporated in a unique model (Dambacher et al., 2007). Third, loop analysis proposes a rigorous approach to diagnosis. Diagnostic approaches are more often requested in the analysis of SESs to causally understand the multiple outcomes that can arise from the interaction of different system attributes (Kittinger et al., 2013). The table of predictions, the main outcome of loop analysis, allows the disentangling of causative mechanisms by linking correlation patterns, sources of change, and network structure (Bodini & Clerici, 2016; Bodini et al., 2018). For any entry point of press perturbation (any row in the table of predictions, see Figure 1C), variables are predicted to change, so that correlation patterns among them emerge. By comparing such patterns with observed changes in the level of the variables, one can identify which component is affected by external drivers and find the cause and effect mechanisms responsible for those changes due to the linkage structure. Fourth, loop analysis incorporates external drivers as inputs to the rate of change of the variables. External drivers, both social and biophysical, have been described as playing an important role in SES dynamics (Kittinger et al., 2013). For example, in Baja California (Mexico) climate-driven hypoxia caused an excess mortality in marine species with limited mobility, resulting in declines of stocks targeted by small-scale local fisheries, which, in turn, caused small-scale fishers to switch fishing effort toward less-affected species (Micheli et al., 2012). Such effect was explored in a scenario analysis using loop analysis, which predicted large-scale consequences of this external driver (Martone et al., 2017). Fifth, the intuitive visualization of the entities and the interactions among them is suitable for accommodating the general framework proposed by Ostrom (2009) for analyzing the sustainability of SESs. Each node in the digraph can be one of the four elements (i.e., core subsystems: governance system, resource users, resource system, and resource units) and either positive or negative links can visualize their direct relationships. So far the main focus has been dedicated to the visualization of ecological variables and interactions, and the inclusion of social–economic aspects has been treated as external to the system (Carey et al., 2014; Espinoza-Tenorio et al., 2013; Reum et al., 2015). Finally, the simple graphical format that constitutes the input for the loop analysis facilitates the participation of all stakeholders to model construction. Although most of the current applications adopted a top-down approach to embed management strategies in models (i.e., literature data were consulted to define the interactions), the study of Espinoza-

Tenorio et al. (2013) presents a valid alternative. In that work, both quantitative and qualitative information regarding the biological and social aspects of fisheries dynamics and management were retrieved using structured interviews with fishers, participatory research, key informant interviews, and workshops.

Limitations of the methodology should be taken into account. Some limitations have already been discussed (Justus, 2006) and here we focus on those that matter with the use of loop analysis in studying SESs. First, there can be difficulties in defining the timing of changing conditions and that of system response to impacts. SESs are resilient and cope with continuous exposure to press perturbations according to adaptive dynamics principles (Folke, 2006; Hughes et al., 2005). The exact moment at which the system responds to a press perturbation cannot be detected with precision and the contribution of concomitant perturbations may further confound this detection. Second, the variables of SESs (e.g., resources and their users) can show asynchronous behavior and heterogeneous geographical distribution (Leslie et al., 2015). Their optimization does not necessarily occur at the same temporal and spatial scale, an aspect that might remain overlooked when constructing graphs. The uneven geographical distribution of the actors might be addressed by including in the models different variables for the same type of user (e.g., various nodes that indicate the fishers and their interactions in different regions). Third, there can be issues in the identification of the variables exposed to press perturbations (i.e., impacts of overfishing vs climate change). For example, while marketing solutions (e.g., the introduction of ecolabels) can be easily targeted to specific user groups (e.g., the members of fishing cooperatives; see Martone et al., 2017), climate change (e.g., warmer winters) may affect many components of the ecological system with different time of response. One possible solution is prioritizing, as press perturbation targets the most responsive biological variables (e.g., jellyfish have faster blooming rates than expected from the body size; see Nival & Gorsky, 2001). Finally, loop analysis is problematic for assessing nonlinear relationships. Nonlinearity can emerge by combining the impacts of pathways of different lengths. Longer pathways have lower intensity than shorter ones since the interaction strengths randomly assigned during the simulations are in the interval $(0,1]$ (i.e., the intensity of each pathway is obtained by multiplying the strength of its constitutive links that have upper bound equal to 1). To avoid penalizing the impact of longer pathways, simulations could be carried out by constraining the lower limit from which interaction strengths are randomly drawn during simulations (i.e., by setting the lower limits of some "strong" interactions closer to 1). As an alternative, one could include nonlinear functions to model those specific interactions that play crucial roles for the dynamics of the SES (e.g., by relying on previous literature data or results from specific experiments and surveys).

Comparison of loop analysis with other qualitative methods for SESs

SESs form complex networks of linkages and loop analysis is designed to qualitatively predict how variables that are embedded in SESs respond to policies and management interventions (e.g., introduction of new regulations for the exploitation of resources, market-based incentives, and adoption of new marketing solutions; Carey et al., 2014; Dambacher et al., 2007; Levin et al., 2009). A limited number of applications to investigate complex SES have made use of loop analysis, but the interest toward the method has taken little ground in the context of fisheries (Anthony et al., 2013; Carey et al., 2014; Dambacher et al., 2015; Espinoza-Tenorio et al., 2013; Martone et al., 2017). These applications highlight that loop analysis has some potential that extends beyond its limitations. For example, predictions are about the equilibrium level of the variables (Justus, 2006), but real systems are generally not at the equilibrium. However, previous studies have offered evidence that predictions from loop analysis apply successfully to changes in average values of the variables (Bodini, 2000). Average values should be long term, and Bodini et al. (2018) showed that averages taken over either 5 or 10 years can be used to grasp variable responses to press perturbations. The appropriate time scale for taking averages, however, very much depends on the system under investigation.

Other qualitative modeling approaches can be used to study SESs. Fuzzy cognitive maps (FCMs) is one of these. It makes the magnitude of links explicit through a semi-quantification of the relationships that link variables (Kok, 2009; Özesmi & Özesmi, 2004). The semi-quantification of the links may resolve the ambiguities typical of loop analysis about the net effect generated by the combination of contrasting pathways. Also, FCMs can make predictions about multiple simultaneous perturbations. Both the state of the variables ("concepts," in the technical language of FCMs) and the strength of the links (edges between the concepts) are quantified by assigning standardized values in the range [0,1] for states and [-1,1] for links. Although these are relative values (i.e., each of them is assigned in relation to the others), some criteria for the quantification must be identified. These criteria must be supported by some knowledge about the level of the variables and interactions in the system, and in particular the use of FCMs seems appropriate when the estimates of variable state and link strength are the outcomes of either a combination of multiple FCMs from individual stakeholders or a set of values defined through participatory workshops. The quantification of variables and interactions requires a certain level of knowledge about the system and it automatically selects the working groups among stakeholders that possess some previous understanding of the system under investigation. It follows that FCMs cannot be public, reproducible, and intelligible in the way that loop analysis is. Kok (2009) posits that vague or complex concepts such as "consumer behavior" must not be taken into account when applying FCMs

because guessing about their magnitude is inherently difficult. On the other hand, loop analysis allows including "awareness" in a malaria model (Yasuoka et al., 2014), "environmental attractiveness" in a tourism model (Bodini et al., 2000), and the "role of the unions" in a model on diabetes (Lewontin & Levins, 2007). In these aspects it seems that FCMs share one limitation with quantitative models: the tendency to exclude from the analysis factors that are difficult or impossible to measure, no matter if they play a role in the dynamics of the system. The connections among the variables in FCMs are designed on the basis of fuzzy conditional statements ("if … then") that are of the type "if the level of variable A is high, that of variable B is low." Thus, connections are deduced from correlations between the variables derived from observing the system (Stylios & Groumpos, 1999). However, Levins and Puccia (1988) point out that patterns of correlation depend on the network structure and the entry point of the perturbation. For example, any two variables may show positive correlation in response to a specific press perturbation but opposite correlation (or no correlation) in response to other press perturbations. It follows that defining interactions between variables on the basis of their correlations may be misleading. In loop analysis, perturbations are variations in parameters that govern the rate of change of variables. For example, a pollutant triggering an increase in the mortality rate of a population. FCMs instead consider the changes in the level of the variables as perturbations. To predict, say, the impacts of a pollutant that affects a population, FCMs consider the reduced abundance induced by the pollutant as the initial event (i.e., the perturbation), on the logical assumption that a toxin, by increasing the mortality of a species, automatically reduces its abundance. Thus, the initial event is deduced from a more or less plausible linear sequence of steps. This series of events overlooks the fact that the response of the target population to the increased mortality is also mediated by the network of interactions with the other variables and that, accordingly, often does not follow commonsense linear expectations. Such assumption leads to the circular argument that FCMs predict the effects given a cause that is in turn an effect that FCMs should predict. On the other hand, we can be confident that the pollutant increases the mortality rate of the target population, which is the initial event in loop analysis. Loop analysis considers the role of the environmental variability in changing the parameters that govern the growth rates of the variables, and does not interpret it solely as the cause of variable fluctuations like FCMs do.

Causal loop diagrams (CLDs; Hanspach et al., 2014; Tenza et al., 2017) and Bayesian belief networks (BBNs; Borsuk et al., 2004; Pollino et al., 2007) have also been applied for analyzing SESs. CLDs make predictions by logically reconstructing the chains of causes and effects between variables on the basis of link polarities (e.g., the signs of the directed links, i.e., the effects of one variable over the other). Predicting the behavior of complex networks by identifying the feedback effects using link polarity (i.e., the effect associated to the link, positive or negative) is difficult and can lead to misleading interpretations (Lane, 2008; Richardson, 1997).

Most problems originate from polarities. Consider, for example, the case in which the level of violence displaces people from rural areas and forces them to move to the cities (Colombia is a paradigmatic example; see Ibáñez & Vélez, 2008). The causal connections are that level of violence increases the migration rate (positive link) which, in turn, increases the population level in the city (positive link). Therefore, the expected trend is: the higher the level of violence the greater the increase of urban population. However, if the level of violence gets lower, the migration rate is reduced but this does not reduce the population in the city as it continues to increase unless an opposite migratory flux occurs. Hence, the articulation of causal pathways gets difficult because variables can be both standing stocks and rates of change (Sweeney & Sterman, 2007). Similarly, specifying the relevant conditional probabilities as required by BBNs can be a laborious and time-consuming process (Marcot et al., 2001; Ticehurst et al., 2007). Moreover, to include feedback mechanisms via cyclic network structures requires dynamic time-explicit BBNs, which depend on extensive parameterization. Similar to FCMs, combining BBNs with loop analysis has great potential for improving predictions and model validation (Anthony et al., 2013; Melbourne-Thomas et al., 2012; Raoux et al., 2018). However, it must be emphasized that these applications of BBNs are based on the signs derived from the analysis of the loop models. As such, their outcomes are contingent on the assumptions and limitations of signed diagraph models.

Central for the understanding of the complex causality in SESs is our ability to individuate what the relevant components of the SESs are and diagram their relationships. The nature of the linkages among these components determines the spreading of the effects through the system and the overall composition of the linkages generates the feedbacks that amplify or buffer such effects. There is no recipe for modeling development but great effort must be devoted to assimilation of facts, observations, and hypotheses. Increasing the reliability of predictions can be possible by designing alternative graphs. This iterative procedure allows addressing uncertainty about the system structure and determining which differences matter. Robust outcomes may be the effect of a core structure common to all models upon which few links added or removed cannot change radically the predictions. The core structure represents the fundamental backbone composed of more certain variables and interactions. Disagreements among stakeholders, scientists, or managers do not limit the application of loop analysis; rather, they offer the opportunity to involve stakeholders in a participatory model construction (Anthony et al., 2013) where different types of system knowledge can be used to determine variables and links that may be important to examine further (Stier et al., 2017). The adoption of such a comprehensive, system-wide approach aims to formulate management strategies that reconcile ecological integrity and intergenerational equity, key dimensions of the sustainable development paradigm.

Possible developments for the application of loop analysis to SESs

Making predictions is difficult, especially when we face the uncertainty associated with new, unknown events, changing dynamics, and lack of quantitative data. This is the case, for example, with climate change, which produces completely new phenomena and dynamics. In such context, an adaptive management that allows for continually assessing new evidence has been called for. We believe that in the new scenarios we are facing, the method of loop analysis can be helpful. It has the necessary adaptability to be used in changing contexts: When in doubt about critical linkages and dynamic features, alternative models can be developed to find out which differences matter and to reach robust conclusions. It is also flexible, as it allows including and discarding variables easily, and above all it permits working with variables and links that are not readily measurable, even though their effects are crucial. However, its suitability to investigate SESs can be improved in several ways. The intricacy of the feedbacks can be better resolved if a specific tool for pathways analysis is developed. Returning the total number of pathways, and their strength, between any pair of variables can show how single pathways contribute to specific effects, and which ones are more important in mediating the press perturbations. The question of link strength deserves attention. We specified in the methodological aspects section that link strength is randomly assigned to interaction links during simulations. But this does not contradict the qualitative nature of the method; it only serves to assign certainty to paths and feedbacks in order to get unambiguous predictions, which remain qualitative in nature as only the direction of change for the variables is predicted. Pathway anatomy would help selecting those causal chains that mostly affect system dynamics. Other relevant features that would improve the suitability of loop analysis for modeling SESs include: (1) considering multiple, simultaneous press perturbations; and (2) delimiting upper and lower limits for the strength of interactions. The first point is related to the fact that SESs are often exposed to different types of disturbances whose interplay gives rise to net cumulative responses that would be useful to disentangle (e.g., through the identification of the specific causative chains). Considering multiple press perturbations would greatly contribute to building up an effective diagnostic approach (Kittinger et al., 2013). For example, by loop analysis Bodini et al. (2018) diagnosed that multiple press perturbations, not only overfishing of small and medium pelagic species, were responsible for the restructuring of the Black Sea community during the period 1960–1989. Moreover, socioeconomic drivers amplify the impacts that are triggered by natural processes: for instance, both hypoxia and fisheries management affected abalone stock in the Baja California SES (Martone et al., 2017). The second line of development is conceived to extend loop analysis in a semi-quantitative direction. So far the simulations are performed by randomly sampling interaction strength in the uniform interval (0,1). There are however cases when some interactions are known

to be either strong or weak; in such cases, varying the strength of these linkages in the whole interval (0,1] does not make sense. However, it is difficult to translate fuzzy concepts such as strong and weak into numbers so that boundaries for the links can be set. In this respect, sensitivity analysis may help. Either the upper (i.e., 1) or the lower (i.e., 10^{-6}) limit of the link magnitude could be iteratively changed so that actual boundaries for certain linkages can be identified through a consistency assessment of the outcomes produced. For example, performing the sensitivity analysis for the strength of specific interactions might help modeling competitive advantages in the ecological domain (e.g., *Noctiluca scintillans* vs zooplankton in the Black Sea; Bodini et al., 2018) and power or information asymmetries between socioeconomic actors (Bousquet et al., 2015). Therefore, exploring alternative scenarios by constraining the strength of some interactions would be of great benefit for modeling SESs. It should also be noticed that a uniform distribution is considered by default for randomly sampling the strength, but it could be substituted by either normal or skewed (e.g., Poisson) distributions.

Concluding remarks

The central issue in the study of SESs is to understand interdependencies that cross the boundaries of the classical domains in which scientific and operational knowledge have been settled. Contributions in this respect are expected from tools that allow reconstructing the causal chains that give rise to such interdependencies and that involve variables or components of different nature. For such reconstruction to be effective, tools must overcome the barriers that make communication between domains difficult: (1) the simpler the language used to describe the phenomena and the interactions, the better it is; (2) a lower level of technicality in the algorithms facilitates understanding the outcomes; and (3) flexibility widens the range of applicability to different contexts. Loop analysis shares most of these features: (1) by classifying the interactions in only two categories, positive and negative, it facilitates creating connections between variables that differ dramatically in physical form; (2) the ease by which a model can be constructed as a graph allows keeping up with rapidly changing conditions (i.e., variables and/or links disappear and others become important); (3) the algorithm for predictions refers directly to structural features of the graph and can be visualized, thus making the outcomes easier to understand; and (4) it is also characterized by a wide applicability (often the question of interest is not a particular system but a whole class of systems with some similarity of structure). Furthermore, loop analysis emphasizes the understanding of mechanisms, which is a prime objective when an intellectual and operative framework is taking shape, as in the case of SESs.

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Shifting Shores and Shoring Shifts—How Can Beach Managers Lead Transformative Change? A Study on Challenges and Opportunities for Ecosystem-Based Management

Marina Ribeiro Corrêa[1]
Institute of Energy and Environment, University of São Paulo, Brazil, and Department of Social Sciences, Leibniz Centre for Tropical Marine Research, Bremen, Germany

Luciana Yokoyama Xavier
Oceanographic Institute, University of São Paulo, Brazil, and Department of Social Sciences, Leibniz Centre for Tropical Marine Research, Bremen, Germany

Eike Holzkämper
Social–Ecological Systems Analysis Working Group, Social Science Department, Leibniz Centre for Tropical Marine Research, Bremen, Germany

Mariana Martins de Andrade
Oceanographic Institute, University of São Paulo, Brazil

Alexander Turra
Oceanographic Institute, University of São Paulo, Brazil

Marion Glaser
Social–Ecological Systems Analysis Working Group, Social Science Department, Leibniz Centre for Tropical Marine Research, Bremen, Germany

Abstract

Beaches provide a range of ecosystem services (ES). They are increasingly impacted by climate change, among other stressors. Ecosystem-based management (EBM) is an approach to cope with a changing environment and ensure long-term ES provision. Local managers may facilitate beach EBM implementation by integrating it into existing governance systems. However, their role in EBM implementation needs clarifying. This paper assesses local government beach managers' perceptions and visions of improvement of the beach ES governance network to face a changing environment. We present a structural analysis of data from the northern coast

1   Corresponding author: marina.ribeiro.correa@usp.br.

of São Paulo state (Brazil) and discuss opportunities and challenges for a regional EBM implementation. Our results point to the local beach managers as potential leaders of transformations towards sustainability.

Keywords: ecosystem approach, governance network, Net-Map, sandy beaches, social network analysis.

Context

Beaches provide a range of benefits for human well-being (Sardá & Azcárate, 2018) but human-induced impacts (e.g., climate change, human activities, pollution, engineering structures) transform beach-related ecological and social processes, threatening their sustainability (McLachlan & Defeo, 2018). To cope with the changing environment, beach management requires effective, collaborative, and inclusive governance structures (Sardá et al., 2015). Analyzing the web of social relations (i.e., social networks) that constitute the governance system can help to identify how to improve it (Bodin, 2017; Bodin & Crona, 2009).

Environmental governance can be seen as a system of "actor-networks at all levels of human society (from local to global) that are set up to steer societies towards … adapting to global and local environmental change … within the normative context of sustainable development" (Biermann et al., 2010, p. 279). A governance network is a set of actors, or "nodes," with distinct attributes (e.g., perceptions, information, power), which may be connected to one another (or not) by pathways through which interactions take place, known as "ties" (Cohen et al., 2012). In addition to the multi-actor structure, the analysis of environmental governance networks needs to consider administrative borders and how administrative units fit (or don't) with ecosystem dynamics (Bodin, 2017; Carlsson & Sandström, 2007). Environmental governance studies often describe the social processes that promote governance networks for sustainability, but with less regard to ecosystem functioning (see Bodin, 2017). The advance of beach governance should recognize both ecosystems functioning and the involved social networks.

Ecosystem-based management (EBM)[2] responds to environmental change (e.g., climate change) to steer multilevel social–ecological systems[3] dynamics toward sustainability (Chapin III et al., 2009; McLeod & Leslie, 2009; Sardá et al., 2015; Wamsler et al., 2014); a desirable approach for beach management

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2 Although EBM and ecosystem approach are not synonymous concepts, they share the same principles and when applied in practice they often lead to similar outcomes (Kirkfeldt, 2019). In order to better discuss the results of the present research, these concepts were used synonymously.

3 Socioecological systems: coupled, coevolving, and dynamic human–nature systems, with reciprocal and interdependent feedback (e.g., McLeod & Leslie, 2009). We use the terms socioecological and social–ecological (e.g., publications by Carl Folke and colleagues of the Stockholm Resilience Centre) synonymously.

(Corrêa et al., in press; Sardá & Azcárate, 2018; Sardá et al., 2015). EBM is rooted in the connections between human well-being and ecosystem functioning (McLeod & Leslie, 2009; Sardá et al., 2015). The ecosystem services (ES) concept (i.e., ecosystem contributions that provide human well-being) operationalizes this idea (Granek et al., 2010; McLeod & Leslie, 2009; O'Higgins et al., 2020; Sardá et al., 2015; Tallis et al., 2010) with a focus on conserving ecosystem functioning to ensure long-term ES provision (Chapin III et al., 2009; O'Higgins et al., 2020; Sardá et al., 2015).

EBM promotes sustainability by eliciting longer term planning in line with ecosystem dynamics (Chapin III et al., 2009; McLeod & Leslie, 2009). It embraces the "adaptive capacity" concept—that is, the ability of humans to manage a changing environment, including their capacity to adjust social networks (Adger, 2003; Chapin III et al., 2009; O'Higgins et al., 2020). Good governance is one of the preconditions for EBM implementation (O'Higgins et al., 2020) and includes building and managing ES governance networks of holistically understood social–ecological dynamics (Imperial, 1999).

However, EBM implementation for beaches is incipient, at best, and understudied (Sardá & Azcárate, 2018). To promote the transformation toward innovative and sustainable forms of environmental governance such as EBM for beaches, critical contextual opportunities and barriers (e.g., stakeholders, networks) need to be identified (Aswani et al., 2012; Christie et al., 2009; Kelly et al., 2018). This paper investigates two barriers to EBM implementation for beaches. Both are related to governance processes and structures.

The first barrier is to overcome current undesirable governance structures. EBM envisages the engagement of a diverse set of stakeholders (Bodin et al., 2017; McLeod & Leslie, 2009). Existing governance systems, however, can hamper innovative EBM implementation (Glaser et al., 2018; O'Higgins et al., 2020; Tallis et al., 2010): a variety of context-specific features may be obstructive (e.g., governance networks) (Bodin et al., 2017; Smythe et al., 2014; Wamsler et al., 2014). Beach management is historically characterized by low stakeholder involvement, fragmented governance, and little regard for ecological features (Sardá et al., 2015; Williams & Micallef, 2009). These issues manifest in undesirable resilient structures (Glaser et al., 2018) that reduce management's capacity to redirect toward sustainability-enhancing management systems such as EBM (Arkema et al., 2006; Leslie et al., 2015). Beach management and governance need to innovate structurally and procedurally to ensure the long-term provision of beach ecosystem services (BES) (Sardá et al., 2015).

The second barrier is to fit governance to multilevel ecosystem dynamics. EBM implementation on any spatial level depends heavily on the local governance context (e.g., social participation, interinstitutional collaboration) (Christie et al., 2009;

Leslie et al., 2015). Beach management usually focuses on the local level—the beach or the municipality (McLachlan & Defeo, 2018; Williams & Micallef, 2009)—but deals with multilevel biophysical processes and impacts (McLachlan & Defeo, 2018). To implement EBM, beach management must operate in a multilevel governance system that addresses all social–ecological system levels that affect beaches, including watersheds (Corrêa et al., in press; Sardá et al., 2015), and consider administrative levels beyond the local to promote beach sustainability (Sardá et al., 2015).

To tackle these EBM implementation barriers, a central actor can orchestrate collaboration among multiple stakeholders and administrative levels (Bodin et al., 2017). Local government officials are potential leaders for EBM implementation (Sandström et al., 2015). By "weaving"—that is, actively developing a collaborative social network among different social groups—they can promote ecosystem fit and break undesirable resilient features (Carlsson & Sandström, 2007; Sandström et al., 2015). However, more information is needed on how local government actors may be able to weave networks (e.g., ES governance networks) to support a transformation towards EBM (Sandström et al., 2015).

Network weaving is shaped by network actors and by their perceptions (Glaser et al., 2018; Holzkämper, 2017). According to Beyerl et al. (2016, p. 4), perception is "the subjective way people experience, think about and understand someone or something." Understanding what local government actors perceive as the changes needed in beach governance networks to safeguard long-term ES is part of the assessment of these central actors' ability to cope with social–ecological change (i.e., perceived adaptive capacity, Grothmann & Patt, 2005). Local beach management actors' perceptions of the network transformations necessary for dealing with a changing environment, therefore, might be a critical "bottleneck" for EBM implementation. We target two questions: (i) As possible leaders of change, how do local government managers perceive needed long-term improvements in their BES governance networks under conditions of ecosystem change? (ii) Can their perceptions promote a fit between the governance structure and beach dynamics?

We adopt an inductive approach using the Net-Map method (Schiffer & Hauck, 2010) and social network analysis (SNA) to investigate the perceptions of municipal beach managers of four municipalities of the northern coast of São Paulo state, Brazil, a region in need of local coastal leadership to cope with ongoing changes (Simões et al., 2017).[4] SNA is a tool to characterize relationships among actors (Freeman, 2004) and has been used to better understand environmental governance structures and EBM implementation processes (Bodin et al., 2017; Smythe et al., 2014). Our analysis centers on the two identified barriers to EBM implementation (undesirable resilient structures and governance misfit). We identify perception patterns and discuss their implications for beach management as well as opportunities

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4   In Brazil, the municipal level is the lowest administrative level, hereafter described as "local".

and challenges for EBM implementation. The article concludes by reflecting on the role of local beach managers as leaders of change towards sustainable system dynamics in Brazil and other coastal regions across the world, especially those with decentralized management.

Methods

Study site

Brazil has one of the longest coastlines worldwide, where beaches provide essential ES subjected to complex, cumulative threats, including climate change (Amaral et al., 2016; Ministério do Meio Ambiente, 2018; Xavier et al., in press). Implementing EBM in Brazilian beach management has the potential to guide, adapt, and improve current structures and processes in a holistic manner (Xavier et al., in press). Beach management in Brazil also faces challenges for EBM implementation including low stakeholder involvement, fragmented governance, and lack of multilevel governance processes (Corrêa et al., in press; Xavier et al., in press).

Brazilian beach management occurs at the municipal level but is regulated by higher level legislation (Xavier et al., in press). Currently, the federal government is transferring management rights and responsibilities to municipalities, in a decentralization process to ensure the sustainable use of the coastal zone and more participatory beach management (Scherer et al., 2020; Xavier et al., in press). This is an opportunity for local governments to become central actors in beach management with increased autonomy and power (Scherer et al., 2020). In line with municipalization, the National Plan of Climate Change Adaptation encourages the inclusion of ES-based strategies in municipal policies and beach management (Ministério do Meio Ambiente, 2018). This creates a new scope for local government actors to weave networks (e.g., ES governance networks) to support EBM implementation.

The north coast of São Paulo state (*Litoral Norte Paulista*—LNP) is a compelling site to study the improvement of beach governance networks to implement EBM. The LNP urbanization process is mainly related to tourism and leisure (Santos & Turra, 2017): both depend on beach quality and long-term beach ES (BES) provision. The four LNP municipalities (São Sebastião, Ubatuba, Ilhabela, and Caraguatatuba) are committed to or in the process of assuming the management of their beaches. They share resources and face common social–ecological vulnerabilities, such as climate change–induced impacts like increased coastal erosion (Santos & Turra, 2017; Simões et al., 2017). At the regional level, the municipalities are integrated into environmental decision-making bodies (i.e., council bodies—composed of multiple sectors and governance levels). These discuss and implement a common

management strategy for the regional coastal, watershed, and protected areas management (Santos & Turra, 2017) but they do not discuss beach management; which is implemented by the municipalities.[5] Local municipalities still need to establish long-term and inclusive strategic planning and local leadership to cope with the changing environment (Simões et al., 2017).

Data collection

Net-Map (Schiffer & Hauck, 2010) is a group dynamic tool for collecting data on social network perceptions. As actors achieve a greater understanding of their networks, they can identify what network changes are needed for specific aims, such as EBM implementation. We applied an adapted Net-Map method developed by Glaser et al. (2018) to visualize municipal beach managers' perceptions of current relations among those dealing with BES governance in the LNP region, and their ideas for needed improvements in social network structure and functioning to ensure long-term BES provision under a changing environment.

Long-term change in the beach system centrally includes the coastal squeeze phenomenon, caused by climate change and uncontrolled urban growth, resulting in beaches eroding and disappearing (McLachlan & Defeo, 2018). These are globally induced impacts that demand local and regional management (McLachlan & Defeo, 2018). Beach managers are government officers: they are concerned with civil society safety, environmental protection, public infrastructure, and the development of areas close to beaches (Moser & Tribbia, 2006). In Brazil, beach management is often performed by different municipal government offices. In each of the four LNP municipalities, we approached the three municipal government offices that were most involved in beach sustainability (for further information on Net-Map participants, see Appendix I).

We conducted 11 Net-Map sessions (each with 3–5 beach managers): three in Caraguatatuba (C1, C2, C3), Ubatuba (U1, U2, U3), and São Sebastião (SS1, SS2, SS3), and two at Ilhabela (I1, I2), yielding 22 networks (11 representing the current scenario and 11 visualizing a desirable future). Sessions were voice-recorded and filmed. This research was approved by the Brazilian Ethics Committee (Plataforma Brasil: 3.337.019), and all participants signed an informed consent form. The sessions followed a six-step procedure (Figure 1).

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5   This information comes from two workshops carried out with the main LNP Council bodies to discuss beach management. The workshops were held by a bigger research project that includes the present research. The data still is unpublished.
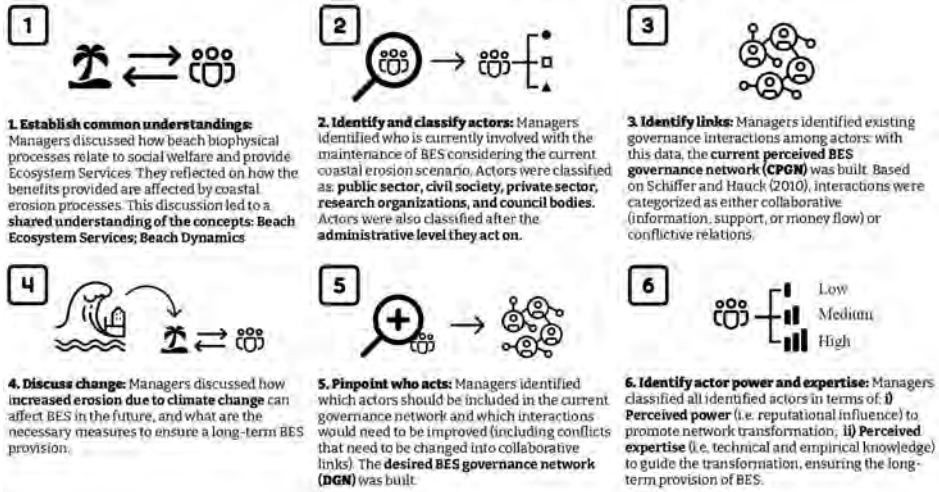
Figure 1. The six-step procedure adopted in the Net-Map sessions performed in this study.

Source: Authors' summary of process.

Data analysis

We digitized the network data for further computerized visual and mathematical analysis, including the application of SNA metrics on the resulting governance network (detailed information on data treatment is provided in Appendix II). We restricted our analysis to collaborative relations since not all informants were comfortable discussing conflicts. With this analysis, we identified the envisioned changes in the BES governance network. We analyzed the perceived BES governance networks and how positive change was envisioned (i.e., transformations in the governance network perceived as necessary to ensure the provision of BES). Using UCINET 6 (Borgatti et al., 2002), we examined current perceived governance networks (CPGN) and desired governance networks (DGN) for differences and similarities. We investigated how interactions between administrative levels in the DGN were perceived. The following paragraphs outline the network metrics on two barriers for EBM: current governance structures and governance fit with ecosystem dynamics.

Barrier 1: Overcome current undesirable governance structures

Actor diversity promotes collaborative governance and EBM implementation (Arkema et al., 2006; Bodin et al., 2017; McLeod & Leslie, 2009), while the links among actor categories enact the exchanges of knowledge and resources needed to achieve collaborative governance for EBM implementation (Bodin et al., 2017; Smythe et al., 2014). Governance network structure and composition can indicate

the ability of actors to overcome challenges for EBM implementation (Bodin et al., 2017). Network metrics were chosen to assess the perceived diversity of actors and links among actor categories (Table 1).

Table 1. Network metrics on actor diversity, links among actor categories, and how these differ between CPGN and DGN.

	Network metric	Description
Actor diversity and influence	Network composition	"Actor categories" are defined in step 2 of Figure 1 We determined the proportion of each actor category in each network.
	Perceived influence (i.e., power and expertise) of each actor category	For both "perceived power" and "perceived expertise," the most frequently attributed strength level ("Low," "Medium," or "High") was used for each actor category.
Links among actor categories	Homophily/heterophily (Bodin, 2017)	The degree of connectivity across actor categories. Homophily/heterophily varies between –1 and 1, where –1 represents complete homophily (connection only between actors of the same category) and 1 complete heterophily (connection only between actors of different categories).
	Network fragmentation (Coleman, 1990; Holzkämper, 2017)	The extent to which actors have access to information and knowledge, measured by the fraction of node pairs that are (un)reachable in a network. Fragmentation is 0 when all nodes are connected and 1 when all nodes are isolated: networks are fragmented (scores 1–0.7), balanced (scores 0.6–0.4), or connected (scores 0.3–0).
	Network centralization (Carlsson & Sandström, 2007; Holzkämper, 2017; Sørensen & Torfing, 2016)	The extent to which network relations and power are centralized with one or more key/focal actors, showing whether different degrees of fragmentation are associated with a high level of cooperation (low fragmentation) or with hierarchical coordination (high fragmentation). Distinguishes between centralized (scores 1–0.7), decentralized (scores 0.6–0.4) and distributed (scores 0.3–0) networks.

Note: CPGN = current perceived governance network; DGN = desired governance network.

Source: Authors' summary. See also citations throughout table.

We compared CPGN and DGN, investigating differences in desired change patterns using the concepts of "collaborative heterogeneity" and "coordinated heterogeneity" (Bodin et al., 2017) for the network structure considered as needed for effective EBM implementation (Table 2).

Table 2. Change patterns examined to analyze beach managers' perceptions of needed governance network changes to ensure BES. In each type of network change, fragmentation decreases or stays constant (as "connected" or "balanced"), envisioning increased collaboration among actors. Change patterns differ in with whom (homo-/heterophily) and how (self-organized/coordinated) actors should ideally connect.

Change pattern	Network indicators	Type of envisioned network change
Self-organized heterophily	• Increase in heterophily; • Centralization maintained as "decentralized."	Increased cooperation among actors of different categories is promoted in a collaborative environment.
Coordinated heterophily	• Increase in heterophily; • Centralization increased and changed from "decentralized" to "centralized."	A central actor (the Net-Map respondent) promotes increased collaboration through hierarchical coordination connecting actors of different categories.
Self-organized homophily	• Increase in homophily; • Centralization maintained as "decentralized."	Increased cooperation among actors of the same category is promoted in a collaborative environment.
Coordinated homophily	• Increase in heterophily; • Centralization increased and changed from "decentralized" to "centralized."	Hierarchical coordination promotes connection among actors of the same category. A central actor (the Net-Map respondent) links to "subgroups" of actors of mostly the same category, promoting a collaborative process.

Note: BES = beach ecosystem services.

Source: Authors' summary, after Bodin et al. (2017).

Barrier 2: Fit governance to multilevel ecosystem dynamics

EBM implementation aims to improve the fit between governance systems and ecosystems by collaboration across administrative units and levels (Smythe et al., 2014). Two additional aspects were analyzed to assess opportunities and challenges for multilevel collaboration:

1. How the participants perceived the connections of their local governance networks to other municipalities. This was indicated by their perceptions of (1) the presence of actors from other LNP municipalities; and (2) the presence of actors from higher administrative levels.

2. How the participants perceived the participation of different administrative levels in governance network transformation. The perceived expertise and power for each actor category was analyzed, focusing on the different administrative levels.

Results

Barrier 1: Overcome current governance structures

Network composition

LPN beach managers identified all five actor categories (research organizations, council bodies, private sector, civil society, and public sector) (Figure 2). All municipal offices named actors from the public sector, civil society, and the private sector, while four municipal offices (SS2, SS3, I1, and I2) did not include council bodies and/or research organizations in their CPGNs or DGNs. The proportion of actors from the public sector reached 60 percent or more in almost all CPGNs, outweighing all other actor categories (Figure 2). There were more actors in almost all DGNs (except for SS3) than in CPGNs.
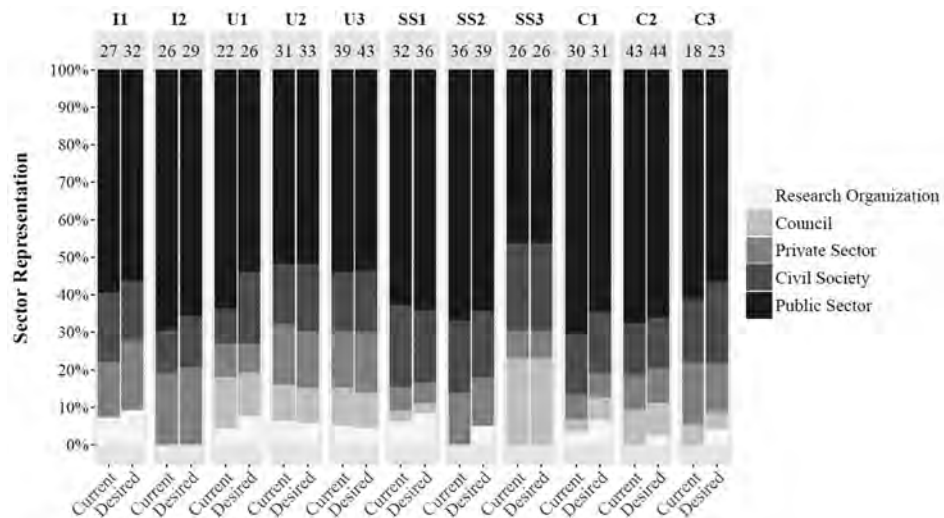

Figure 2. Overview of perceived governance network composition (actor categories: research organization, council, private sector, civil society, public sector).

Note: Y-axis indicates percent of actor category. X-axis indicates the governance network (current/desired) for each municipal office (I-Ilhabela; U-Ubatuba; SS-São Sebastião; C-Caraguatatuba). The number above the bar indicates how many actors were named in the network.

Source: Authors' summary.

Actor category representation differed between CPGNs and DGNs (Figure 3). Public sector representation was lower in most DGNs, in all municipalities. Civil society representation was constant or higher in most DGNs, and at least one municipal office per municipality pointed to the need of increasing it. The representation of research organizations increased in most DGNs in all studied municipalities. Qualitative data supported this: research organizations were generally considered important for capacitation and knowledge exchange (Figure 3).
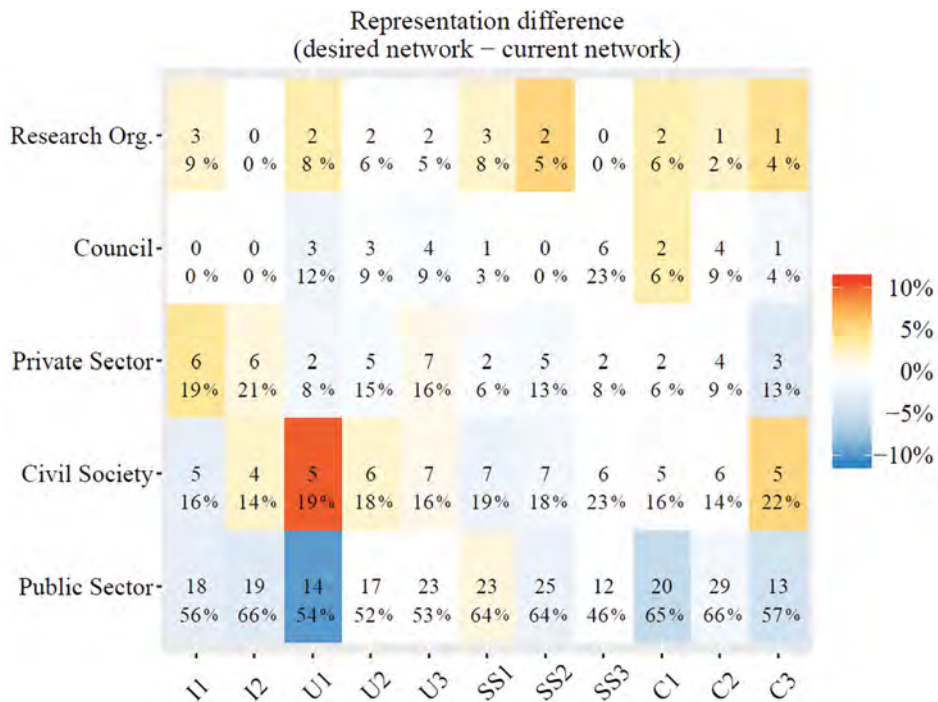
Figure 3. Actor categories' representation (in percent) in current CPGNs and DGNs.

Note: Y-axis shows actor categories (research organization, council, private sector, civil society, public sector). X-axis represents the municipal offices (I-Ilhabela; U-Ubatuba; SS-São Sebastião; C-Caraguatatuba). Color scale indicates the difference (percent) between DGN and CPGN by category. The numbers inside the boxes indicate the absolute number (top) and representation percent (bottom) by category in each DNG.

Source: Authors' summary.

Perceptions of expertise and power to guide transformation varied by actor category (Table 3).

Table 3. The perceived expertise and power of actor categories to promote and guide the desired changes in the governance networks towards long-term BES provision.

	Research organization	Council bodies	Private sector	Civil society	Public sector
Perceived expertise	High	High	Low	Low	Medium
Perceived power	Low	High	High	Low	High

Note: BES = beach ecosystem services.

Source: Authors' summary.

Linkages among actor categories

Most envisioned network changes indicated self-organized processes. One DGN (SS3) did not envision any change. All envisioned transformations were toward decreased fragmentation. Half of the DGNs had homophily tendency and half had heterophily tendency. Two DGNs (SS1 and U3) envisioned less fragmentation by increasing the centralization of municipal offices: SS1 with a heterophily tendency and U3 with a homophily tendency (Figure 4).
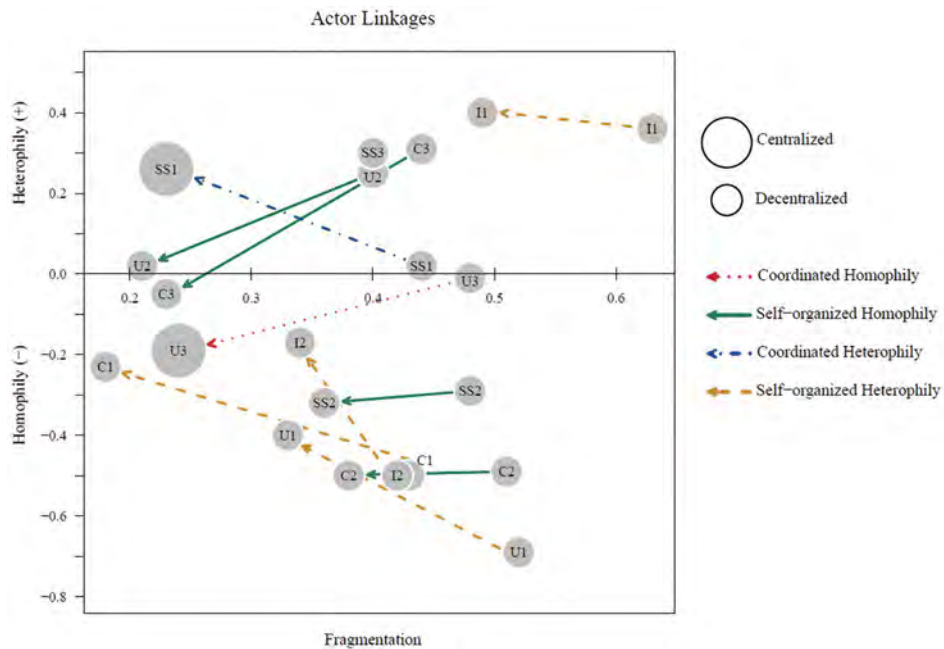

Figure 4. Governance networks of study municipalities (circles: I-Ilhabela; U-Ubatuba; SS-São Sebastião; C-Caraguatatuba).

Note: Circle size represents the centralization metric. Arrows point to the desired ES governance network configuration. Y-axis shows homophily/heterophily; X-axis fragmentation. Four patterns of envisioned change from CPGN to DGN to ensure BES: coordinated homophily; self-organized homophily; coordinated heterophily; self-organized heterophily.

Source: Authors' summary.

Barrier 2: Fit governance to multilevel ecosystem dynamics

In all the municipalities, at least one municipal office named actors from higher administrative levels as endowed with high expertise and power (Table 4). Each Net-Map group only perceived their own municipality as a network actor at the local level: stakeholders from other municipalities were not mentioned. The beach managers perceived municipal actors as having low expertise, while regional, state, and federal level actors were seen as having high expertise. Although all administrative

levels were associated with a high level of power to promote desired transformations in the governance network, the federal and state governments were generally seen as exerting their relatively high power through formal command, without spaces for participation in decision-making (e.g., "as a municipality, we cannot change how it works").

Table 4. Perceived expertise and power of administrative actors at different levels for guiding governance network changes towards long-term BES provision.

	Municipal	Regional	State	Federal
Actors perceived by all municipalities	None	Nongovernmental organization who operates regionally (civil society actor) (n=8)	State environmental surveillance agency (n=8), State Civil Defense (n=5), State Public Prosecution Office (n=7)	Navy (n=8), governmental actor with authority on beach territories (n=5)
Perceived expertise	Low	High	High	High
Perceived power	High	High	High	High

Note: BES = beach ecosystem services.
Source: Authors' summary.

Discussion

We mapped municipal government actors' perceptions of current governance network structure and changes needed to ensure BES provision, and then discussed the implications of these perceptions, highlighting opportunities and challenges for EBM implementation for beaches under conditions of change.

Barrier 1: Overcome current governance structures

Actor diversity is an important asset for EBM implementation (Bodin et al., 2017; Smythe et al., 2014), especially in beaches, due to their multiple uses (Sardá et al., 2015). The involvement of varied backgrounds increases the available pool of knowledge, experiences, and resources (Bodin et al., 2017; Carlsson & Sandström, 2007; Smythe et al., 2014). The more diverse an environmental governance network, the more adaptability to local particularities and potential for innovative management it generates (Holzkämper, 2017). Diversity, therefore, benefits EBM implementation by improving the capacity to manage social–ecological change and uncertainty (Chapin III et al., 2009). Although the public sector was the dominant category, its lower representation on DGNs indicates that beach managers recognized the need to increase network diversity beyond the government sector.

Civil society involvement in governance networks can increase the legitimacy of decision-making and improve governance effectiveness (Carlsson & Sandström, 2007). Beaches support a wide range of uses, often by the private sector, which must thus be involved (Sardá et al., 2015; Williams & Micallef, 2009). City councils can support EBM implementation by endorsing the participation of the private sector and civil society, and trigger changes at formal planning stages, for instance by promoting seminars and funding projects (Wamsler et al., 2014). Along with locally grounded, empirical knowledge, scientific knowledge is fundamental for EBM implementation (Arkema et al., 2006; McLeod & Leslie, 2009), and must be improved in the LNP region (Simões et al., 2017). Our Net-Map participants aimed to increase nongovernmental sector participation (e.g., civil society, research organizations) in beach management. They also perceived the private sector, council bodies, and research organizations as endowed with the high power and/or expertise needed to promote desired changes. By shifting beach governance toward desired constellations, the government may thus enable a successful EBM implementation within multi-actor comanagement.

Actor diversity is an asset to EBM implementation, but it requires a network structure that enables actors of different sectors to interact in a cohesive (i.e., with low fragmentation, see Coleman, 1990) and collaborative governance network (Bodin et al., 2017; Smythe et al., 2014). Decreased fragmentation enhances the exchange of resources (Bodin & Crona, 2009), enabling responses to complex environmental challenges (Bodin & Crona, 2009; Bodin et al., 2017; Smythe et al., 2014) and supporting a network's overall adaptive capacity and resilience (Bodin & Crona, 2009). Since fragmentation is a major challenge for sustainability in marine governance (Kelly et al., 2018), the participants' desire for decreased fragmentation in their beach management networks is another opportunity for EBM implementation.

Brazil's beach management faces discontinuities in management programs and public policies due to personnel changes associated with newly elected governments, and also because procedural practices are often not formalized (Xavier et al., in press). Managers stated that "a limiting issue [for the changes in the governance network] is the discontinuation of projects. Every time a new government initiates its mandate, the ongoing projects are delayed." A decrease in network fragmentation increases the stability of the network (Carlsson & Sandström, 2007), which might enable the managers to better deal with sudden changes in beach management and support EBM implementation.

EBM implementation requires networks that connect different sectors (Bodin et al., 2017; Sardá et al., 2015), which depends on trust and collective action (Bodin et al., 2017). Trust can be improved by social ties among actors with similar backgrounds (Bodin & Crona, 2009; Holzkämper, 2017), such as perceived by the "homophily" types of change. However, actors who only interact within their

own social group might experience a homogenization of assets and ideas (Bodin, 2017). "Self-organized homophily," therefore, may not include the exchange of knowledge and resources required by EBM, while the "coordinated homophily" approach envisions a central actor linking mostly homogeneous "subgroups," thereby connecting different sectors of society.

The heterophily-oriented change also supports cooperation between actors of different sectors of society. Developing cooperation between actors with different backgrounds, however, requires resources that, if absent, can hamper EBM implementation processes (Bodin et al., 2017). In our Brazilian study area, local beach managers' desire for governance with increased heterophily is challenged by a lack of resources and skills, such as lack of public participation, knowledge, and power-sharing, and difficulties in engaging stakeholders (Corrêa et al., in press; Xavier et al., in press). LNP beach management will require coordination to benefit from actor diversity. A leader with a central network position can promote interaction between different social sectors thus facilitating the collaborative governance needed for EBM implementation (Bodin et al., 2017). High levels of centralization are associated with better coordination among diverse actors (Smythe et al., 2014), which can render decision-making more efficient (Carlsson & Sandström, 2007). The "coordinated homophily" type of network change might thus best promote knowledge exchange and coordination for EBM implementation.

Only one municipal office envisioned "coordinated homophily" as a needed network change. Reasons for this range from feasibility considerations to individual perceptions of good governance or network knowledge. At the same time, some sectors of society were not perceived at all by individual municipalities or were seen as having either no power or no expertise for governance network transformation. For example, although research organizations were perceived only as providers of information and knowledge (i.e., high expertise and low power), several cases have shown that researchers can foster the participation of other social actors in coastal management (e.g., Araçá Bay, and RESEX-CT Bragança, see Glaser et al., 2020), thus improving governance (Carlsson & Sandström, 2007). The near absence of these visions among LNP beach managers might hamper the likelihood of EBM implementation seizing the opportunities generated by the recognized need for increasing actor diversity and network interactions.

Barrier 2: Fit governance with multilevel ecosystem dynamics

Beach management occurs mostly at the local level (Williams & Micallef, 2009), but deals with multilevel biophysical processes (McLachlan & Defeo, 2018). Connecting managers beyond the boundaries of their municipal territories is likely to improve the management of ecosystems that cross administrative borders (Bodin, 2017). An intermunicipal collaborative network that creates horizontal

connectivity between localities sharing the same beach systems can better account for ecosystem dynamics in EBM implementation (Christie et al., 2009; Eisma-Osorio et al., 2009; Wamsler et al., 2014).

Local-to-local (i.e., intermunicipal) collaboration in EBM can increase stakeholder participation and the exchange of information and resources to enhance local formal institutions, coastal law enforcement, and the implementation of new approaches (Eisma-Osorio et al., 2009). It can also foster watershed-level coordination (Wamsler et al., 2014), necessary for sustainable beach management (Sardá et al., 2015). In Brazil, intermunicipal collaboration has increased local municipalities' innovation capacity and their power to negotiate with state and federal governments (Grin, 2019). Intermunicipal collaboration would address further challenges pointed out by LNP beach managers: the perceived low expertise and relatively low power of the municipal level, and the continuation of projects and plans beyond single electoral periods. Additionally, intermunicipal collaboration is fundamental for enhancing social–ecological fit and promoting the municipalities as a regional group.

EBM implementation that links local municipalities may be motivated by three main perceptions among ecosystem managers: (1) there is a natural biophysical interdependence in ecosystem functioning (Bodin, 2017); (2) local municipalities affect each other; and (3) local municipalities share issues and resource bases (e.g., financial, infrastructure) (Eisma-Osorio et al., 2009). In the LNP region, we found no indication that managers held any of these perceptions. Net-Map participants included actors from other municipalities in neither their perceived (CPGN) nor desired (DGN) networks. Although some of their perceptions might hamper EBM implementation, municipal officers also envisioned opportunities for EBM implementation in the governance network. If municipalities are to succeed in seeing themselves as a regional group, their perceptions will be a base for overcoming the challenges for EBM implementation in the region. It seems unlikely that, without external influence, the LNP municipalities will establish an intermunicipal network to exchange and share resources such as information, knowledge, experiences, and perceptions.

Actors from higher administrative levels might be needed to horizontally connect the municipalities and promote exchange between them. Gorris (2015), for example, found low horizontal connectivity between local administrative units in large marine protected areas in both northeast Brazil and Indonesian South Sulawesi. In the Net-Maps conducted in our study, higher level actors were seen as having high power and expertise, which enabled them to promote the envisioned BES governance network. Their coordination of actors across administrative boundaries can promote a better fit between collaborative network structures and multi-level ecosystem dynamics (Bodin, 2017). Thus, coordinated actions to implement EBM locally and regionally can increase the adaptive capacity of governance (Christie et al., 2009; Österblom et al., 2010).

The regional level is fundamental for connecting multiple system levels and scales that influence ecosystem dynamics (Glaser & Glaeser, 2014). Regional council bodies can connect municipalities, and also connect with higher level government actors to obtain financial and technical training or education support, increase social–ecological fit, and promote political continuity for EBM implementation (Eisma-Osorio et al., 2009). In the LNP, regional council bodies already connect all municipalities, state, and federal actors from all sectors of society (Santos & Turra, 2017). Although their decisions affect beach management, the LNP council bodies do not discuss beach management.[6] This lack of focus on beaches may explain why the regional councils were not identified as BES network actors by several of the Net-Map participants. However, when identified by the participants, the regional council bodies, and some of their member organizations including regional nongovernmental organizations (NGOs), research organizations, and higher level public sector actors, were ascribed high power and expertise. This perception might foster the regional council bodies' role in integrating key actors. The LNP council bodies, in partnership with higher level authorities, regional NGOs, and research organizations, could support discussions on regional EBM-based beach management through intermunicipal, multilevel, and multi-sector collaboration.

Local managers as leaders of EBM implementation

Our Net-Map participants provided an important picture of beach management in the LNP region. All beach managers saw the need to increase diversity and collaboration in governance networks. They perceived both the local and regional levels as endowed with a high level of power, and therefore as potentially effective in promoting the transformations needed for the long-term provision of BES. These perceptions provide a point of departure to develop strategies for beach management challenges, such as discontinuity in management and public policies, lack of inclusive social participation, and the science–practice gap. In a collaborative framework, a leader ensures the effective exchange of information, resources, and knowledge and facilitates collaboration among multiple sectors (Bodin et al., 2017; Simões et al., 2017). This study demonstrates that local government managers envision network changes that might support local EBM implementation and that they can thus be regarded as potential local leaders for such a venture.

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6   As previously mentioned, this information comes from two workshops carried out with the main LNP Council bodies to discuss beach management. The workshops were held by a bigger research project that includes the present research. The data still is unpublished.

However, given the low degree of perceived horizontal connectivity between the municipalities of the LNP region, beach managers might require a facilitator to enhance their skills and expertise and to foster their perception of themselves as a regional group. The participating beach managers' lack of shared interests or identity reduces their potential as leaders for EBM implementation. Their perceptions of BES governance improvement might undermine the fit between governance and environmental dynamics of the beaches of the study region, and hamper the horizontal, intermunicipal exchange of knowledge that is needed to seize the potentials revealed by the beach managers' perception patterns.

This study revealed the willingness of managers to better involve research organizations in the governance network, allowing for researchers to act as facilitators for beach managers to establish their leadership role. Partnerships to capacitate and empower local managers and to enhance knowledge exchange with key actors (e.g., regional council bodies) would promote long-term BES provision based on effective EBM implementation. Future perception studies might extend to other beach management stakeholders' understandings of governance and management and thus lay additional foundations for increasing stakeholder collaboration for EBM. Moreover, the link types (information, support, resources, and conflicts) between actor categories might be analyzed separately to clarify their role in EBM implementation.

Our use of Net-Map and SNA methodologies in the EBM context facilitated cooperation between researchers and managers in adapting management practices. This study demonstrates how local government managers' perceptions of the necessary improvements to the ES governance network are a critical precondition for EBM implementation. We focused on the perceptions of beach managers as primary ecosystem governance actors, a focus that can also support EBM implementation in other types of ecosystems. As humanity's impact on nature becomes ever more dominant, the focus on collaborative governance networks we develop in this study is likely to gain wider relevance. Since other contextual conditions are also critical for EBM implementation, further research is needed on public policies, institutions, usable knowledge, information basis, and innovation uptake.

Acknowledgments

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Appendix I

Determining Net-Map participants

Beach managers are government officers concerned with civil society safety, environmental protection, public structure, and the development of coastal areas close to beaches (Moser and Tribbia, 2006). In Brazil, the beach managers can be permanent public officers, who hold their public sector positions when political mandates change, carrying knowledge and experience about the organization functioning, and technical knowledge, across changes in governance. As part of a technical team, beach managers often provide important knowledge to guide decision-making. Beach managers can also be temporary officers who work during a single electoral mandate and, as municipal officers, are responsible for final decision-making in that period. These nonpermanent municipal officers can also be part of the technical team but are usually more involved with political decision-making. For this research, we set up Net-Map sessions with the municipal officer and with at least two permanent members of the technical teams working in the selected municipal offices of the LNP municipalities.

In order to develop a list of selection criteria, we reviewed municipal policies concerning the administrative structure and competencies of the municipal offices in the four municipal governments in the LNP region (Ilhabela, Caraguatatuba, São Sebastião, and Ubatuba), matching relevant terms with those used in the formulation of policies. This review resulted in the following list of nine terms related to beach management: (1) vulnerability reduction, (2) monitoring, (3) disaster prevention, (4) sustainability, (5) planning, (6) integration of sectors, (7) beaches, (8) climate change, and (9) erosion. We compared these nine terms with the mandates of all government offices in the LNP region and selected those offices where mandates matched the selection criteria. Additionally, we reviewed national public policies associated with the terms "beach," "shoreline," and "climate change." We identified the municipal government actors quoted in these policies and thus were able to cross-check our selection of municipal offices and obtain data on which municipal governmental bodies are formally responsible for beach management in the LNP region. Of the 12 offices contacted, 11 responded. Table A1 presents an overview of the 11 offices (and their tasks) selected for conducting Net-Map sessions.

Table A1. List of municipal government offices associated with beach management that attended the group interviews.

Municipality	Municipal office*	Municipal office's official tasks	Code
Ilhabela	Civil Defense Office	Plan, coordinate, and execute activities and studies to prevent conditions of vulnerability and threats caused by situations of public calamities and disasters that put people's lives and well-being at risk.	I1
	Urban Planning, Public Works, and Housing Development	Formulate, execute, and evaluate the Municipal Policy for Urban Development and Housing. Among other assignments, this office aims to understand and prevent the impacts of urban growth on the environment as well as to identify and promote opportunities for sustainable urban development in the municipality.	I2
Ubatuba	Civil Defense Office	Communicate and coordinate studies to track situations of risk for the population's well-being (e.g., natural disasters), as well as develop action plans to deal with risks.	U1
	Urban planning Office	Formulate, execute, and evaluate the Municipal Policy for Urban Development and urbanization projects. Among other assignments, this office aims to understand and prevent the impacts of urban growth on the environment. It also aims to ensure the regulation of areas that belong to federal entities.	U2
	Environment Office	Organize, plan, and guide the municipality's environmental policy. This office attends to the environmental demands of the city. In partnership with the Urban Planning Office and other offices, this office aims to ensure the protection, conservation, and recovery of the environment, as well as to promote sustainable actions in the municipality.	U3

Municipality	Municipal office*	Municipal office's official tasks	Code
São Sebastião	Civil Defense Office	Assess and prevent disasters, vulnerabilities, and risks to which the municipality is subjected. This office is responsible for planning institutional activities, providing human resources (training courses), developing scientific/technological studies, mobilizing, monitoring, and alerting the municipality, and providing logistical support following disasters.	SS1
	Beach Management Office	Not specified in the legislation.	SS2
	Environment Office	Develop studies, actions, and activities related to the protection, conservation, and recovery of the environment. This office is responsible for including all sectors of the society and the different municipal offices in the promotion of environmentally sustainable actions in the municipality.	SS3
Caraguatatuba	Civil Defense Office	Develop and implement policies and plans that promote the protection of the citizens' well-being against disasters. This office unifies and integrates government agencies and society, aiming to organize and expand the adaptive capacity of the municipality to prevent and address environmental risks within it.	C1
	Urban Planning Office	Develop, study, and revitalize municipal urban planning, legislation, and projects, ensuring the preservation of the natural environment and population well-being.	C2
	Fisheries, Aquaculture and Environment Office	Promote the integration of municipal offices, citizens, research institutions, state and union actions, and knowledge with respect to the planning of use, conservation, recovery, and protection of the environment. Among other assignments, this office is responsible for advising and offering training about the environment and its sustainable use, with a holistic, scientific, and participatory approach that considers the interdependence of the natural, socioeconomic, and cultural environments.	C3

* Denominations of offices translated to English by authors.

Source: Authors' summary.

Appendix II

Data treatment

1. Actors were grouped to generate a simplified overview of all the networks. For example, divisions within the Environmental State Office were grouped as "Environmental State Office."

2. Relations (links) were classified as either "collaborative relations" or "conflict relations," thus allowing for the construction of two coexisting networks: the "governance collaboration network" and the "governance conflict network."

3. To represent participants' assessment that some relations "need improvement," two procedures were adopted:

    - existing "collaborative relations" (in CPGN) that were marked as "need improvement" (in DGN) received a weight of 1 in CPGN, while all other relations were weighted as 2 (indicating a stronger link);

    - existing "conflict relations" (in CPGN) that were marked as "need improvement" (in DGN) were disregarded in collaborative CPGN (only positive links were represented) and considered in DGN as "new" positive links.

Information Transmission Capacity and Robustness of Natural Resource Governance Networks in Brazil and Indonesia: A Comparative Analysis

Philipp Gorris[1]
Institute of Geography, Osnabrück University, Lower Saxony, Germany

Marion Glaser
Social–Ecological Systems Analysis Working Group, Social Science Department,
Leibniz Centre for Tropical Marine Research, Bremen, Germany

Abstract

How do different approaches to collaborative natural resource governance impact the associated actor networks' potential for rapid information transmission, and their robustness when subject to sociopolitical change? This is studied in the context of two cases that represent different archetypal regional approaches to coral reef governance. The case in Brazil adopts a centrally coordinated, large-scale protected area governance approach, whereas a self-organized polycentric governance approach is evident in the Indonesian case. Extensive empirical data are analyzed based on social network analysis and an innovative approach for simulating the effects of sociopolitical change on networks. The results show that both governance approaches shaped networks with surprisingly similar information transmission capacity. The network formed by the self-organized polycentric governance approach is found to be more robust than the centrally coordinated network. Mechanisms that contribute to shape the network pattern in the study areas are discussed.

Keywords: collaborative governance, comanagement, coral reef, polycentric governance, protected area, social network analysis.

1. Introduction

This research focuses on the information transmission capacity and robustness of actor networks that emerge from different approaches to collaborative governance of coastal and marine natural resources. Coastal and marine ecosystems are among the most productive ecosystems on earth and humans derive a wide variety of benefits from

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them (Cinner, 2014; Ferrol-Schulte et al., 2015). However, increasing anthropogenic pressures have led to extensive and sometimes irreversible damage of these ecosystems (Hughes et al., 2017). The human–nature relationships associated with these ecosystems are dynamic, place-specific, and may cause surprising repercussions across sectors and large territorial distances (Hughes et al., 2013). This renders governance highly challenging and the availability of information key for successfully resolving coastal and marine sustainability problems (Cinner et al., 2012).

Natural resource governance networks are widely recognized as playing an essential role in gathering and synthesizing knowledge (Alexander et al., 2016; Gerhardinger et al., 2018). Information and knowledge are not equally distributed in a social system, but certain actors possess information on a particular subject, while other actors hold more detailed information in another field of expertise (Wilson, 2002). Actors in the social system thus function as sources of different types of information due to their specific knowledge (Glaser, Radjawali, et al., 2010). For instance, some actors (e.g., fishers) may provide detailed information on changes to one resource (e.g., pelagic fish stocks), while other actors (e.g., dive tourism operators) may hold knowledge on changes to another resource (e.g., coral reefs) (Alexander et al., 2017; Galaz et al., 2016). Scholars consequently argue that integrating a wide variety of actors in governance networks is useful; for instance, for combining local and traditional knowledge with modern science-based knowledge to expand the overall knowledge base in management (Aswani & Hamilton, 2004; Berkes, 2004) and to foster collective learning (Newig et al., 2010). In practice, such governance networks consist of different relational configurations between the actors with distinct (dis-)advantages for information transmission (Bodin, 2017).

This research centers on the question of how natural resource governance approaches impact the associated actor networks' potential for facilitating rapid information transmission between actors, and their robustness in terms of maintaining this function when subject to sociopolitical changes. This is studied based on a comparative case study approach in the context of coral reef governance in two cases: the "Coral Coast Environmental Protection Area (CC-EPA)" in the northeast of Brazil and the "Spermonde Archipelago" off the southern coast of Sulawesi in Indonesia. These cases were selected because they are very similar with regards to two important characteristics. First, the sustainability challenges surrounding the use of coral reef ecosystems are addressed through decentralized political systems in both countries (Wever et al., 2012). Second, regional collaborative approaches to environmental governance are in place with the purpose of bridging jurisdictional boundaries to address the problem of fit between ecological and governance processes in decentralized political systems (Jones, 2014; Young, 2006). These two characteristics are representative for many coastal marine natural resource governance efforts (Jones, 2014; Wever et al., 2012). In such contexts, integrated, regional, and collaborative governance approaches are initiated and implemented differently in practice. According to Jones (2014), two different archetypal

approaches can be identified for this type of governance effort. First, governance may be initiated and implemented through a self-organized polycentric approach and, second, through an externally coordinated central government-led approach with procedural mechanisms for stakeholder participation. The cases selected for this research represent one case from each category, to improve understanding of the presumably differing potentials of the resultant governance networks with regard to their information transmission capacity and robustness.

Social network analysis (SNA) is used to examine the social structural configurations of the two governance networks for their information transmission capacity. For the robustness assessment, a consecutive targeted node removal procedure is used to simulate the impact of sociopolitical changes on the governance networks. Mechanisms that contribute to shape the observed network pattern in the study areas are discussed based on qualitative data.

The findings of this study fill at least two important gaps in the literature. First, research on the (dis-)advantages of distinct relational structures in environmental governance networks is constantly growing (Bodin, 2017; Groce et al., 2019; Kluger et al., 2020). Yet, whether these structures are shaped by different approaches to collaborative natural resource governance remains an open question. Moreover, second, while the interplay between information transmission capacity and network structure has received some attention in conceptual research (Bodin & Crona, 2009; Newig et al., 2010), empirical social network studies on information transmission in environmental governance are scare and empirical studies on robustness of environmental governance networks absent. In addition, the findings of this study contribute to understanding of the (dis-)advantages of adopting one or another type of governance approach for resolving natural resource problems.

The article proceeds as follows: Section 2 combines literature from social network studies with research on governing natural resources to formulate hypotheses on how the two governance approaches impact their associated actor networks' capacity for transmitting information and their robustness. Section 3 describes the methods for data collection and analyses before the results are presented and discussed in Section 4. The article concludes with Section 5, which highlights key insights of the study.

2. Governance networks, information transmission, and robustness

Social network scholarship highlights that a network's potential for the transmission of information and knowledge is tightly linked to reachability (Bodin et al., 2006). A high degree of reachability in a network is achieved when all actors are connected to the network; that is, the network displays a low degree of fragmentation. This ensures that all actors in the network can be reached via direct contact by at

least one other actor. Another important determinant of reachability is whether the network is patterned in a way that most actors can directly contact the majority of other actors, or at least indirectly reach each other via only a few steps between other actors in the network (Wasserman & Faust, 1994). Actors can thus gain fast access to information from all others in the most direct way (Abrahamson & Rosenkopf, 1997).

Robustness generally refers to the capacity of a system to maintain key properties and functions either when subject to external perturbations or internal stresses (Anderies et al., 2004). In this article, the term robustness specifically refers to the network's capacity to maintain its information and knowledge transmission capacity in the face of sociopolitical change. Sociopolitical change alters the composition of a governance network. This occurs, for instance, when important government agencies experience cutbacks in terms of personnel allocated to contribute to the governance process, or when funding for projects or nongovernmental organizations (NGOs) breaks away (thereby reducing or erasing the role that respective actors can play in the governance process). Another case of even larger scale changes in governance networks might occur when a subject to be governed (such as marine conservation) loses priority with shifts in the general political agenda (e.g., following elections). Then, multiple actors may withdraw from an ongoing governance process and turn their attention to another subject. This has severe consequences for the capacity of the entire governance network to resolve sustainability problems (Folke et al., 2005).

For investigating the information transmission capacity and the robustness of governance networks, this study focuses on a large-scale marine protected area (MPA) managed by a central government authority in Brazil and a self-organized polycentric regional governance approach in Indonesia. The Brazilian "Coral Coast Environmental Protection Area" (CC-EPA), established in 1997, is located in the states of Pernambuco and Alagoas. A large-scale MPA approach was adopted to ensure the conservation of coral reefs, beaches, mangroves, and manatees, and to maintain the culture of coastal communities by regulating tourism and fishing (ICMBio,[2] 2013). Covering a total area of 413.563 ha, the CC-EPA extends from 33 meters above the average high tide to 18 nautical miles off the coastline, and includes 135 km of coastline (ICMBio, 2013). The CC-EPA is under federal responsibility and managed by the national government authority ICMBio. The "consultative council of the CC-EPA" (the locally used acronym of the council is CONAPACC, for "Conselho Consultivo da Área de Proteção Ambiental Costa dos Corais") is composed of governmental and nongovernmental actors and complements management through a regional forum for stakeholder involvement. Any rules and regulations are formulated through an interactive process between

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2   Instituto Chico Mendes de Conservaçacao da Biodiversidade (Chico Mendes Institute for Biodiversity Conservation).

the MPA managers and the CONAPACC (Glaser et al., 2018). Such participatory large-scale MPA approaches led by national government authorities are widely used in Brazil and are very common in many countries all over the world (Jones, 2014).

The Indonesian Spermonde Archipelago is located off the southern coast of Sulawesi and comprises about 80–100 small islands. The Spermonde Archipelago territory is, just as in the Brazilian case, subdivided into the two administrative units Makassar district and Pangkajene Kepulauan district (Pangkep), each with responsibility to manage the islands and the sea within their jurisdictional territory. Unlike in the Brazilian case, with its central government-led participatory MPA approach, a range of governmental and nongovernmental actors from multiple levels in the state hierarchy are involved in collaborative strategic marine planning, implementation of conservation programs, monitoring, and enforcement (Glaeser et al., 2017). Whereas an overarching institutional framework at the regional level (e.g., a large-scale MPA) is de facto absent, a number of small community-based no-take areas are declared (Glaser, Baitoningsih, et al., 2010). Moreover, independent of these small MPAs and other higher level marine management measures, effective area-based rules surrounding a number of islands have emerged at the community level all over the archipelago (Glaser, Baitoningsih, et al., 2010). These include, for instance, the prohibition of destructive activities (e.g., bomb and poison fishing) by informal agreements, which are enforced locally (Gorris, 2016). Such dispersal of authority across the political system in combination with high degrees of overlap of responsibilities establishes a polycentric governance system that strongly relies on self-organized coordination and collaboration among the relevant actors (Andersson & Ostrom, 2008; Carlisle & Gruby, 2019; Gorris et al., 2019).

Social network theory suggests that the existence of central coordinators increases information transmission in governance networks (Bodin & Crona, 2009). In the Brazilian case, MPA managers actively coordinate coral reef governance and steer the network. Furthermore, the CONAPACC offers a platform to integrate actors from the relevant sectors and the different affected communities in the Brazilian governance network. Such active coordination in combination with the existence of boundary-spanning multi-actor platforms are viewed as particularly important for enhancing the information transmission capacity of governance networks (Berdej & Armitage, 2016; Hamilton et al., 2020). As for the Indonesian case, conversely, previous research suggests that dispersed responsibility for environmental governance across the political hierarchy and the lack of a regional overarching coordinating framework often result in fragmented regional governance (Jones, 2014; Wever et al., 2012; Young, 2006). Such fragmented regional governance most likely leads to deficits in information transmission among the relevant actors (Bodin & Crona, 2009). Consequently, we deduce the following hypothesis:

> Hypothesis 1: The centrally coordinated governance approach in the Brazilian case shapes an actor network with a higher information transmission capacity than the polycentric governance approach in the Indonesian case.

Information transmission capacity is measured based on the networks' reachability. A lower reachability of the governance network in the Indonesian case than in the Brazilian case provides support for hypothesis 1.

With regards to the robustness of a governance network, in terms of maintaining its information transmission capacity when subject to sociopolitical change, network theory suggests that if only one or few actors are responsible for connecting large numbers of actors, the disappearance of these key actors causes numerous actors to be connected in less direct ways, or causes a full disconnection of parts of the network (Borgatti, 2003). This indicates vulnerability of the network to the removal or failure of the key actors (Frank et al., 2007). In the Brazilian case, the MPA managers assume an outstanding key role in the governance system through their coordinating and steering function. Polycentric approaches with overlapping authority and responsibilities, as in the Indonesian case, rather create redundancy of actor roles (Carlisle & Gruby, 2019). This redundancy is a critical element to enhance robustness in the face of sociopolitical change (Janssen et al., 2006). Consequently, we assume the following for our cases:

> Hypothesis 2: The polycentric governance approach in the Indonesian case shapes a more robust actor network than the centrally coordinated approach in the Brazilian case.

The networks' robustness is tested by simulating the effects of sociopolitical change on the governance networks' reachability through a targeted elimination of actors from the network. For supporting hypothesis 2, we expect that the withdrawal of actors from the governance networks decreases the degree of reachability in the Brazilian case faster than in the Indonesian case.

3. Methods

3.1. Data collection

The hypotheses are tested using extensive empirical data collected from the two study areas. A list of institutional actors (a so-called stakeholder roster in SNA terminology) with functional roles in marine governance was developed based on reviewing official documents (e.g., meeting protocols) and in-depth interviews with district administration personnel and university scholars. The stakeholder roster was left open so that respondents could add links as needed. Subsequently, face-to-face interviews with a structured survey instrument were conducted to collect data

about interaction among marine governance actors in the Indonesian Spermonde Archipelago and the Brazilian CC-EPA. The use of a stakeholder roster was chosen rather than snowball sampling to ensure that possibly disconnected components of the network could be detected. 105 interviews were conducted in Indonesia with governmental and nongovernmental actors (n = 129) from September 2012 to March 2013 (ca. 80 percent response rate). Eighty-nine interviews were conducted with actors (n = 110) in the Brazilian study region from July to December 2013 (ca. 80 percent response rate).

While all actors listed on the stakeholder roster were approached to take part in the study, some actors did not want to be interviewed. Yet, according to the key informants who helped to develop the stakeholder roster, the missing actors did not assume important roles in the networks (which, for some actors, may also be the reason why they refused to take part in the study). We thus decided to include the not-interviewed actors in our analysis and use a symmetric non-directional relational data set. We generally acknowledge that missing data reduce the validity of the results, because network analysis is sensitive to missing data (Groce et al., 2019). However, we believe that, for this study, including the "missings" enhances the validity of the results more than excluding them (and their links).

The relational data were complemented by semi-structured key informant interviews (KIIs, $n = 18$ in Brazil, $n = 21$ in Indonesia) to allow for a more in-depth understanding of the roles and responsibilities of the different actors in marine governance and of the impact of governance design instruments (i.e., regional stakeholder meetings) on the network structure, and to contextually ground the findings of the SNA. These interviews were held with government officials, representatives of NGOs, and university scholars. KIIs were recorded and transcribed, but no systematic content analysis was carried out. Publicly available documents including project descriptions, management plans, legal documents, and written agreements were reviewed to validate qualitative data.

3.2. Data analysis

Analysis of the relational data was carried out in two steps to investigate differences in the actor networks resulting from the two different approaches to governance. First, reachability was assessed to examine the networks' information transmission capacity. Second, we conducted a network robustness assessment to test whether this information transmission capacity can be maintained over time when the network is subject to sociopolitical change. UCINET (Borgatti et al., 2002) and Gephi (Bastian et al., 2009) software was used for analysis of the relational data and the latter also for visualization of the networks.

3.2.1. Assessment of reachability in the networks

Following the suggestion by Bodin et al. (2006), reachability at the network level is assessed by analyzing the fragmentation and diameter of the networks. Fragmentation is measured through *component analysis*. A component is a part of a larger network that is disconnected from the rest of the network (Wasserman & Faust, 1994). If a network consists of more than one component, it is considered fragmented (Bodin et al., 2006). The degree of fragmentation is quantified by the number of components; that is, the higher the number of components in a network, the higher is its fragmentation, because the actors in one component cannot directly communicate with the actors in another component. This reduces reachability in the network. The *diameter* measures the actors' ability to directly communicate with all other actors in the network. The *diameter* is defined as the average length of the shortest paths between any two nodes in the network (Wasserman & Faust, 1994). The smaller the *diameter* is, the better the ability of all actors in the network to communicate with each other.

In addition to these two reachability measurements suggested by Bodin et al. (2006), we include the network measure *density* in our reachability assessment, because we consider the connectedness of networks to also be an important enhancing factor of reachability that improves information transmission in networks. *Density* analyzes to what extent all actors in the network are tied to one another. *Density* is calculated as the proportion of links realized relative to the maximum number of links possible in the network (Wasserman & Faust, 1994). A *density* score of 1 indicates that all actors of the network are directly linked with each other (i.e., the network is fully connected). A score of 0 indicates that no single actor has a link to any other actor in the network (i.e., the network is fully disconnected). Although the two cases have a relatively similar number of actors in their networks, note that smaller networks tend to have higher densities (Wasserman & Faust, 1994).

3.2.2. Assessment of network robustness

The robustness of the networks is studied by examining the governance networks' ability to maintain their information transmission capacity based on the reachability of the network when subject to sociopolitical change. The withdrawal of any actor from the governance network removes that actor's links that contribute to the reachability of the network. For simulating such changes in the two cases' governance networks we used a consecutive targeted *node removal procedure* (for details see Albert et al., 2000). In each step, the actor with the highest *closeness centrality* was removed until no link was left in the network. The node-level measure *closeness centrality* analyzes an actor's reachability in a network by calculating the average geodesic distance between the actors; that is, the average number of steps needed for any actor (ego) to reach all other actors (alters) in the network (Freeman, 1979).

Actors with high *closeness centrality* scores function as important hubs for information transmission, because they can reach all other actors in the network through only a few steps. *Closeness centrality* was chosen (rather than *degree centrality*), because it indicates actors with high importance for maintaining the network's information transmission capacity considering the entire network, rather than only an actor's direct links (i.e., actors with high *degree centrality*) (Freeman, 1979).

Following Anderies et al. (2004), we consider the robustness of a network to be high if the network is able to (at least partly) maintain its key properties and functions in the face of (simulated) change. Two measures were used to assess the networks' robustness. First, we measured the number of nodes to be removed until decay (i.e., no link in the entire network was left). The percentage of nodes to be removed from the network until decay indicates the speed with which the network decays (relative to the size of the network); that is, the lower the percentage of nodes to be removed until decay, the faster the network decays and, consequently, the lower is its robustness. Second, the development of the networks' reachability during the node removal process was measured. Therefore, the network's density and fragmentation (i.e., number of components) are calculated at each step in the consecutive node removal process until the network is fully decayed. We compared the slopes produced by the values for density and fragmentation between the two governance networks to assess their robustness; that is, the faster the density decreased and the fragmentation increased, the less robust we consider the network to be with regards to maintaining their information transmission capacity. For determining the steepness of the slopes, the following geographical slope estimation was used.

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

y_1 represents the first point and y_2 the last point on the y-axis (same for x_1 and x_2). m denotes the absolute value of the slope. The higher the value for positive values (and the lower for negative values), the steeper the slope. Separate slope estimations were calculated for (A) the density values and (B) the number of components (indicating fragmentation) obtained after each step during the node removal procedure in each case.

Note that the networks' diameter (i.e., the third characteristic of reachability used in this study), for which only the largest component is measured, could not be included in the network robustness assessment. This is because the node removal process quickly leads to fragmented networks and the measure becomes highly biased with increasing network fragmentation.

4. Results and discussion

4.1. The governance networks' information transmission capacity

Figure 1 shows a visualization of the networks. Table 1 shows the results of the networks' reachability analysis. Interestingly, both regional governance approaches trigger actor networks with the same *density*. The *component analysis* shows for the Indonesian governance network that any actor in the network can be reached via direct or indirect social interactions and the network is not fragmented. For the Brazilian network, the results show two components in the network. Yet, similar to the Indonesian network, the Brazilian network consists of one large component, which represents the overall governance network, and one only very small component (see Figure 1). The small component consists of only four actors who are connected to each other, but not to the overall network. Hence, the Brazilian networks also has a very low degree of fragmentation. The *diameter* in the Brazilian network is slightly higher than in the Indonesian network; that is, one more step is needed on average in the Brazilian network to reach all other actors from any given node than in the Indonesian network. In conclusion, while the reachability in the actor networks is surprisingly similar, the higher number of components and the higher diameter in Brazilian case show a slightly lower overall reachability compared with the Indonesian case.

Table 1. Characteristics of the governance networks.

Case	Governance approach	No. of actors	No. of links	Density	Diameter	Components
Coral Coast Environ. Protection Area, Brazil	Large-scale marine protected area governance approach	110	478	0.07	6	2
Spermonde Archipelago, Indonesia	Self-organized polycentric governance approach	129	655	0.07	5	1

Note: See Section 3.2 for details on how density, diameter, and number of components are calculated.
Source: Authors' summary.

These results thus do not support hypothesis 1, that the governance approach in the Brazilian case shapes an actor network with higher information transmission capacity than the one in the Indonesian case. Instead, the results suggest that the polycentric approach shaped a network with a slightly higher information transmission capacity than the centrally coordinated governance approach. This result is surprising given that scholarship emphasizes the importance of coordinators and of boundary-spanning multi-actor platforms, as implemented in the Brazilian case, for enhancing the information transmission capacity of governance networks (Berdej & Armitage, 2016; Bodin & Crona, 2009; Hamilton et al., 2020).
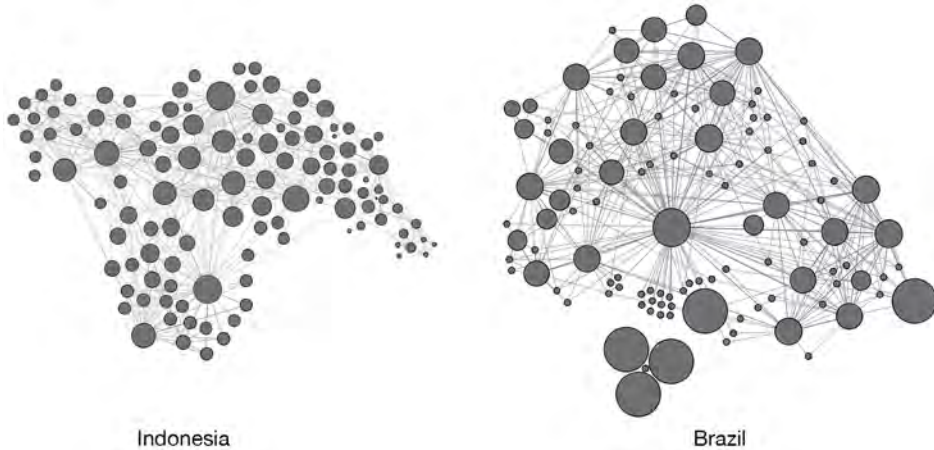
Figure 1. Visual representation of the governance networks. The node size is scaled to the actors' "closeness centrality" scores (the larger the nodes, the higher the score).

Source: Authors' representation.

Information from the Brazilian KIIs helps to explain these results. Interviewees confirmed that the MPA managers take a strong steering role in governance. Furthermore, interviewees stated that the regional forum, the CONAPACC, led to the formation of what may be called a "regional conservation clique." More specifically, the CONAPACC is a membership organization joined by a (limited) number of governmental and nongovernmental actors and, as both the network analysis and qualitative data show, this seems to have facilitated the formation of a strongly connected core group in the network. Actors outside this clique, who are mostly local actors and with limited organizational capacity (e.g., small-scale fisher associations, small tourism business associations, local NGOs), do not participate in the regional forum and are only weakly connected. A core–periphery network structure with high inequality in the distribution of links (i.e., high variance in the *closeness centrality* scores, see Figure 1) is thus formed. In this overall structure, the network's core involving the MPA managers and the conservation clique is tightly connected whereas the periphery is only sparsely connected. This sparsely connected periphery reduces overall reachability in the governance network and inhibits the information transmission capacity of the network as a whole.

In contrast, the expected fragmentation of the Indonesian governance network resulting from the dispersal of responsibilities across the political system is not reflected in the results. According to information from Indonesian KIIs, when relevant issues arise, actors from the involved communities and from the different levels in the Indonesian political system (villages, districts, and the province) include the topic on the agenda of other more general forums or organize ad hoc meetings. Most importantly, the Indonesian informants emphasized that the actors exchange

information through informal interaction. A decentralized, more integrative network with a low inequality in link distribution was thus formed, rather than a core–periphery network as in the Brazilian case. This self-organized polycentric governance approach in the Indonesian case thus shaped an actor network with a slightly higher information transmission capacity than the centrally coordinated approach in the Brazilian case.

4.2. The governance networks' robustness

How well is the information transmission capacity of the governance networks maintained when subject to sociopolitical changes? The results of the robustness assessment are presented in Table 2 and Figure 2. The results show that, compared with the Indonesian case, in the Brazilian case a lower percentage of nodes had to be removed until the network was completely disconnected (Table 2). Moreover, the slopes produced by the values for density and the number of components during the simulation process show that the Brazilian network's connectivity decreased (Figure 2A, Table 2) and fragmentation increased faster than in the Indonesian network (Figure 2B, Table 2).

Table 2. Results of the network robustness assessment.

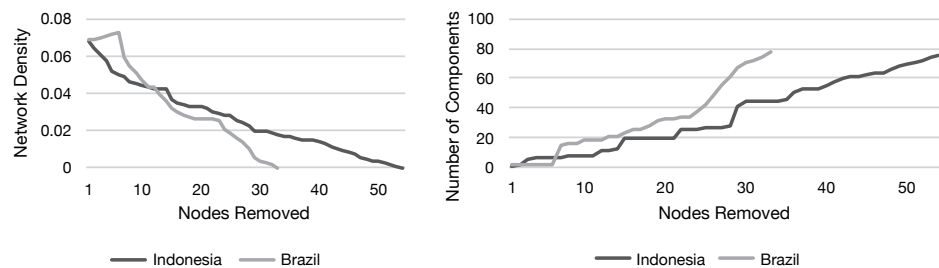| Measure	Indonesia	Brazil
Steps to decay (0 edges left)	54	32
Percent of nodes removed until decay (0 edges left)	42%	29%
Network density: steepness of slope	−0.00132	−0.00219
Fragmentation: steepness of slope	1.396	2.375

Source: Authors' summary.

Figure 2. (A) Development of networks' density and (B) degree of fragmentation, during the targeted node removal process.
Source: Authors' representation.

These results support our hypothesis 2 that the Indonesian governance network is more robust than the Brazilian network. As expected, the coordinated governance approach in Brazil resulted in a lack of redundancy of actors with structural key roles in the network. This renders the governance network in the Brazilian case structurally vulnerable to the loss of critically important actor roles (Borgatti, 2003). The Brazilian governance network consequently fragmented more rapidly than the Indonesian network, as the MPA managers with key roles and, subsequently, the actors from the "regional conservation clique" were removed very early in the simulation.

The results of the simulation are supported by the KIIs. A number of Brazilian informants emphasized that the MPA managers do their job very well and that they are critical to ensure effective coral reef governance, especially by means of their function as knowledge hubs in the network. This key role, however, has led to a situation in which the overall success of the MPA highly depends on the capacity of the MPA managers. Moreover, Brazilian KIIs stated that the "regional conservation clique" plays a central role for the information transmission in the network. Hence, while previous research suggests that leadership is an important driver of resource governance effectiveness (Gutiérrez et al., 2011), the results of this study emphasize that the reliance on the capacity of leaders and a small conservation elite may be problematic, because it increases vulnerability to sociopolitical changes.

In line with the arguments by polycentricity scholars (Carlisle & Gruby, 2019; McGinnis, 2000), the Indonesian network shaped by the self-organized polycentric governance approach, in contrast, is found to be more robust than the coordinated Brazilian one. The main reason is that the polycentric approach formed a network with much lower inequality in reachability among the governance actors than the Brazilian approach. Both the results of the network analysis and the Indonesian KIIs suggest that the actors in the Indonesian case form several sub-clusters in different governance units nested across the political system (i.e., villages, districts, province). These sub-clusters are also connected with each other via information exchange. A high degree of robustness in terms of maintaining the network's structural capacity to transmit information when subject to sociopolitical changes could thus be achieved in the Indonesian governance network.

Table 3. Summary of the results.

Case	Location	Governance approach	Information transmission capacity	Robustness
Coral Coast Environmental Protection Area	Northeastern Brazil	Centrally coordinated large-scale MPA governance approach	Very similar (slightly lower)	Lower
Spermonde Archipelago	Central Indonesia	Self-organized polycentric governance approach	Very similar (slightly higher)	Higher

Source: Authors' summary.

4.3. Limitations of the study

There are limitations to this study. Importantly, the results are not generalizable, because this is a two-case comparative study. The quantitative network analysis as used in this study can only shed light on the *potential* of a given relational structure among actors in a governance network in terms of information transmission, but neither deliver insights on the actual content transmitted through the network, nor on the quality or usefulness of transmitted information for the actors. Finally, the simulation of sociopolitical change through consecutive node removal does not take into account that the loss of actors from the governance network might, in practice, lead to reactive link formation to cope with the change.

5. Conclusion

Based on two archetypal cases, this comparative research examined how adopting different approaches to collaborative regional natural resource governance impacts the associated actor networks' capacity for facilitating information transmission and their robustness in terms of maintaining this function when subject to sociopolitical changes. A centrally coordinated regional MPA governance approach is adopted in the Brazilian case, whereas a more self-organized polycentric governance approach is evident in the Indonesian case. Social network analysis and an innovative simulation approach was used to analyze extensive empirical data.

The findings contribute interesting insights on the interplay between governance characteristics, the resultant actor network structure, and their specific (dis-) advantages. The different governance approaches shaped actor networks with distinct relational structures. Both networks entail a similar capacity for information transmission, while the self-organized polycentric governance network is more robust when subject to sociopolitical change. Consequently, this study contributes further evidence that self-organized polycentric approaches are a viable alternative for natural resource governance (Carlisle & Gruby, 2019; McGinnis, 2000). How natural resource governance networks can be better supported to enhance their robustness in times of sociopolitical change remains an important question for future research.

Acknowledgments

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Social (–Ecological) Network Analysis in Environmental Governance: Central Publications, Important Concepts, and Areas of Application

Theresa Schwenke[1]
Social–Ecological Systems Analysis Working Group, Social Science Department, Leibniz Centre for Tropical Marine Research, Bremen, Germany

Eike Holzkämper
Social–Ecological Systems Analysis Working Group, Social Science Department, Leibniz Centre for Tropical Marine Research, Bremen, Germany

Abstract

Social and social–ecological network analysis (S(E)NA) have recently emerged as new methods in the environmental governance (EG) literature. By investigating networks of connections between actors, S(E)NA advances the understanding of who is involved in EG and how. We provide an overview of the EG literature applying S(E)NA and map (1) the citation network emerging from cross-references and (2) the similarity network emerging from word similarities between publications. We show that S(E)NA application in EG is in the process of developing into a field of research where publications frequently cite each other. We identify 20 publications which occupy positions as sources, storers, or bridges of knowledge in the citation network. While we see S(E)NA applied in diverse resource contexts, these are mainly discussed on the local spatial level, with a focus on "policy" or "collaboration." We discover that "power structures" and "the production of knowledge" are themes influencing the whole field.

Keywords: bibliometric network analysis, environmental management, Latent Dirichlet Allocation, social network analysis, topic detection.

1   Corresponding author: theresa.schwenke@leibniz-zmt.de.

1. Introduction: Applying social network analysis in environmental governance

The growing impact of human activities on the geo-bio-physical environment has led to the dawn of the Anthropocene, where alarming developments like climate change, ecosystem degradation, and unsustainable resource exploitation dramatically affect the populations that depend directly on the ecosystem they live in (Glaeser, 2016), and favor feedbacks between ecological and social systems that trigger global crises (Wijkman & Rockström, 2013). Facing these worrying—and likely intensifying—trends, the question of how to govern the human use of the geo-bio-physical environment is ever more salient (Young, 2016).

Environmental governance (EG) is a field of research that aims to improve our understanding of human–nature relations and to develop evidence-based recommendations on how to balance ecological with social needs. The field traditionally focuses on the human use of the geo-bio-physical environment, which is often challenged by (anthropogenic or other) threats. The geo-bio-physical environment encompasses the environmental goods and services or "resources … at stake" (Borrini-Feyerabend, 2011) like the climate, biodiversity, freshwater, oceans, forests, wildlife, air, and land (Paavola, 2007). Natural resources and ecosystem services explicitly include immaterial goods such as knowledge, learning, and recreational or aesthetic values (Chiesura & Groot, 2003).

EG investigates societal decision-making processes and institutions steering human behavior regarding the use of the geo-bio-physical environment (Armitage et al., 2012). It focuses on structures and processes that guide how humans interact with each other, make decisions, and pursue their (often conflicting) interests regarding environmental goods and services. These structures and processes encompass formal (e.g., legal frameworks, government regulations, officially responsible organizations) or informal (e.g., social pressure, values, norms, market forces) institutions that influence environmental agendas and decision-making. EG comprises development, function, and change of these institutions, as well as decisions themselves and the measures taken to implement them (Armitage et al., 2012).

Management is often used interchangeably with "governance." While both are closely interrelated, they are different concepts (Armitage et al., 2012). Management deals with technical issues like operational decisions, rule implementation, and monitoring specifications. It is about the procedural "what to do?" (Borrini-Feyerabend, 2011) with the managed aspects of the natural geo-bio-physical environment.

Governance emerges when various social actors from public, market, and civic spheres (such as government agencies, businesses, nongovernmental organizations [NGOs], and local communities) focus around a problem to address challenges and

resolve conflicts while advocating their respective agendas (Lee, 2003). Governance implies a certain share of power between the different spheres as it actively involves different societal actors in public decision-making (Lebel et al., 2006). It can be seen as a "continuum of systems of governing, in which state and non-state actors play a variety of roles" (Bulkeley, 2005, p. 877). Governance is about "who decides what to do and how?" (Borrini-Feyerabend, 2011), as well as who should execute the how (Glasbergen, 1998). Thereby it provides "the context that enables management" (Alexander, 2015), which means "the essential direction, resources, and structure needed to meet the overarching resource governance goals" (Crona et al., 2011, p. 45). Management SENA is thus an essential, but not sufficient, part of governance. Management concepts like co-management, collaborative management, participatory management, and community-based management involve a variety of societal actors which share decision-making power. Therefore these concepts actually refer to systems of governance as defined above. Table A in the supplemental material for this article (Schwenke & Holzkämper, 2020) provides a short overview of some of the actors and types of governance found in the EG literature.[2]

The challenges characteristically addressed by EG exceed typical sectoral, spatial, and disciplinary boundaries, making them complex and wicked problems (Balint et al., 2011). Recently, the application of a new method emerged in the EG literature: social network analysis (SNA). SNA is an analytical tool to mathematically describe, visualize, and investigate the networks of connections between social actors. The method advances the understanding of who is involved in governance processes (and who is not), as well as what type of relations and interactions connect governance actors. But SNA is more than just a method; it is the application of a network perspective by analyzing through the lens of social relations. The basis of SNA is the modeling of social actors as nodes that are connected by links representing the relations between these actors. Actors can be individual or collective social entities and connections between actors are social relations such as friendship or kinship ties, interactions (e.g., advice-seeking), or similarities (e.g., membership). Nodes and links together form a unique network structure at one point in time (Alexander, 2015). Thus, the number of actors and connections becomes quantifiable, offering opportunities for the mathematical investigation of the structure of social relations as networks (Marin & Wellman, 2014). The graphical network visualization provides additional opportunities for analytical explorations (Venturini et al., 2015). In an effort to reduce complex interrelations to an analyzable degree, SNA examines actors and their connections within specific contexts (such as EG) and defined boundaries that set the frame for the network data collection. Today, SNA is endorsed by a broad spectrum of disciplines in the social and natural sciences, and the study of networks was in turn influenced by ideas from many of these areas. The analysis of EG as

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2   See file: Schwenke&Holzkaemper_SENA in EG Table A_Governance types.pdf (Schwenke & Holzkämper, 2020).

networks of connections between societal actors has emerged as a "powerful and practical tool" for the study of EG issues (Alexander, 2015). EG networks are one type of context-specific network that are exogenously built and/or endogenously form around a governance issue, such as the use or conservation of the geo-bio-physical environment (Borrini-Feyerabend, 2011). These networks usually involve actors at the organizational level from different social realms (e.g., NGOs, government agencies, or businesses). Acknowledging the manifold interlinkages of humanity with its geo-bio-physical environment, which are of special importance for EG related questions, an area of network science emerged that includes ecological entities: the social–ecological network (SEN) approach. This approach assumes that social–ecological systems can be investigated, analyzed, and modeled as SENs. It expands the classical SNA, which focuses on social actors, by adding non-human actors (e.g., ecological resources) and their interdependencies. Ideally, a social–ecological network analysis, or S(E)NA, includes all possible types of links within the system: (1) social-to-social, (2) social-to-ecological, (3) ecological-to-ecological, and (4) ecological-to-social (Bodin & Tengö, 2012). The inclusion of non-human actors in the network analysis of EG topics is a valuable addition to traditional SNA methods and increases our understanding of EG.

To our knowledge, there have been no previous studies which provide an overview of or investigate bibliometric patterns within the scientific literature applying S(E) NA approaches in EG. We conduct a Web of Science search and show the growing body of literature within the research fields EG and S(E)NA and provide first insights to the question if the use of S(E)NA in EG is developing into a distinct research field. We then analyze the intersection of both fields by investigating (1) the structure of the citation network emerging from cross-references of publications and (2) the similarity network emerging from word similarities between publications. We provide visualizations of both networks and discuss their structural elements to tackle our main research questions: (1) In which peer-reviewed publications is S(E) NA applied to investigate EG issues? (2) Is the body of literature applying S(E)NA in EG interconnected by a network of direct citations between publications, thus indicating the formation of an individual subfield of research? (3) If so, what are influential publications for the development of the subfield? (4) Which EG related topics are frequently addressed by applying S(E)NA?

2. Methods

Scientific progress, such as the generation of insights into EG by applying S(E)NA, takes place through the production and propagation of knowledge. An essential (although not sufficient) part of this process is the exchange of ideas and knowledge among academia. Databases of peer-reviewed literature (e.g., Web of Science) record the flows of knowledge which are associated with citation processes. A citation

between two publications occurs when one publication refers to another as a source of knowledge. It thus establishes a documented, formal communication channel between these two publications (Shaw, 1981). The publication which is sending a link is then called the citing publication, while the publication which is receiving a link is referred to as the cited publication. The patterns of citing and being cited can be depicted as a citation network with publications as nodes and citations as links. The emerging network structure visualizes the communication system of contemporary science based on citations in peer-reviewed literature and can be used to reveal the "intellectual linkage" of articles (Barnett et al., 2011). Small et al. (2014) have shown that citation-based methodologies can be used to identify emerging topics in science.

While "similar citation patterns … represent similarities of academic perceptions and opinions" (Barnett et al., 2011), the second approach to cluster a body of publications considered in this research is a more direct indication of similarity between publications. The similarity network approach defines a relation between two publications based on the similarity of their texts, rather than on citation processes between them. In a similarity network, publications are nodes. A link between two nodes indicates a certain level of text similarity between these, identified by shared words found in both publications. In conjunction with topic detection methods, clustering a body of literature by text similarity adds a different, topic-centered perspective to a bibliometric analysis.

We investigate the body of literature applying S(E)NA in EG in two ways: by conducting (1) a citation network analysis and (2) a similarity network analysis including topic detection. We further assess the importance of publications within the body of literature by their position in the citation and similarity network. Table 1 gives an overview of the network metrics we applied and their meanings in the context of a citation or similarity network, respectively.

Because publications within a module in a similarity network likely address similar information content, clustering a publication similarity network into modules can be employed to detect topics from texts (Larsen & Aone, 1999). The detection of topics for modules adds meaning to the network structure and describes how a research field is structured topically. Words that describe a topic very likely occur more often in a publication's text than other words (after eliminating stop words[3]). Under this assumption, word frequency can identify topics of publications. Similarly, the frequency of publication topics in a module of publications can identify the general topic for the complete module.

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3   Stop words (e.g., I, and, of) are common in all kinds of text, irrespective of its content.

Table 1. Network metrics applied in this study and their interpretation in (A) a citation network and (B) a similarity network.

(A) Metric and reference	Interpretation in a citation network
Modularity: partitions the network into groups of nodes that are densely connected among each other and sparsely connected to other groups (Blondel et al., 2008).	Modules are groups of publications in which knowledge circulates: in a citation network, publications cite each other frequently while they refer to few publications outside the module they are part of (Baggio et al., 2015).
HITS (hyperlink-induced topic search): ranks publications by the number and quality of their citation links; identifies hubs and authorities (Kleinberg, 1999).	The HITS algorithm was originally developed to assess a website's significance in an interlinked (web)space. It is also applied in bibliometric analyses. Highly cited documents are called "authorities" and are often referred to as sources of knowledge. They propagate highly significant content for the research community. Highly citing documents, also referred to as storers of knowledge, are called "hubs." They refer to many sources of knowledge (authorities) and are very likely review papers. A good hub points to many good authorities; a good authority points to many good hubs.
Betweenness centrality (BC): measures the importance of a node in a network based on its position between modules (Freeman et al., 1991).	A BC-high publication is an important paper bridging the flow of scientific knowledge between different schools of thought or disciplines. BC thus is an indicator for the degree of interdisciplinary connections (Leydesdorff, 2007).
(B) Metric and reference	Interpretation in a similarity network
Modularity: partitions the network into groups of nodes that are densely connected among each other and only sparsely connected to other groups (Blondel et al., 2008).	In a similarity network, modules are groups of publications that share similar text. Analyzing modularity means organizing a considerable number of data objects in a network into a smaller number of coherent groups. It can thus give an overview and aid in the exploration of large data sets such as a body of literature (Huang, 2008).
Degree centrality: counts the number of nodes a node is linked to (Freeman, 1978).	In a similarity network, high degree centrality indicates that the publication shares word similarity with many other publications.

Note: HITS = hyperlink-induced topic search; BC = betweenness centrality.

Source: See citations throughout table.

In Figure 1, we provide an overview of the workflow and the software we used. After data collection, the body of literature is analyzed in two ways: by investigating (1) the citation network and (2) the similarity network between publications. The steps to analyze both citation and similarity network can be roughly divided into: creation of the networks, calculation of network measures, and visualization of the network. We give a detailed description of each step below. In addition to the workflow shown in Figure 1, we also applied the Latent Dirichlet Allocation (LDA) as a second method to detect topics within our collection of literature (see 2.3.7).
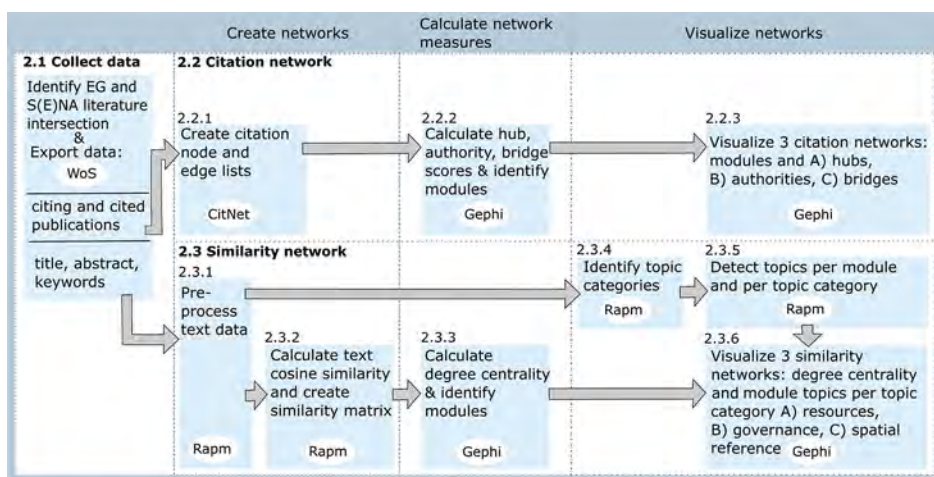
Figure 1. Workflow to map the use of S(E)NA in EG by combining a document similarity and a citation network analysis.

Note: CitNet = CitNet Explorer (van Eck & Waltmann, 2014); WoS = Web of Science online tool (ISI Thomson Reuters); Rapm = RapidMiner Studio 9.3 (Mierswa & Klinkenberg, 2018); Gephi = Gephi 0.9.2 (Bastian et al., 2009).

Source: Authors' description of workflow.

2.1. Data collection

We queried the Web of Science database (ISI Thomson Reuters) to identify academic literature with an explicit focus on EG, S(E)NA, or both. For this, we used two separate search strings: (1) a combination of "environmental" and "governance" search terms to identify the body of literature relating to the EG field, and (2) "social and social–ecological network analysis" search terms to identify the body of literature relating to the research field S(E)NA. Our search query included terms that identify EG and S(E)NA after our definition in the introduction and under the acknowledgment of common synonyms—the full list of search terms is in the supplemental material.[4] We searched for articles that contain our search terms in title, keywords, or abstract. The time frame of the search was set from the earliest record to the end of the year 2018 and was limited to peer-reviewed articles, books, and book chapters in English language. We then filtered the search results for those publications that connect to both fields. The search results were stored as citation files (simple-text "full record and cited references" format, tab-delimited[5]) , featuring the publications' titles, keywords, abstracts, author/s, and dates of publication, and including the full list of references each publication cites. Our search resulted in 69,463 EG related publications and 5,125 S(E)NA publications.

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4   See file: Schwenke&Holzkaemper_SENA in EG I&II_Web of Science search syntax.pdf (Schwenke & Holzkämper, 2020).
5   See file: Schwenke&Holzkaemper_SENA in EG Table E_WoS search results.csv (Schwenke & Holzkämper, 2020).

For our further analysis, we consider the body of literature that intersects between our focus research themes EG and S(E)NA, which consists of 241 publications. In the citation network, we additionally show the 10 publications that were most frequently cited by the intersection, but not part of the intersection.

2.2. Citation network

2.2.1. Creation of citation node and link list

We imported the search results into CitNet Explorer (van Eck & Waltman, 2014) and included "non-matching references" with a minimum number of 33 citations in our analysis. "Non-matching references" are those publications which are on the list of references of any of the publications in the original search results, but not part of the search results themselves. The matching of reference lists and search results in CitNet Explorer is done based on either DOI or the combination of first author's first name and first initial, publication year, volume number, and page number (van Eck & Waltman, 2014). As our aim is to focus explicitly on the body of literature dealing with S(E)NA in EG, we chose to only include the 10 non-matching references that are cited most frequently by our focus literature.

CitNet Explorer created a node list (publications) and a link list (citations between publications) from the information on cited and citing publications stored in the search results, while removing citation links that point forward in time or cause acyclicity[6] (van Eck & Waltman, 2014). Node and link list together define the citation network.

2.2.2. Calculation of citation network measures

After importing the node and link lists into Gephi (Bastian et al., 2009), we used the HITS (hyperlink-induced topic search) algorithm (Kleinberg, 1999) to identify hubs and authorities, while betweenness centrality indicated where bridges were located (Table 1). We thereby identified publications which stood out by their position in the network. We read these publications to find out the concepts they deal with. We detected modules by applying the modularity optimization algorithm for directed networks (Blondel et al., 2008), with a resolution setting of 1.0.

2.2.3. Visualization of the citation network

While it is possible to visualize citation networks historiographically, displaying time at the x-axis and arranging nodes accordingly (Garfield, 2004), we aim to focus on citation clusters rather than timelines. To visualize the citation network, we therefore used the "Force Atlas" algorithm, a spatialization algorithm from the force-vector family, which places nodes with stronger and/or more connections closer together

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6   Acyclicity in a bibliographic network context refers to citation processes in which older publications cite more recent ones.

and more central nodes to the center (Jacomy et al., 2014). We labeled nodes with "author_year." As newer papers often cite older papers, this label can indirectly also visualize the chronological order of citation (Nakazawa et al., 2018). We visualized different modules with different colors, and the "Non-matching references," as well as links pointing toward them, in light gray. In 2.2.2, we calculated values that assess the importance of publications as either hubs (A), authorities (B), or bridges (C). Consequently, we produced three distinct visualizations of the citation network, each visualizing one of these network measures as node size. The size of a node is proportional to its value, with larger nodes representing higher values. We selected the publications with the highest authority ($n = 8$) and hub scores ($n = 8$) and those with the highest betweenness values ($n = 7$) for an in-depth content analysis. For better visibility of the publications we consider in our content analysis, all other nodes were assigned a minimum size.

2.3. Similarity network

2.3.1. Text data preprocessing

We imported the search results from the data collection into RapidMiner (Mierswa & Klinkenberg, 2018). Using RapidMiner, we assembled title, keywords, and abstract of each publication into one document per publication. We further treated these text attributes as a "bag of words," disregarding the semantic relationship of words (Zhang et al., 2010). Very small words are very likely either stop words or abbreviations. Both are unwanted words as they are not helpful to model documents in a meaningful way. To reduce this noise, we removed stop words and filtered out words smaller than four characters. For the remainder of the analysis, the "bag of words," containing only informative words from title, keywords, and abstract of each publication, was used to model publications. We call these publication models "documents."

2.3.2. Calculation of the text cosine similarity and creation of the similarity matrix

A similarity matrix is an adjacency matrix which represents a network between publication models based on their word similarity. To create the similarity matrix, we used the documents which resulted from Step 2.3.1. and applied the vector space model (Larsen & Aone, 1999) to these documents. More explicitly, we counted the occurrence of words for each document, and each word corresponded to a dimension in a resulting data space. Each document became a vector consisting of word frequency values on each dimension (i.e., each word).[7] When documents are represented as vectors, we can measure the degree of similarity of two documents as the correlation between their corresponding vectors. This measure is quantified

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7   See file: Schwenke&Holzkaemper_SENA in EG III_VectorRepresentation.pdf (Schwenke & Holzkämper, 2020).

by the cosine of the angle between the two vectors, thus called cosine similarity (Huang, 2008). The similarity network consists of n (number of documents) nodes and n*n similarity links between nodes, weighted by the cosine similarity with possible values between 1 and 0. A cosine similarity of 1 means an identical replication of the document in terms of word occurrence. A similarity link scoring 0 can be excluded from a similarity network, as it means "no similarity at all." For texts of the same language, however, the cosine similarity will almost never be 0. Thus, similarity networks of documents of the same language, and based on the cosine, often result in a network with a density equal 1, which means that every node is linked to every other node. Such a network does not display any structural features. Yet it is our intention to represent the documents in a meaningful network structure. We therefore set a threshold for the level of similarity that we still consider as forming a similarity link. Due to the very specific research question and search query, we assumed that the identified publications already have a high level of similarity—therefore we chose a rather low similarity threshold to still include all relevant relations. The step of selecting the threshold was aided by a visualization of the similarity network. The network started to form distinct clusters at a threshold for the cosine similarity of 0.1, removing links between documents that show less than 10 percent similarity. The value setting of the threshold was sufficiently low to still show important connections between documents. This procedure also produced isolates which no longer shared any connection with the main network. By the logic inherent in the cosine similarity, we assumed that the isolates of the similarity network distinctly differ from the rest of the network in their contents. We read the abstracts of these isolates to assess their relevance for our body of literature. A publication was considered relevant if it addressed S(E)NA as well as EG.

2.3.3. Calculation of the similarity network measures

After importing the similarity matrix into Gephi, we calculated the degree centrality for each document. The degree centrality equals the number of documents with which a document shares a similarity link (Table 1). We detected modules using the modularity optimization algorithm for undirected networks (Blondel et al., 2008) with a resolution setting of 1.0.

2.3.4. Identification of the topic categories

Modules in the similarity network are clusters of documents that share more similarity with each other than with documents in other clusters. To label the modules in a meaningful way, we explored which topic was mainly addressed. The clustering of documents, however, might be influenced by different topic categories which exist in parallel. To extract these topic categories, we took the whole collection of documents and summed up the frequency values of each word across all documents. We discarded those words that occurred less than three times in the whole collection of documents. We manually perused this list and heuristically

defined three different categories of topics: (1) the resources at stake and their uses or threats, (2) governance types, measures, and outcomes, and (3) the spatial reference or level of the study. The topic categories each consist of a list of words assigned to it. All the words that are not part of a topic category list are disregarded in the further topic detection analysis. The list of words assigned to the categories "Resource," "Governance," and "Spatial reference" can be found in Table B of the supplemental material.[8] We searched for word occurrences from each topic category list in each document. As a result, documents were represented by three attributes: one word list per topic category per document. For the remainder of the topic detection analysis, the topic categories were treated separately to distinguish the different levels of content we are interested in.

2.3.5. Detection of topics per module and per topic category with the frequency ranking technique

We developed a process in RapidMiner to detect topics per module and topic category, based on the assumption that frequently occurring words determine topics. We ranked the words in each document attribute by their frequency. We created new attributes for each document which only contained the first- and second-highest ranking words per topic category. We took the attributes of all documents pertaining to a module and defined them as a bag of words for each module in each topic category. We took the bag of words of each module and counted word frequencies. We kept only those words that occurred at least 10 times. These highest ranking words are the most frequent words in a module and thus we considered these words as representing the main topics addressed in it.

2.3.6. Visualization of the similarity network

Citation and similarity networks are two different methodological approaches to a bibliometric analysis of literature and are used to answer different questions. Therefore, we did not explicitly strive for visual coherence between the two network visualizations (e.g., regarding their size, color, modules, etc.).

We visualized the similarity network structure using the "Force Atlas" algorithm in Gephi, with link weights (i.e., cosine similarity) influencing the attraction force between documents. A higher cosine similarity was interpreted as a stronger attraction. To each module, we assigned a different number and color. Each node we labeled with the number of the module it belongs to and colored it accordingly. Larger nodes indicate a higher degree. The thickness of links between documents is proportional to their cosine similarity. The links are colored after their nodes of origin; this means that links connecting nodes of different modules feature a mix of their modules' colors.

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8   See file: Schwenke&Holzkaemper_SENA in EG Tables B&C_TopicCategory WordLists.pdf (Schwenke & Holzkämper, 2020).

We produced one visualization per topic category, labeled the modules according to the main topics they address, and sized the labels proportional to the word frequency. Accounting for distinct sub-clusters in each module, we labeled them with the locally frequent topics: We temporarily labeled single documents with their first- and second-ranked words and thereby could localize accumulations of words. We labeled sub-clusters when the locally accumulating word was among the 10 highest ranking words for the whole module.

2.3.7. Detection of topics with Latent Dirichlet Allocation (LDA)

We used the Latent Dirichlet Allocation (LDA, see Blei et al., 2003) operator in RapidMiner as a parallel method to detect topics in each topic category of the similarity network. Including a second, parallel method gave us the opportunity to complement the topic detection and to corroborate the results found by both methods. LDA is an automated method to identify topics in documents. The method assumes that there are multiple topics addressed in a collection of publications and that each publication can reveal characteristics of several topics. LDA identifies topics by word co-occurrences across publication models. It defines a topic by words that occur frequently across the same set of publication models. LDA then allocates words of the publication model collection to topics and weighs the words by how often they occur in the topic. Each topic is then modeled by a list of descriptive words with their respective weights. LDA might allocate words so that they describe several topics, but with different weights. Topics are modeled by a topic word list. Publications are modeled by a publication word list. By comparing topic word lists with publication word lists, LDA is able to measure the relative influence each topic has on each document. LDA assigns a value between 0 and 1 to each topic, with 0 indicating no influence of the topic model on the publication model and 1 indicating that the publication model is entirely influenced by the respective topic model. This value indicates the topic by which a publication can be best assigned, thus called confidence value.

Typically, LDA is applied to detect topics of single documents in a collection of documents. Our intention, however, was to detect topics for modules and not for single documents. For our use of the LDA operator, a topic category thus equaled a collection of documents, while each module equaled a document. We set the "number of topics" parameter according to the number of modules identified with the modularity optimization algorithm in Gephi. We used alpha and beta heuristics and the setting "optimize hyperparameters."[9] From the topic word lists identified

9   Alpha and beta are hyperparameters that define how much either a document is allowed to be associated with more than one topic or a word is allowed to be associated with more than one topic. Alpha influences the number of topics per document, while beta influences the number of words per topic. In practice, a high alpha value will lead to documents being more similar in terms of what topics they contain. A high beta value will similarly lead to topics being more similar in terms of the words they contain. RapidMiner gives the option to optimize the hyperparameters alpha and beta during every iteration. This means that documents are likely to contain a mixture of most of the topics, but could also display a specific topic distribution.

with LDA, we kept those words that occurred at least 10 times to describe a topic. A complete list of the topics identified by LDA and the five highest weighted words can be found in Table C of the supplemental material.[10] Table 6 (A–C) in the Results section shows the confidence value tables, indicating the allocation of topics across each module and of modules across each topic. The values indicate the confidence by which a module is influenced by a certain topic. The values also indicate to which module a topic can be best assigned.

3. Results

Between the vast amount of literature from the field of EG (>69,000 articles) and the considerable amount of S(E)NA literature (>5,000 articles), there is an intersection of 241 articles (Figure 2). The list of all 241 publications and their topics is provided in Table D of the supplemental material.[11] Figure 2 indicates that although this intersection is still proportionally very small compared to the EG and S(E)NA fields (0.3 percent and 4.7 percent respectively), there is a continuous increase of articles that apply or discuss the application of S(E)NA in EG contexts in the last decade (Figure 3).
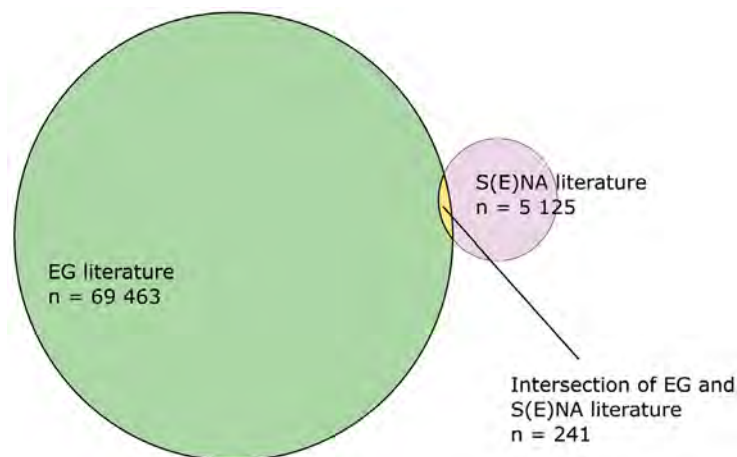

Figure 2. Schematic representation of the bodies of scientific literature addressing (A) EG (green), (B) S(E)NA (violet), and (C) their intersection (yellow).

Note: The size of circles and their intersection is proportional to the absolute number of articles (*n*) attributed to the different bodies of literature.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters) and includes literature from the earliest record until the end of 2018.

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10 See file: Schwenke&Holzkaemper_SENA in EG Tables B&C_TopicCategory WordLists.pdf (Schwenke & Holzkämper, 2020).
11 See file: Schwenke&Holzkaemper_SENA in EG Table D_PublicationList.csv (Schwenke & Holzkämper, 2020).
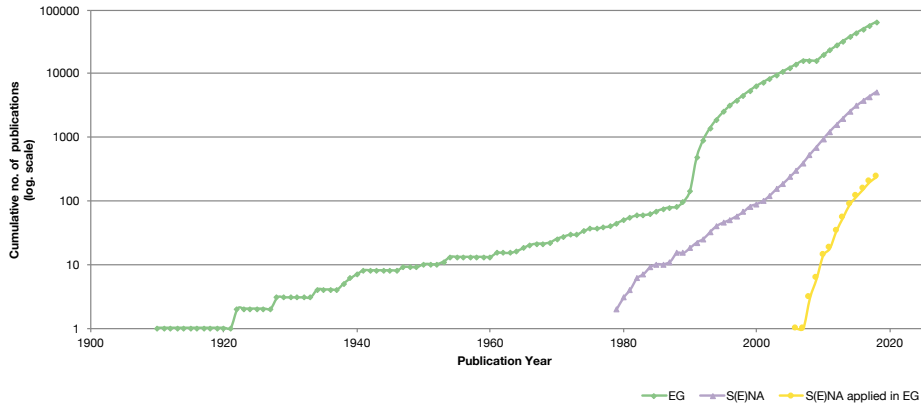
Figure 3. Development of scientific literature addressing EG, S(E)NA, and both research fields in combination.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).

3.1. Descriptive statistics for the citation and similarity networks

The citation network comprises 241 nodes (= publications); of these, 122 are isolates and 15 form small components (dyads and triads) not connected with the main network component. The main component consists of 104 articles which are connected by 173 citation links (Table 2).

The similarity network comprises the same 241 nodes, but it greatly differs from the citation network in the composition of links. The procedure to reduce density by applying a threshold of 10 percent cosine similarity cut off 16 articles from the network, which then became isolates (Table 3). From these publications, 7 were not related to the application of S(E)NA in EG, while 9 were assessed as relevant, among them highly relevant publications such as Scott (2015) and Schoon et al. (2017).

Table 2. Network metrics for the citation and similarity networks from scientific literature applying S(E)NA in EG.

Network metrics	Citation network	Similarity network
Total no. of publications	241	241
No. of isolates or small components	137	16
Network metrics of main component		
No. of publication nodes	104	225
No. of links	173	1,904
Density	0.013	0.038
Max. Authority score	0.49	–

Network metrics	Citation network	Similarity network
Max. Hub score	0.31	–
Max degree	13	60
Max. betweenness centrality	24.83	1,526
No. of modules	9	9

Note: S(E)NA = social (–ecological) network analysis; EG = environmental governance.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).

Table 3. Isolates of the similarity network of scientific literature applying S(E)NA in EG, and their contents.

Isolated article	Content	Relevant?
Alexander (2012)	Brownfield remediation and redevelopment projects as social networks	yes
Chen et al. (2018)	Sustainable resource flows in entrepreneurial networks	yes
Holmes et al. (2017)	Supportive networks for threatened bird species conservation	yes
Kreakie et al. (2016)	Conservation alliance network	yes
Le et al. (2018)	Stakeholder networks of sustainable waste management	yes
Ngaruiya (2015)	Application of SNA to analyze medicinal plant conservation governance	yes
Ramirez et al. (2018)	Use of SNA to explain inclusion of small agri-food producers	yes
Scott (2015)	SNA application in environmental governance	yes
Schoon et al. (2017)	EG networks	yes
Datta et al. (2012)	IBM's jazz initiative	no
Fazekas & Toth (2016)	State capture and corruption	no
Gluckler & Ries (2012)	Philanthropy	no
Ireni-Saban & Borohowitch (2017)	Embryonic stem cell research	no
Kinsella (2014)	Small arms illegal trade	no
Sciarini (2014)	Swiss consensus democracy	no
Sohn & Giffinger (2015)	Cross-border metropolitan governance	no

Note: S(E)NA = social (–ecological) network analysis; EG = environmental governance.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters). Complete references can be found in the supplemental material.[12]

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12   See file: Schwenke&Holzkaemper_SENA in EG Table D_PublicationList.csv (Schwenke & Holzkämper, 2020).

3.2. Citation network

Figure 4 (A–C) shows network visualizations of the main components of the citation network of literature applying S(E)NA in EG. (A) highlights sources (authority), (B) highlights storers (hub), and (C) highlights bridges (betweenness centrality) of knowledge. In total, we identified 20 of 241 publications with central positions as either sources, storers, or bridges of knowledge in the citation network. Of these 20 central publications, two stand out in terms of several of our measures. The content analysis of the 20 most central publications showed that eight feature "management/planning/policy," seven feature water related topics ("water," "river," "coastal," "marine") and six feature "collaboration." For further discussion, we included those publications that showed noticeably higher values than the other references: the eight publications with the highest HITS values (authorities and hubs), and the seven publications with the highest betweenness centralities (Table 4). Nearly all publications that occupy bridging positions (six of these seven) mention "collaboration" in their titles. "Collaboration" is not mentioned in the titles of the publications that rank highly in authority and hub values.

The most prominent structural roles in the citation network are occupied by Fliervoet et al. (2016) and Mills et al. (2014). These publications attain high values in betweenness centrality and authority (Mills et al., 2014), or in all three of the calculated measures (Fliervoet et al., 2016). The publication by Mills et al. (2014) occupies a relatively central hub position within the citation network as well (hub score = 0.14), even though it is not among the highest ranking hubs. In their publication, Mills et al. (2014) explain three potential contributions SNA has to offer to conservation planning: (1) identifying stakeholders and their roles, (2) purposefully creating and facilitating links, and (3) prioritizing conservation action by using social connectivity along with ecological data. They describe SNA as a valuable tool for conservation, which supports decision-making, copes with challenges, and is useful to design future research actions.

Fliervoet et al. (2016) is among the publications ranking highest in terms of authority, hub, and betweenness centrality values. This publication gives a detailed description of relevant network metrics and a comprehensive overview of the theories behind natural resource governance. Furthermore, Fliervoet et al. (2016) explain the consequences of removing central actors from natural resource governance networks.

Most nodes that occupy structurally important positions in the citation network are associated to the Modules 5 (light green) and 6 (violet). Module 5 encompasses two (of eight) of all authorities, three (of eight) of all hubs, and two (of seven) of all publications with a high betweenness centrality. Module 6 assembles three (of eight) of all authorities, four (of eight) of all hubs and two (of seven) of all publications with a high betweenness centrality. In Table 5, we list the ten publications cited most often by the 241 publications applying SNA in EG, including the number of

times they have been cited. Six of these ten publications are about theories, methods and tools for the analysis of social networks (Wasserman & Faust, 1994; Borgatti et al., 2002; Freeman, 1978; Granovetter, 1973; Hanneman & Riddle, 2005; Scott, 2000), one deals with governance theory (Ostrom, 1990), and three publications address the central topic of this article: the application of S(E)NA in EG (Bodin & Crona, 2009; Prell et al., 2009; Folke et al., 2005).
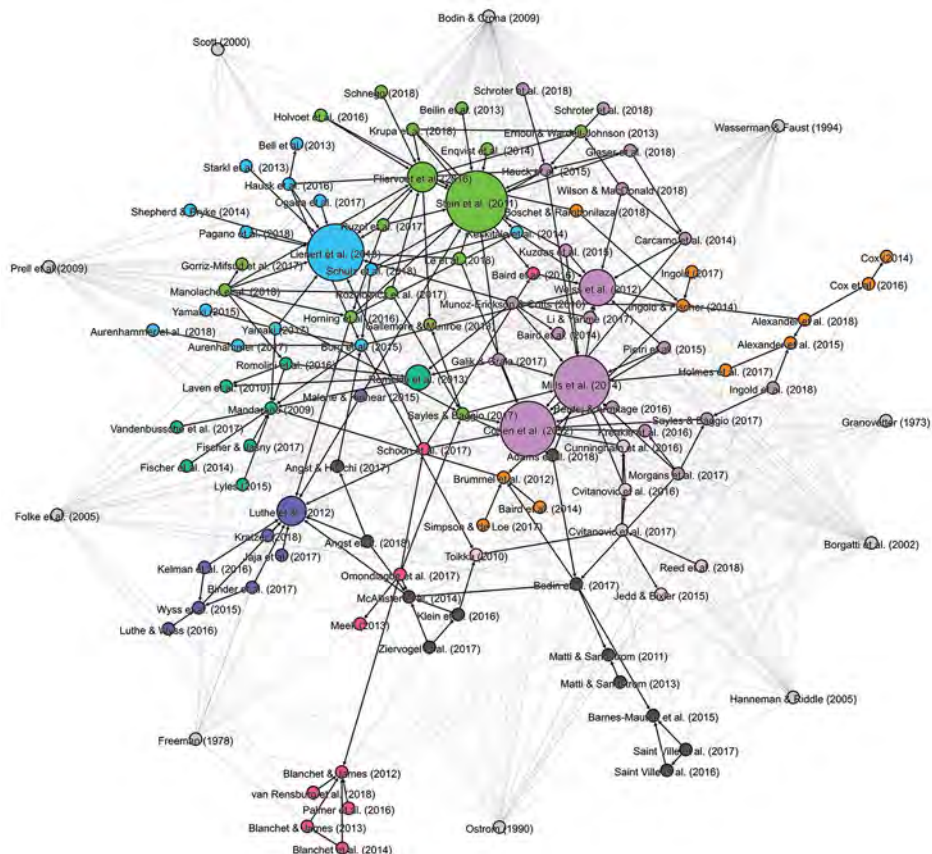

Figure 4A. Citation network of the scientific literature applying S(E)NA in EG: sources (authority score, *n* = 8).

Note: Figure 4 (A–C). Citation network of the scientific literature applying S(E)NA in EG. Includes the 10 most-cited references (light gray) that are cited but are not among the results of the literature search; thus they are not considered parts of the citation network. Node color indicates modules, calculated using Gephi (Bastian et al., 2009). The highest ranking publications, regarding their influence as (A) sources (authority score, *n* = 8), (B) storers (hub score, *n* = 8), and (C) bridges (betweenness centrality, *n* = 7) of knowledge, are sized according to their values. All other nodes are visualized by a minimum size.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).
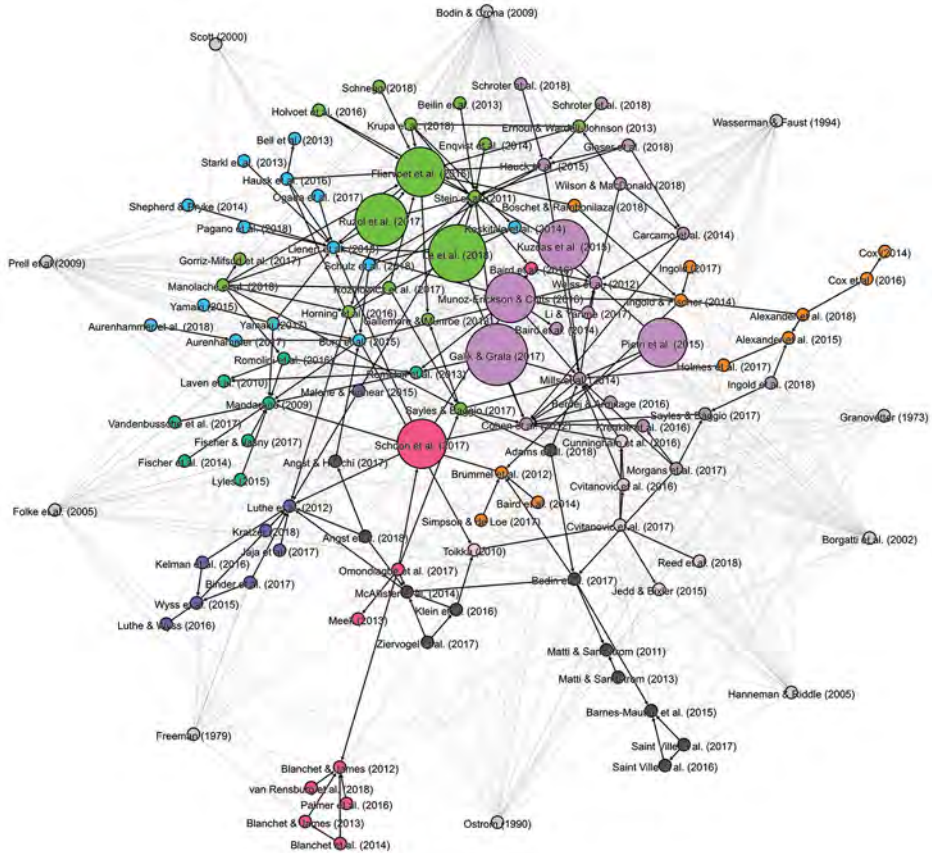
Figure 4B. Citation network of the scientific literature applying S(E)NA in EG: storers (hub score, *n* = 8).

Note: Figure 4 (A–C). Citation network of the scientific literature applying S(E)NA in EG. Includes the 10 most-cited references (light gray) that are cited but are not among the results of the literature search; thus they are not considered parts of the citation network. Node color indicates modules, calculated using Gephi (Bastian et al., 2009). The highest ranking publications, regarding their influence as (A) sources (authority score, *n* = 8), (B) storers (hub score, *n* = 8), and (C) bridges (betweenness centrality, *n* = 7) of knowledge, are sized according to their values. All other nodes are visualized by a minimum size.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).

Figure 4C. Citation network of the scientific literature applying S(E)NA in EG: bridges (betweenness centrality, *n* = 7).

Note: Figure 4 (A–C). Citation network of the scientific literature applying S(E)NA in EG. Includes the 10 most-cited references (light gray) that are cited but are not among the results of the literature search; thus they are not considered parts of the citation network. Node color indicates modules, calculated using Gephi (Bastian et al., 2009). The highest ranking publications, regarding their influence as (A) sources (authority score, *n* = 8), (B) storers (hub score, *n* = 8), and (C) bridges (betweenness centrality, *n* = 7) of knowledge, are sized according to their values. All other nodes are visualized by a minimum size.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).
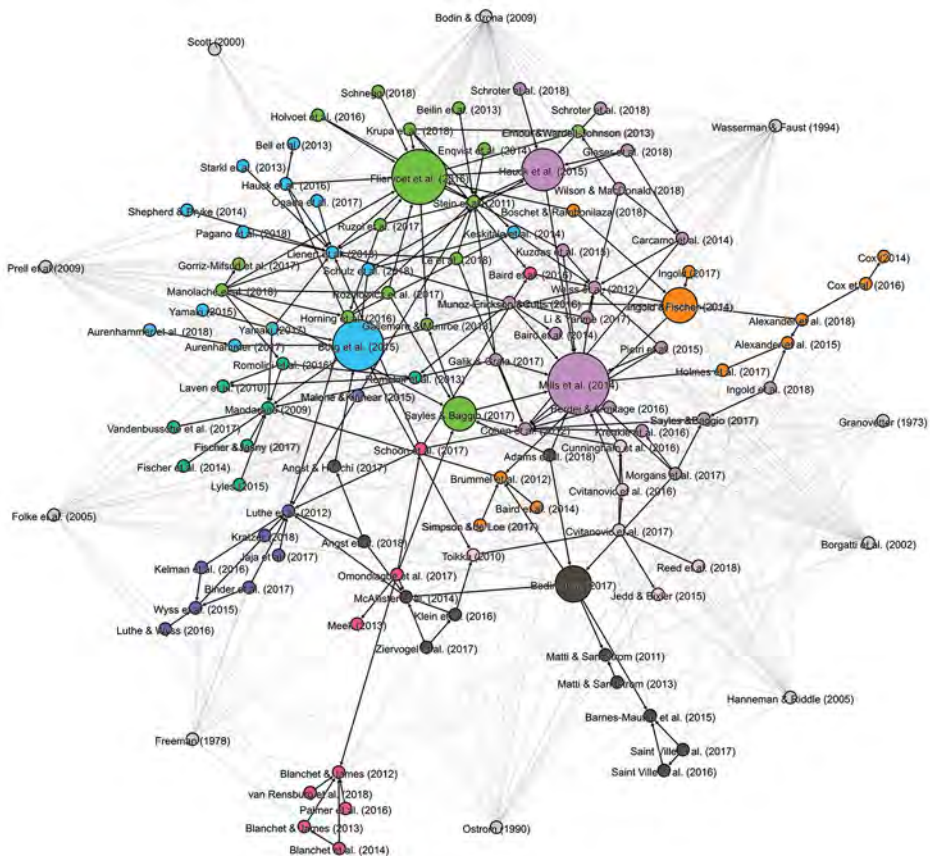
Table 4. Publications representing authorities, hubs, and bridges (betweenness centrality; BC) of knowledge in the citation network of scientific literature applying S(E)NA in EG.

Author (year)	Title	BC	Authority	Hub
Bodin et al. (2017)	Collaborative Networks for Effective Ecosystem-Based Management: A Set of Working Hypotheses	12.00	0.05	0.01
Borg et al. (2015)	Social Capital and Governance: A Social Network Analysis of Forest Biodiversity Collaboration in Central Finland	19.50	0.07	0.07
Cohen et al. (2012)	Social Networks Supporting Governance of Coastal Ecosystems in Solomon Islands	0.00	0.42	0.00
Fliervoet et al. (2016)	Analyzing Collaborative Governance Through Social Network Analysis: A Case Study of River Management Along the Waal River in The Netherlands	21.50	0.17	0.23
Galik & Grala (2017)	Conservation Program Delivery in the Southern US: Preferences and Interactions	0.00	0.00	0.31
Hauck et al. (2015)	Seeing the Forest and the Trees: Facilitating Participatory Network Planning in Environmental Governance	15.00	0.07	0.19
Ingold & Fischer (2014)	Drivers of Collaboration to Mitigate Climate Change: An Illustration of Swiss Climate Policy over 15 Years	11.50	0.07	0.05
Kuzdas et al. (2015)	Integrated and Participatory Analysis of Water Governance Regimes: The Case of the Costa Rican Dry Tropics	0.00	0.00	0.24
Le et al. (2018)	Understanding the Stakeholders' Involvement in Utilizing Municipal Solid Waste in Agriculture through Composting: A Case Study of Hanoi, Vietnam	0.00	0.00	0.29
Lienert et al. (2013)	Stakeholder Analysis Combined with Social Network Analysis Provides Fine-grained Insights into Water Infrastructure Planning Processes	0.00	0.44	0.00
Luthe et al. (2012)	Network Governance and Regional Resilience to Climate Change: Empirical Evidence from Mountain Tourism Communities in the Swiss Gotthard Region	0.00	0.17	0.00
Mills et al. (2014)	Linking Regional Planning and Local Action: Towards Using Social Network Analysis in Systematic Conservation Planning	24.83	0.43	0.14
Muñoz-Erickson & Cutts (2016)	Structural Dimensions of Knowledge–Action Networks for Sustainability	9.00	0.01	0.24
Pietri et al. (2015)	The Coral Triangle Initiative and Regional Exchanges: Strengthening Capacity through a Regional Learning Network	0.00	0.00	0.23
Romolini et al. (2013)	Assessing and Comparing Relationships between Urban Environmental Stewardship Networks and Land Cover in Baltimore and Seattle	6.00	0.13	0.02
Ruzol et al. (2017)	Understanding Water Pollution Management: Evidence and Insights from Incorporating Cultural Theory in Social Network Analysis	0.00	0.00	0.25

Author (year)	Title	BC	Authority	Hub
Sayles & Baggio (2017)	Who Collaborates and Why: Assessment and Diagnostic of Governance Network Integration for Salmon Restoration in Puget Sound, USA	11.00	0.08	0.20
Schoon et al. (2017)	The Emergence of an Environmental Governance Network: The Case of the Arizona Borderlands	3.50	0.01	0.23
Stein et al. (2011)	A Social Network Approach to Analyzing Water Governance: The Case of the Mkindo Catchment, Tanzania	0.00	0.49	0.00
Weiss et al. (2012)	Knowledge Exchange and Policy Influence in a Marine Resource Governance Network	0.00	0.24	0.00

Note: As shown in the network representation in Figure 4. Gray shaded boxes indicate top ranked values. Publications are highlighted by shades of gray and thick lines when they are among the highest ranking articles in more than one of the three measures. BC = betweenness centrality; S(E)NA = social (–ecological) network analysis; EG = environmental governance.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters). Complete references can be found in the supplemental material.[13]

Table 5. Ten publications cited most often by the main cluster of the citation network emerging between scientific literature applying S(E)NA in EG. The publications we list are cited by but are not part of the citation network under consideration.

Author (year)	Title	In-degree
Wasserman & Faust (1994)	Social Network Analysis: Methods and Applications	100
Bodin & Crona (2009)	The Role of Social Networks in Natural Resource Governance: What Relational Patterns make a Difference?	98
Borgatti et al. (2002)	UCINET for Windows: Software for Social Network Analysis	78
Freeman (1978)	Centrality in Social Networks Conceptual Clarification	55
Prell et al. (2009)	Stakeholder Analysis and Social Network Analysis in Natural Resource Management	52
Folke et al. (2005)	Adaptive Governance of Social–ecological Systems	51
Granovetter (1973)	The Strength of Weak Ties	50
Hanneman & Riddle (2005)	Introduction to Social Network Methods	44
Ostrom (1990)	Governing the Commons: The Evolution of Institutions for Collective Action	43
Scott (2000)	Social Network Analysis: A Handbook	33

Note: S(E)NA = social (–ecological) network analysis; EG = environmental governance.

Source: Authors' summary.

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13   See file: Schwenke&Holzkaemper_SENA in EG Table D_PublicationList.csv (Schwenke & Holzkämper, 2020).

3.3. Similarity network

Figure 5 (A–C) shows network visualizations of the main component of the similarity network mapping the literature applying S(E)NA in EG and the topics addressed by its modules, as identified using the frequency ranking technique. Table 6 gives the topics as identified by the LDA technique, labeled with the first and second ranking words. Each figure and table is divided by topic category: (A) "Resources," (B) "Governance," and (C) "Spatial references." Using the frequency ranking technique, we could assign topics to eight of the modules in the "Resource" category, whereas we only found six topics in the "Governance" and the "Spatial reference" categories. In category (A) "Resources," the frequency ranking technique results in the topics "water," "climate," and "forest" for Modules 5, 6, and 0 respectively. Each of these modules features a distinct topic, identified by a very high occurrence of topics commonly addressed in the modules' publication models. In the "water" module, we also find a sub-cluster dealing with energy generation and in the "climate" module, there is a sub-cluster on tourism. Apart from the overarching distinct topic "climate," Module 6 also includes subtopics like "learning" and "capital." Modules 3, 8, 1, and 4 exhibit "ecosystem," "health," "fisheries," and "flood/disaster" as shared highest ranking publication topics respectively. However, these modules have less distinct topics. Both the "ecosystem" and "fisheries" modules also often feature the term "knowledge" ("fisheries" also "communication"). Module 7 differs from the other modules in that it does not represent a single influential topic, but several, less prominent topics. It is likewise influenced by the topics "food," "biodiversity," "innovation," "capacity," and "education." In the "Governance" category, the most distinct module is Module 1, which is mainly influenced by "collaboration" and "conservation." Several topics are repeated across modules: Module 5 is also assigned to the "collaboration" topic and Modules 0 and 7, and a sub-cluster of Module 6, are assigned to the topic "policy." Module 6 is strongly influenced by the topic "adaptation" (including a sub-cluster influenced by "resilience" and "change"). These topics occur only in Module 6. The category (C) "Spatial reference" is dominated by the topic "local," which is a shared publication topic across all modules. The "local" topic influences Modules 5, 1, and 6 to a high level, either exclusively (Module 5), or in combination with other spatial references (Module 1 "local/ marine" and Module 6 "local/ regional"). Both Modules 0 and 7 are separated into sub-clusters; they both feature the "local" topic toward the core of the network, and feature different topics toward the periphery of the network: "countries/national" (Module 0) and "international/ global" (Module 7). Module 3 distinguishes itself by a distinct "urban" topic, which is also unique for the whole network in this topic category.
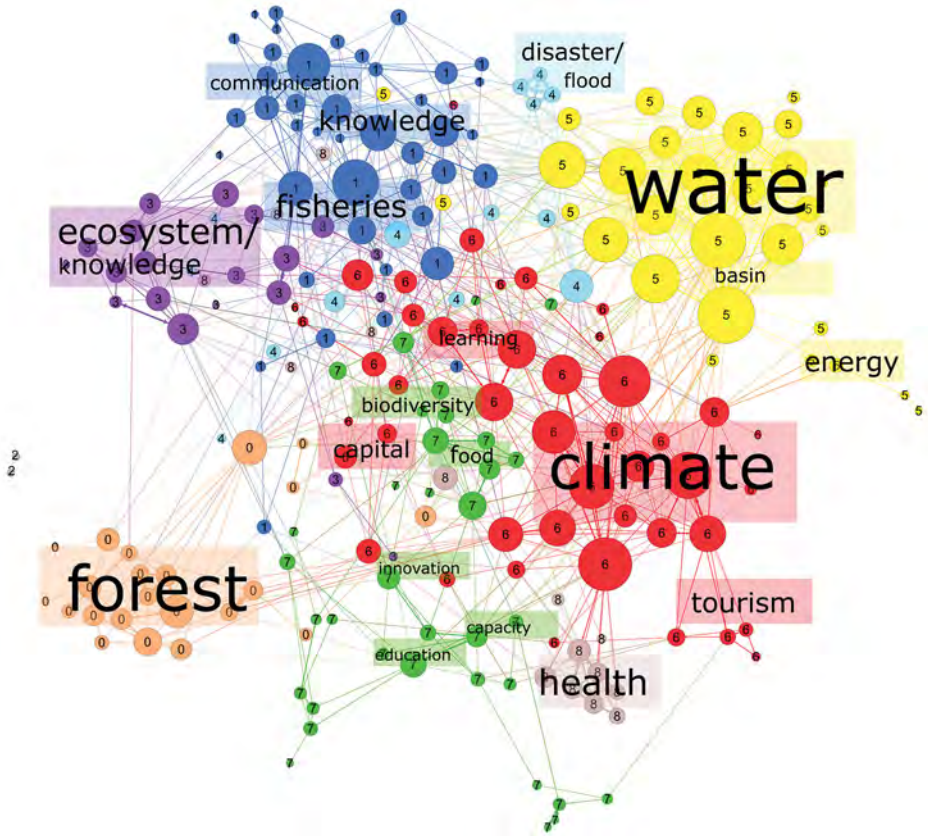
Figure 5A. Similarity network for the category "Resources."

Note: Figure 5(A–C). Similarity network for the category (A) "Resources," and (C) "Spatial reference" categories. Nodes are publication models: links indicate text similarity between publication models above a cosine similarity threshold of 0.1. The thickness of links between publication models is proportional to their cosine similarity. Link color equals node color; links connecting two differently colored nodes display a mixed color. Nodes are sized after the degree measure, indicating the number of articles with which the node shares a similarity link. We numbered modules starting with 0. Module labels are sized according to word frequency.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).
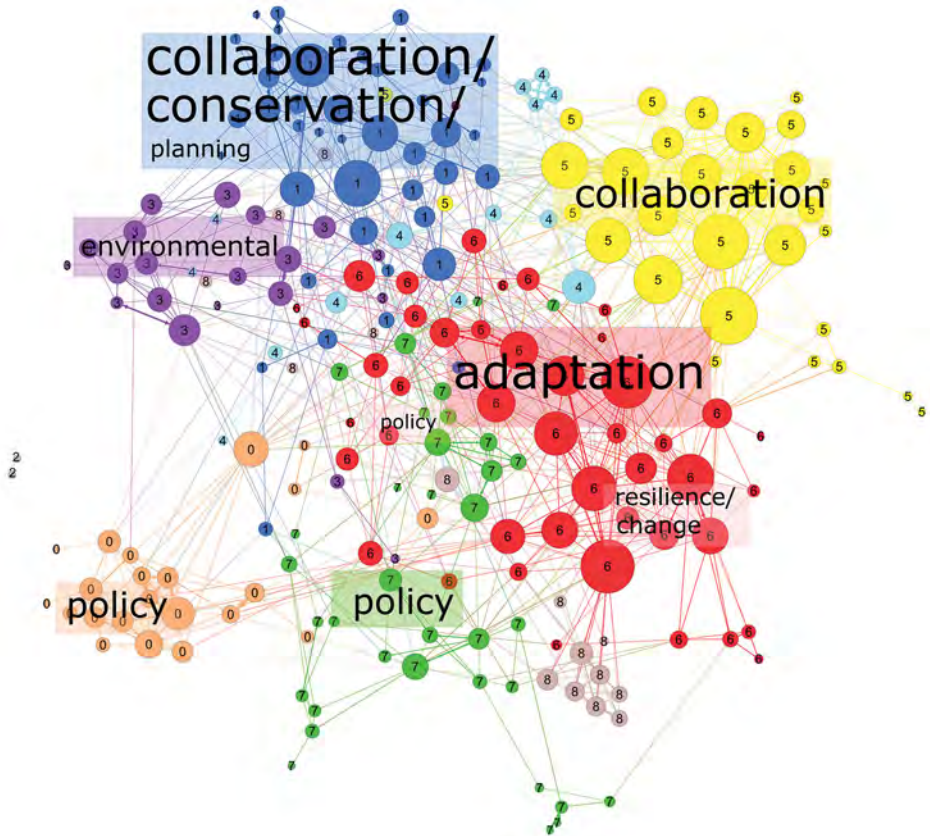
Figure 5B. Similarity network for the category "Governance."

Note: Figure 5(A–C). Similarity network for the category (A) "Resources," (B) "Governance," and (C) "Spatial reference" categories. Nodes are publication models: links indicate text similarity between publication models above a cosine similarity threshold of 0.1. The thickness of links between publication models is proportional to their cosine similarity. Link color equals node color; links connecting two differently colored nodes display a mixed color. Nodes are sized after the degree measure, indicating the number of articles with which the node shares a similarity link. We numbered modules starting with 0. Module labels are sized according to word frequency.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).

We detected topics with the LDA method and found that in several cases, words that describe a LDA topic are similar to or match words that describe a topic after the frequency ranking technique. Table 6 (A–C) shows the topics for each topic category, as detected by the LDA method (top) and the frequency ranking technique (left; numbers indicate the respective module to which the topic is assigned). We only considered words with weights of nine and higher as LDA topic descriptions—thus, rejected complete topics where the word weights of each topic-describing word is below nine. Matches between the two methods, indicated by shared topic-describing words, are set in bold script. The brackets under the LDA topic give the number of the module(s) whose topic as identified by the frequency

ranking technique matches the respective LDA topic by having one or more topic-describing words in common. Values indicate the influence a topic has on the content of a module (confidence value), thereby visualizing the distribution of LDA topics across all modules. Darker colors were used to visualize highest confidence. Comparing values column-wise informs about the composition of a specific module by different LDA topics; comparing values per rows informs about the attribution of different modules to a specific LDA topic. Black boxes indicate that, for this module, the topic detected by the frequency ranking method coincides with the highest LDA confidence per topic. The total value under each topic indicates how much the complete topic category is influenced by the respective topic.
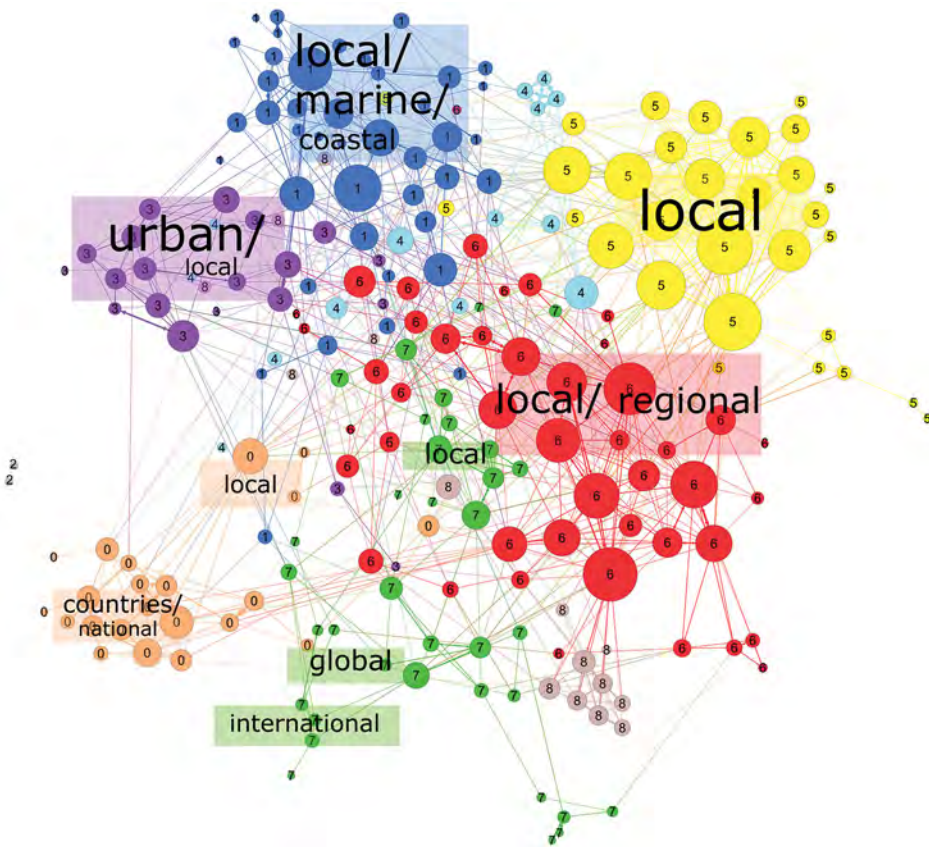

Figure 5C. Similarity network for the category "Spatial reference."

Note: Figure 5(A–C). Similarity network for the category (A) "Resources," (B) "Governance," and (C) "Spatial reference" categories. Nodes are publication models: links indicate text similarity between publication models above a cosine similarity threshold of 0.1. The thickness of links between publication models is proportional to their cosine similarity. Link color equals node color; links connecting two differently colored nodes display a mixed color. Nodes are sized after the degree measure, indicating the number of articles with which the node shares a similarity link. We numbered modules starting with 0. Module labels are sized according to word frequency.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).

The LDA technique detected nine topics in the "Resources" category, eight topics in the "Governance" category and seven in the "Spatial reference" category. In category (A) "Resources," LDA identified topics with a high resemblance to those identified with the frequency ranking technique (see Figure 5). LDA confirms the assignment of modules to topics detected with the frequency ranking technique in nearly all cases: Module 0 = "forest," 1 = "fisheries," 4 = "flood," 5 = "water, basin," 6 = "climate, capital," and 7 = "innovation, food." While Module 8 exhibits a high confidence score for the "health" topic, Module 7 turns out to be even more influenced by the "health" topic than Module 8. Considering the word matches, Module 3 indicates a good fit with the topic "knowledge, ecological, learning, fisheries, diversity," yet Module 6 ("climate") turns out to be more influenced by this topic than Module 3. Module 3, however, can be best attributed to the topic "information, influence, power, support, ecosystem." This also resonates with the attribution of Module 3 to the topic "ecological, knowledge" by the frequency ranking technique. It is noteworthy that the "information, influence, power, support, ecosystem" topic is prevalent with very high confidence values in all modules, reaching the highest total confidence value (3.234) for the category "Resources." In category (B) "Governance," one topic that LDA detects cannot be interpreted due to low word weights. The remaining eight topics resemble those detected with the frequency ranking method by having one or more topic-describing words in common (Figure 5). The confidence values for these topics indicate a good fit with the topic assignment by the frequency ranking method in three cases: Module 0 = "policy," 1 = "collaboration, conservation," and 6 = "change, adaptation." "Policy" is identified as a module-crossing theme with the frequency ranking method, and the frequency of "policy" as a shared topic-describing word and the high confidence value of the topic "policy, environment, framework, government, development" across all modules agrees with this finding (total confidence value of 2.828). A similarly high confidence value across all modules can be found for the topic "stakeholder(s), collaborative, conservation, organization" (total value of 2.315). Topic analysis of the "Spatial reference" category reveals the importance of the topic "local" for all modules with both the ranking and the LDA method (total confidence value of 3.314), reaching its highest value in Module 6 ("climate"/"adaptation"). LDA also corroborates the assignment of the following modules: 1 = "coastal, marine," 3 = "urban," and 7 = "international." While the frequency ranking method detects the highest occurrence of shared attributes for Module 3 in the "Spatial reference" category, LDA detects the highest confidence value for Module 3 in the "Resources" category.

Table 6 (A–C). Confidence values to evaluate how much a module in a similarity network of literature applying S(E)NA in EG is influenced by the topics detected with the LDA technique in the topic categories (A) "Resources," (B) "Governance," and (C) "Spatial reference."

(A) "Resources"

Module and frequency ranking topic	LDA topic								
	forest (0)	natural, fisheries (1)	knowledge, ecological, learning, fisheries, diversity (1, 3, 6)	information, influence, power, support, ecosystem (3)	flood(s) (4)	water, river, supply, basin (5)	capacity, climate, natural, capital (6, 7)	innovation, food, agriculture, farmers/ing (7)	health (8)
0 – forest	0.202	0.027	0.111	0.406	0.003	0.033	0.168	0.033	0.018
1 – fisheries, knowledge, communication	0.018	0.223	0.201	0.346	0.002	0.033	0.113	0.047	0.017
2 – low count	0.042	0.060	0.156	0.354	0.007	0.073	0.170	0.085	0.052
3 – ecosystem, knowledge	0.026	0.043	0.214	0.448	0.003	0.053	0.120	0.068	0.025
4 – disaster, flood	0.022	0.025	0.141	0.331	0.189	0.091	0.129	0.038	0.034
5 – water, energy, basin	0.008	0.025	0.068	0.326	0.002	0.288	0.198	0.040	0.045
6 – climate, tourism, capital, learning	0.020	0.086	0.242	0.272	0.002	0.034	0.258	0.057	0.029
7 – food, biodiversity, innovative, capacity, education	0.018	0.028	0.117	0.342	0.002	0.036	0.158	0.209	0.091
8 – health	0.022	0.039	0.173	0.408	0.004	0.046	0.187	0.032	0.089
Total	0.377	0.556	1.422	**3.234**	0.213	0.688	1.501	0.608	0.402

(B) "Governance"

Module and frequency ranking topic	policy, environment, framework, government, development (0, 3, 6, 7)	stakeholder(s), collaborative, conservation, organization (1, 5)	change, adaptation, policies, involved, traditional (1, 6, 7)	political, science (scientist) policy (0, 6, 7)	power, political, sustainable, economic	co-management, legitimacy, common (s)	adaptive, challenges, framework, individuals, participants (6)	coordination, changes (6)	low weights
0—policy	0.372	0.149	0.068	0.007	0.187	0.022	0.036	0.144	0.015
1—collaboration, conservation, planning	0.244	0.452	0.046	0.003	0.072	0.084	0.074	0.009	0.015
2—low count	0.362	0.257	0.113	0.011	0.109	0.031	0.070	0.032	0.014
3—environmental	0.308	0.259	0.131	0.078	0.121	0.028	0.054	0.012	0.008
4—low count	0.333	0.198	0.130	0.011	0.171	0.043	0.076	0.033	0.005
5—collaboration	0.321	0.315	0.122	0.004	0.101	0.028	0.065	0.030	0.014
6—adaptation, resilience, change, policy	0.316	0.187	0.197	0.002	0.055	0.068	0.124	0.032	0.019
7—policy	0.310	0.198	0.152	0.051	0.166	0.021	0.038	0.059	0.005
8—low count	0.262	0.299	0.123	0.007	0.094	0.015	0.080	0.029	0.090
Total	**2.828**	**2.315**	1.083	0.175	1.075	0.341	0.617	0.381	0.185

(C) "Spatial reference"	LDA topic								
Module and frequency ranking topic	national, cities (0, 3)	marine (1)	coastal, global (1)	countries, rural, urban (0, 3)	region(s)/regional, local, Australia (0, 1, 3, 5, 6, 7)	international, European (7)	Europe	low weights	low weights
0 – local, countries, national	0.169	0.084	0.069	0.14	0.334	0.089	0.09	0.011	0.014
1 – local, marine, coastal	0.097	0.119	0.106	0.114	0.396	0.092	0.049	0.018	0.009
2 – low count	0.135	0.064	0.081	0.15	0.366	0.109	0.059	0.023	0.014
3 – urban, local	0.164	0.063	0.061	0.176	0.325	0.116	0.059	0.017	0.02
4 – low count	0.124	0.048	0.1	0.158	0.356	0.118	0.055	0.024	0.017
5 – local	0.146	0.043	0.075	0.139	0.381	0.128	0.065	0.011	0.013
6 – local, regional	0.116	0.054	0.092	0.135	0.432	0.104	0.051	0.009	0.008
7 – local, global, international	0.144	0.039	0.081	0.172	0.346	0.131	0.062	0.016	0.009
8 – low count	0.128	0.048	0.072	0.167	0.378	0.122	0.054	0.019	0.011
Total	1.223	0.562	0.737	1.349	3.314	1.009	0.543	0.149	0.114

Note: Word matches between topic descriptions detected by the LDA and by the frequency ranking method are highlighted in bold. The highest confidence values per LDA topic are boxed where the topic matches those detected by the frequency ranking technique. Higher confidence values are indicated by darker color. S(E)NA = social (–ecological) network analysis; EG = environmental governance.

Source: Authors' summary. Data were collected on January 22, 2019, using the Web of Science database (ISI Thomson Reuters).

4. Discussion

4.1. Bodies of literature and histogram

What has been observed as an overwhelming increase in the number of scientific literature within the second half of the last century (Cummings, 1973) and is today culminating in a "publication explosion" (Ware & Mabe, 2015) is mirrored in the strong rise of all three histograms of scientific fields we represent in Figure 3 from approximately 1980 onwards. While the fields of EG and S(E)NA began to rise in 1910 and 1979 respectively, we find the first record of the application of S(E)NA in EG fairly late, in 2006. The application of S(E)NA in EG is, compared to both research fields observed separately, still nascent and developing. The increasing number of studies applying S(E)NA in EG could imply an increasing importance of network approaches to support and inform decision-making in EG.

4.1.1. Limitations of our approach to data collection

During data collection, we may have failed to detect all relevant literature with our search because: (1) we consulted only one database (Web of Science), which represents only a selection of the literature available; (2) our search terms might fail to target a relevant article because the database is missing entries (e.g., missing keywords), or (3) our search terms might fail to match with any word in the abstract, title, or keywords of a relevant article. The articles by Bodin and Crona (2009), Prell et al. (2009), and Folke et al. (2005) provide good examples for this phenomenon. These publications are of high importance to the investigated field of research, S(E)NA in EG, but not listed under the Web of Science results from our search query, as they are not included in the Web of Science selection of journals.

Web of Science results may vary according to an array of conditions. The same query conducted in different libraries or research institutions may produce different search results, due to differences in access. On top of the time lag between the publication of an article and its actual entry in scientific databases, and the selection of journals and articles each database includes (or not), the problem of differences in access further adds to the difficulty of reliably reproducing bibliometric studies.

4.2. Citation network

From the 241 publications resulting from our search regarding the application of S(E)NA in EG, only 104 publications cite each other. This means that less than half of the publications influence or are influenced by one or more publications within this field of research. The high number of isolates indicates that the application of S(E)NA in EG is only just beginning to develop into an actual subfield in which publications widely and routinely refer to each other and thus create a distinct field (Zhuge, 2016, Chapter 8). This is corroborated by the fact that authorities in the

field (Table 4) are relatively recently published (2012 onwards), although one would expect older papers to be the most frequently cited—due to the higher chance of a paper being cited the longer ago it has been published (Adams, 2005).

Investigating the 10 most frequently cited "non-matching" publications revealed that the field S(E)NA in EG is building on literature addressing theories of EG as well as social network theory. Additionally, works that provide practical applications of the analysis of social networks (e.g., software, handbooks) have proven to be of great importance for the emergence of the field (see Figure 4 and Table 5).

The publications included in the citation network contribute the following discoveries and discussions to the field: the effect of social networks on governance capacity (Stein et al., 2011), the combination of SNA with stakeholder analysis (Lienert et al., 2013), the importance of SNA in planning processes (Mills et al., 2014), the use of network analysis in adaptive co-management to facilitate coordination and learning (Cohen et al., 2012), the impact of social networks on resilience and complex resource management (Weiss et al., 2012), the role of central organizations in natural resource governance networks (Fliervoet et al., 2016), the role of socioeconomic–ecological networks for system resilience facing climate change (Luthe et al., 2012), and the relationship between environmental conditions and environmental stewardship networks (Romolini et al., 2013). We assume that these discussions and lines of thought will remain central in the formation of the emerging research field S(E)NA in EG.

Due to their position as hubs in the citation network, several publications can be considered as important storers of knowledge: Galik and Grala (2017), Le et al. (2018), Ruzol et al. (2017), Kuzdas et al. (2015), Muñoz-Erickson and Cutts (2016) Fliervoet et al. (2016), Schoon et al. (2017), and Pietri et al. (2015). They provide a good overview about theory and development of applying S(E)NA in EG. As the hubs are situated closer toward the core of the observed citation network than the authorities, we assume that the authors of these articles are at the moment the best informed ones within the field and thus are able to refer to many different colleagues.

We identify the publications written by Mills et al. (2014), Fliervoet et al. (2016), Borg et al. (2015), Hauck et al. (2015) Bodin et al. (2017), Ingold and Fischer (2014), and Sayles and Baggio (2017) as bridges of knowledge. These publications link different, otherwise unconnected parts of the research field S(E)NA in EG and are important for the formation of a distinct and well-connected field of research, where different theories and lines of thought relate to and inspire each other. As the observed citation network is not very clustered yet, not all bridging positions are very pronounced. Interestingly, five of the seven bridging publications mention collaboration in their titles. Collaboration sticks out as a possibly important interconnecting topic within the research field. Collaboration as a topic could be the context or frame which connects studies that have otherwise different

focal points. With its high authority score, Mills et al. (2014) is a well-recognized publication within the S(E)NA in EG research community. Mills et al. (2014) list challenges and potential contributions SNA can make to environmental decision-making. By reviewing a variety of different sources within the research field, Mills et al. (2014) establish themselves as a bridge of knowledge. Fliervoet et al. (2016) are structurally prominent in all three of our investigated network measures. The article compiles information on relevant network metrics for analyzing natural resource governance. We identify that Fliervoet et al. (2016) is the most central publication in the research field S(E)NA in EG to date and therefore presume that the knowledge transferred by this publication will also remain important for the future development of the field.

4.2.1. Limitations of the citation network analysis and future work

As citation records of articles accumulate over time, older publications have a higher chance of being cited. Thereby, the likelihood of reaching a high authority score increases with age. Compared to that, recent articles have a shorter time span in which they might have been recognized and cited by the scientific community. This effect might be less pronounced as digitalization improves. Even so, the identification of authorities is only possible for publications after a certain minimum of time after their publication. Not only age and content, but other factors like language, journal, and open access status might affect authority scores in citation networks, which we did not look at.

4.3. Similarity network

The analysis of a large number of scientific publications as a similarity network is helpful as it reduces complexity to a rapidly interpretable degree. By analyzing the similarity network, we could identify different modules in which publication models cluster. These modules clearly exhibit topics differing from the other modules in one or several topic categories. A researcher can take the similarity network maps as guides to the body of literature; to provide a rapid general overview of the field, as well as to indicate literature associated with a specific topic. Publications at the border between two modules are likely to address topical aspects from both modules. Similarly, articles at the center of the network have connections to different modules. They may either cut across topics or deepen a shared underlying topic that is addressed in many other publications (see supplemental material, Table D[14]).

4.3.1. Developing a classification of module characteristics

Based on our results, we argue that similarity networks can be characterized on two different levels of topic distribution: (1) on the local (module) level—regarding how topics structure a specific module—and (2) on the global (network) level—

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14   See file: Schwenke&Holzkaemper_SENA in EG Table D_PublicationList.csv (Schwenke & Holzkämper, 2020).

regarding how topics influence the overall similarity network. On the local level, a module might feature a single, distinct topic or they might be composed of several less prevalent topics. On the global level, a module might be unique in that its topic does not recur across modules, or a topic might influence the whole network as an underlying topic across modules. In Table 7, we develop an overview of module characteristics on the local and global level.

Table 7. Module characteristics for bibliometric network analysis on the local and global level, as suggested by the authors of this article.

Local characteristics (module level)	
distinct	Dominated by one topic: The module is characterized by a single central, prevalent topic, indicated by a high number of shared publication topics and a centralized word frequency (i.e., a large gap between the counts of the most frequent topic-describing word/s and the less frequent words).
composite	Composed of several topics: The module is influenced by several topics, indicated by a variety of publication topics, each with a relatively low number of shared publication topics and a distributed word frequency (i.e., a close distance between the counts of topic-describing words).
Global module characteristics (network level)	
discrete	Not repeating: The module's topic is unique for the whole network, not recurrent across modules.
underlying	Repeating: The module's topic is recurrent across two or more modules.

Source: Authors' summary.

For the majority of modules, we found the most discrete topic assignments in the "Resources" category, where each module could be assigned an individual topic. The application of S(E)NA in EG spans material resources and their uses and threats, from water, forest, and fisheries to climate, health, and floods/disasters. Modules 5 and 6 include many publications (5: $n = 49$; 6: $n = 71$), hence they are big enough for distinct subtopics to emerge. These subtopics can be localized in the network and are characterized by a far lower word frequency than the dominating topic. The largest module (7: $n = 83$), however, is not influenced by a single distinct topic. Rather, this module is composite: it features a collection of topics which are difficult to localize in the network. This also applies to Module 1 and to some degree also to Module 3. These modules might be tied together either by a distinct topic in another topic category or by underlying topics that are also common across modules. The existence of an underlying topic parallel to the discrete "Resources" topics is corroborated by the module topic detection with the LDA technique. LDA identified an underlying topic that strongly influences the network across all modules in the "Resources" category: immaterial resources like information, influence, and knowledge. The detection of this underlying topic strengthens the idea that in the context of EG, independently from the kind of material resource at stake, relations of power and the production of knowledge play a crucial role (Kütting & Lipschutz, 2009).

We further detected several distinct topics in the "Governance" and "Spatial reference" categories: Module 1, for example, is composed of several "Resources" topics, but with "collaboration/ conservation" it shows a distinct shared topic in the "Governance" category. This topic, however, is not discrete, but shared across modules. Overall, we find fewer discrete topics in the "Governance" and "Spatial reference" categories than in the "Resources" category: both topic detection methods applied in this study stress the prevalence of underlying topics in these categories. In the "Governance" category, only Modules 6 and 3 feature discrete topics ("adaptation" and "environmental"). "Policy," however, is identified as an underlying topic with the frequency ranking method, and the high LDA confidence value for this topic across all modules agrees with this finding. A similarly high confidence value can be found for the topic "collaboration," which can also be interpreted as an underlying topic for all modules in the governance category. With the exception of Modules 6 and 3, the "Governance" category appears divided into either a "policy" or a "collaboration" focus. We could not explain what causes this divide between "policy" and "collaboration" in the S(E)NA in EG literature that we found by applying our topic detection methods. Rather, we find it debatable if the terms "policy" and "collaboration," which can be filled with a variety of different and contextual meanings, are suitable for discussion in a mere word frequency-based analysis.

In the "Spatial reference" category, several modules show discrete topics (Module 3: "urban," Module 1: "marine/coastal," Module 6: "regional," Module 7: "global" and "international," and Module 0: "countries/nations."). However, all these modules are not only influenced by their discrete topics, but also by the underlying module-crossing topic "local"—often to a high degree. This finding mirrors the fact that the EG topic focus only recently shifted from local issues to the global (Pattberg & Widerberg, 2015) and more articles applying S(E)NA in global EG contexts are expected in the future.

4.3.2. Limitations of the similarity network and LDA and future work

a) Data preprocessing: For creating the similarity network and for detecting topics, we opted to not include a stemmer for the text data preprocessing. A stemmer maps words with a different ending into a single word and thus accounts for morphological variations of the same word (plural forms, declinations, etc.). Unfortunately, stemming algorithms often reduce words such that their original meaning becomes unintelligible. For example, government and governance would both be reduced to the stem "govern" while having very different meanings. While we could maintain exact word meaning, not including a stemmer resulted in an underestimation of word occurrence, as variations of a word with the same meaning were counted as different words. This has implications for the creation of the similarity matrix (reduced similarity between documents), as well as for the topic detection (lower word counts and weights).

b) Similarity network creation: In the first step of the similarity network analysis, unrelated articles could be filtered out. By the logic inherent in the cosine similarity, we assumed that the isolates of the similarity network distinctly differed from the rest of the network in their contents. After identifying the content by manually perusing the abstracts of the respective articles, this turned out to be only partially true. The investigation of isolates showed that articles were filtered out although their content was relevant for the network.[15] The reason for this might be a missing step in the data preprocessing. For cosine similarity calculation, title, abstract, and keywords were each treated as a single text attribute of each document and compared separately. Missing attributes (e.g., missing keywords) can thus create a bias in the data that very likely affected the whole structure of the similarity network we presented. Further, we did not consider a normalization of the similarity network. This may lead to an overrepresentation of publications with a large number of keywords in the data set. However, the bias introduced by the number of keywords may be partially reduced by the fact that we included not only keywords, but also title and abstract to build the similarity network. Therefore, a high total number of words per publication was included. We thus assume that the differences in the number of words per publication are relatively small. Future applications of the method, however, should merge single text attributes of a document before computing cosine similarity. Yet, even after merging text attributes, related articles could still become isolates. A similarity network analysis has to consider the trade-off between a sufficiently high similarity threshold to allow for network structure to emerge and a sufficiently low similarity threshold to include all relevant articles.

c) Topic categories: It is very likely that there exist more topic categories or content levels according to which a similarity network can be analyzed than those we focused on in this study. Although we were guided by the word list with summed word occurrences from all articles, we still heuristically determined the three categories that we focused our analysis on. Several other topic categories may influence clustering; thus it may turn out that single articles of a module are not related to the topic of the module identified for a certain category. Instead, the reason why these seemingly unrelated articles belong to the module may be based on a different topic category. Module 8, for example, is assigned to the "health" topic in the "Resources" category. Yet, only approximately half of these publications actually deal with health. A perusal of abstracts showed that these publications have something else in common: the application of mixed methods approaches to SNA, among them participatory methods such as Net-Map. This exemplifies the relevance of additional topic categories we did not cover in this study. Analyzing the application of different

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15 For example, the publication of Schoon et al. (2017), which was identified as a hub in the citation network analysis, but was isolated in the similarity network.

SNA approaches could (1) give insights to what the overall important methods and metrics applied in EG are and (2) identify whether certain SNA approaches or metrics are applied more often in certain resource or governance contexts.

d) Topic detection methods: We achieved topic detection for this article by two methods: the word frequency ranking and the LDA method. We observed that LDA was less suitable for assigning distinct topics to modules, which could be easily identified by the frequency ranking method. LDA, however, was better in detecting underlying (latent) topics. This is not a surprise, as LDA is mainly designed to detect underlying topics in text (Gropp et al., 2019). With the settings we used in RapidMiner's LDA operator (optimize alpha and beta parameter), we could detect underlying topics, but could also corroborate several distinct topic assignments. We therefore propose that combining the LDA method and the frequency ranking method, as we did in this article, can improve topic detection in a bibliometric analysis of literature. Future research should evaluate the consistency of our results with other types of data sets and LDA settings.

e) Language as a "Bag of Words": Both topic detection methods in this study work with the "Bag of Words" model; that is, disregarding semantic relationships. While we could produce meaningful results in the "Resource" and "Spatial Reference" categories, our methods reached their limits when trying to assess the "Governance" category. This category is unlike the other two categories, because it consists of terms that have different meanings in different contexts. What exactly is meant by "policies" or "collaboration" has to be explained and defined for each study context. Meaning develops in language in more complex ways than with the occurrence of individual nouns, verbs, and adjectives. Language creates meaning by semantic relationships between words. Exactly this type of meaning escapes common topic detection methods by disregarding semantic relationships. These methods can thus only produce informative results where single terms are unambiguous in all contexts.

5. Conclusion

The research field S(E)NA in EG is in the process of developing into a distinct field of research where publications frequently relate to each other. To date, Fliervoet et al. (2016) provide a good overview of theories behind EG,[16] as well as network metrics relevant for the investigation of EG topics. We identified 20 publications which occupy structurally important positions within the research field S(E)NA in EG and recommend the publication of Fliervoet et al. (2016) or one of the other identified central publications (Table 4) to readers aiming to familiarize themselves with the application of S(E)NA in EG.

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16   Referred to by Fliervoet et al. (2016) as "natural" governance.

We see S(E)NA frequently applied in EG contexts such as water, climate, forestry, and fisheries. We propose that a more detailed analysis of the schools of thought, in the course of a citation network analysis, will be helpful to explain why these resource topics are addressed by S(E)NA and others are not. Power structures and the production of knowledge are shared underlying topics for the whole field and S(E)NA in EG literature mainly deals with the local spatial level. Regarding the "Governance" level, part of the S(E)NA in EG literature focuses on the analysis of policies, while another part of the literature more explicitly addresses the analysis of collaboration. "Collaboration" is identified as an important theme by both the citation and the similarity network analysis.

The publication list, citation analysis and science maps developed in this study may help researchers interested in the field to navigate the body of literature, so that they can find literature on S(E)NA in EG more easily in different contextual frameworks. Both the citation and topic detection analysis could further be underpinned by integrating a temporal component: How does the research field develop and how do topics evolve (emerge or become obsolete) over time? Additionally, we propose that future research should investigate the synergies of the LDA method and the frequency ranking method we developed in this study. With this study, we provide a comprehensive methodological approach which generates a first overview of the nascent field of S(E)NA application in EG. We hope to generate impulses that might influence future research to discuss or apply S(E)NA in different EG related specializations under consideration of the literature we present here and thereby to interconnect this growing field further.

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Social Network Analysis as a Tool for Studying Livelihood Adaptation to Climate Change: Insights from Rural Bangladesh

Ben Nagel[1]

Department of Social Sciences, Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

Abstract

Social network analysis (SNA) is increasingly being applied as a tool for investigating the role of actor ties within social systems, and transparency regarding methodology and fieldwork insights is of importance to this growing field. This paper reviews a study of the rural farming community of East Jelekhali in climate-impacted coastal Bangladesh, where SNA was applied to investigate the role of social network connectivity in household access to climate-adaptive innovative production technologies, such as saline-tolerant rice and high-yielding vegetables, which may provide a means of climate adaptation for agricultural households. Insights are shared on how SNA was applied to map and analyze a community-level livelihood adaptation network. A particular emphasis is made on discussing the benefits, practical applications, and challenges in applying the "whole" network methodology within a community survey-based approach. Methodological limitations and options for future applications of SNA design to climate adaptation research are then presented.

Keywords: Bangladesh, climate change, community adaptation, social network analysis.

1. Introduction

There has been increasing interest in the role of social network dynamics in climate adaptation in recent years (Borgatti et al., 2018; Chaudhury et al., 2017; Jaja et al., 2017). Rather than actor outcomes within a climate-impacted community being a function only of that actor's attributes, such as income or education (which may also serve an important role), a social network analysis (SNA) approach posits that an actor's outcomes are to some degree related to the actor's position within

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1   Corresponding author: ben.nagel@leibniz-zmt.de.

a network of relations with other actors (Marin & Wellman, 2011). Applying SNA to studies of local community dynamics can provide a valuable tool to measure and understand local social support ties and exchanges between households, such as in relation to climate change adaptation. The field of social network research, however, is a relatively new and growing field, where applications of the approach vary between research disciplines and new methods and approaches are constantly in development (Groce et al., 2019; Narayan et al., 2020). This paper contributes to the literature by exploring a case study where survey-based social network design was applied to study the role of local social networks in climate adaptation and access to innovative production technologies (IPT), in this context defined as production-based livelihood technologies introduced or adopted as climate change adaptive measures. The findings and discussions herein are based on experiences from a master's research project with the Leibniz Centre of Tropical Marine Research in Bremen, Germany, with fieldwork conducted from October 2018 to February 2019 in the community of East Jelekhali in coastal southwest Bangladesh. The primary research objective of this study was to contribute to the growing but incomplete understanding of the relationship between local social networks and access to IPTs by exploring why certain households in a climate-impacted agricultural community engage with these technologies as climate change adaptation strategies, and others do not. The specific objectives of this paper are to (1) explore the background context of the study, (2) detail the social network design methods and analysis applied, (3) discuss lessons learned from this approach in terms of benefits and limitations to the study design, and (4) use this information for future recommendations both in the context of livelihood adaptation, as well as in regards to methodological approaches for applying survey-based SNA.

1.1. Climate adaptation in Bangladesh

In coastal Bangladesh, vulnerable rural communities are situated at the frontlines of climate change due to several coalescing factors. Bangladesh is frequently cited as one of the most climate vulnerable countries in the world by organizations such as the World Bank and the Intergovernmental Panel on Climate Change (IPCC) (Ahmed et al., 2017). With a tropical monsoon climate, rainfall variability and flooding have always been a risk to coastal natural resource-dependent communities in Bangladesh (Dasgupta et al., 2011). The frequency and intensity of flooding events, however, has been steadily increasing as a result of climate related factors (Caesar et al., 2015). Climate impacts cited in coastal Bangladesh have included increased occurrences of both flooding and droughts, land and bank erosion, sea level rise, and increased storm surges and severe cyclones, as well as salinity intrusion (Yu et al., 2010). Salinity intrusion has particularly impacted agricultural livelihoods in the coastal zone; it reduces crop production by making land completely uncultivatable, and also contaminates sources of drinking water (Rabbani et al., 2013). In addition,

river diversions and dams such as the Farakka Barrage have reduced freshwater flow into Bangladesh in the dry season, causing water scarcity and contributing to increased salinity intrusion (Mahmuduzzaman et al., 2014). The expansion of shrimp aquaculture in southwest Bangladesh has also acted as a major contributor to saline water introduction (Tauhid Ur Rahman et al., 2017), adding to an array of growing climate impacts on the predominantly rural agricultural livelihoods in the region.

One of the most frequently proposed ways to adapt agrarian livelihoods to climate change is through innovations in technology and production strategies (Adenle et al., 2015; Lybbert & Sumner, 2012), which may have the potential to allow agriculture users to continue practicing production-based livelihoods while mitigating climate impacts and reducing vulnerability (Lybbert & Sumner, 2012). In coastal Bangladesh, a number of IPTs have been identified as climate adaptation measures within local communities, including saline-tolerant rice varieties (Mallick & Sultana, 2015), homestead vegetable gardens (Uddin et al., 2014), floating agriculture (Chowdhury & Moore, 2017), and mud crab fattening (K. A. Huq et al., 2015). Nongovernmental organizations (NGOs) and community-based organization development projects have been major drivers in providing IPT resources and training to climate change-impacted regions of rural Bangladesh, particularly at the local scale (Pouliotte et al., 2009). These innovations are adopted not just as general technological improvements, but as "deliberate adaptation measures … occurred as a result of real or perceived change in the climate condition"—indeed, coastal farmers in Bangladesh have been identified as being highly aware and perceptive of climate change risks (Saha et al., 2016, p. 68). IPTs have the potential to play a critical role in climate risk mitigation by providing viable alternative incomes following disasters and meeting food security needs in areas where environmental change has rendered traditional forms of production unviable (Mallick & Sultana, 2015).

Within a local community, however, not all climate change-impacted households might have the same access to such IPTs as livelihood adaptations. Households with greater access to financial or physical capital, for example, might have more resources with which to adapt to climate impacts or engage with innovative technologies. While such attributes have often been studied as forms of household capital, less understood is the role of community social relations and social network structures on access to climate-adaptive technologies. Climate adaptation at this local scale is a subject of increasingly emphasized importance in climate change research (Naess, 2013; Rauken et al., 2015). As climate change impacts and socioeconomic conditions tend to be highly variable on a local level, local institutions and communities need to have the capacity to respond to this localized variability if climate change adaptation is to be successful (Laukkonen et al., 2009). Institutional actors such as government organizations and NGOs may play an important driving role in introducing adaptive technologies or facilitating climate change mitigation

measures through formal training and adaptation networks (Rodima-Taylor et al., 2011). However, rural farming communities are also often heavily dependent on and imbedded in informal social networks, where informal ties between neighbors, friends, and kin allow the exchange of resources and labor to support livelihoods, as well as information and knowledge about adaptation strategies (Eriksen & Selboe, 2012). To explicitly explore the link between these social networks and climate change adaptation, this study investigated the role of social ties and social network connectivity to household access to IPTs as adaptation strategies in rural southwest Bangladesh, through the framework of SNA.

1.2. Whole network analysis

Applying SNA of actors and ties to studies of community dynamics can provide a valuable tool to measure and understand local social support ties and exchanges between households (Cassidy & Barnes, 2012; Chaudhury et al., 2017), such as in relation to climate adaptation outcomes in the case of this study. To explore how different households with different traits and engagement rates with climate innovations are embedded within a local community social network, a whole network analysis approach was applied in this study. Whole network analysis, as described by Scott and Carrington (2011), involves the complete analysis of all actors and their ties within a given set of network boundaries defined by the research interests. To clarify the whole network approach, it might be best contrasted with another common social network design, the personal or ego network approach, where the focal actor or "ego" is studied, and each ego gives a list of "alters" or ties to others, who are not necessarily studied as separate egos (Borgatti et al., 2018). Whole network design, by including all actors within a given network boundary, allows a broader application of network analysis measures, particularly relating to how network position affects actor outcomes, such as through various network centrality measures (Borgatti et al., 2018).

The whole network approach was applied with a household survey to characterize an entire community adaptation network of all social ties relevant to household livelihood adaptation. The goal was to understand how position within a local community adaptation network relates to individual household attributes and engagement with climate-adaptive technologies, as well as how overall community network structure might impact adaptation. Social interactions between households can have a major influence on long- and short-term decisions by households, such as in decisions to engage with or access particular livelihood strategies (Ettema et al., 2011). Whole network analysis was employed here to quantify social ties in the adaptation network.

In a rural farming community in southwest Bangladesh, both formal social network connections to external organizational actors and informal ties and exchanges between households in the community were examined to understand how they influence access to IPTs. Primary research questions of the case study included:

1. What social network structures and processes in the local livelihood adaptation network are facilitating or constraining engagement with IPTs?
2. Which types of households engage with IPTs as adaptations to environmental disturbance? Which types of households do not? Why?

It was hypothesized that households with higher connectivity in the community adaptation network would have higher engagement rates with innovative technologies. Position within a community social network has been shown to relate to certain measures of household climate resilience (Cassidy & Barnes, 2012). I specifically expected that households with a higher degree centrality, or number of direct ties to neighbors, in the network would have higher engagement rates with innovative technologies as climate change adaptive measures (and therefore more climate-resilient livelihoods) than less connected households, through increased access to relevant important social ties for climate adaptation.

1.3. Study site

The study was conducted in the community of East Jelekhali, located in the rural subdistrict of Munshiganj Union bordering the Sundarbans mangrove forest in southern Satkhira district, Bangladesh (Figure 1). Local experts identified this region as a climate- and specifically salinity-impacted area where a number of innovations had been adopted by farming communities in response to these stresses. East Jelekhali itself consists of "para" subcommunities of approximately 50 households each, divided primarily based on kinship and family ties. The clear and distinctive social boundaries of these para communities therefore formed the boundaries of the social networks analyzed. Within the study community, the primary research consideration was to complete the household network surveys to obtain the quantitative network data on household livelihood adaptation, as well as on household socioeconomic attributes and engagement with IPTs. Secondary considerations were to incorporate local knowledge into the study through interactions outside of the rigid quantitative survey design. This was accomplished through focus group discussions, key informant interviews, and informal conversations with community members. Through these interactions, I hoped to inform the SNA with a broader contextual understanding of local climate impacts and attitudes; household opinions on various innovative technologies and why households chose to engage or not engage with IPTs. These discussions helped build a narrative on how the community transformed over time in relation to climate impacts and livelihood change.
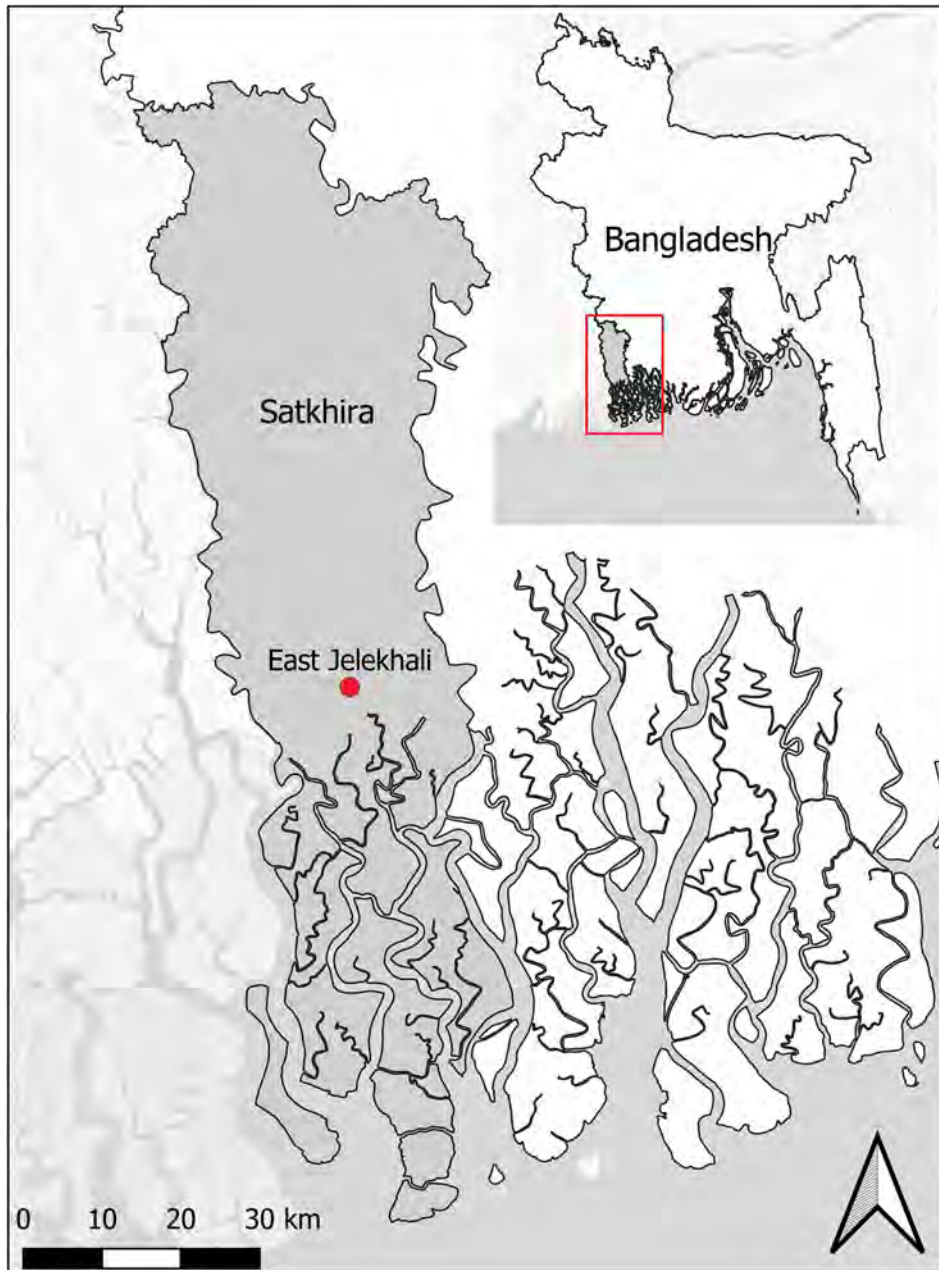
Figure 1. Location of study site: East Jelekhali, Satkhira district, Bangladesh.
Source: Author's representation.

2. Methods

Fieldwork was conducted with three researchers from the Social Science Discipline of Khulna University in the community of East Jelekhali from December 2018 to February 2019. To obtain a detailed overview on topics of climate change, agricultural innovations, and our study site in general, we conducted nine semi-structured key informant interviews with local experts, NGO representatives, and selected community members and local opinion leaders. At the study community, actors were identified via "convenience" sampling, based on availability and interest in participating, and selected to represent community members of varying demographics, such as gender, wealth, and status in the community. Topics included: household and community response to and perceptions of climate change; changes in various aspects of household capital before and after environmental disaster; and knowledge of innovative production strategies. Community key informant interviews were conducted in Bangla and transcribed and translated after obtaining permission to record.

In addition, two focus group discussions were conducted with local community members. Each focus group discussion was divided into two parts: a semi-structured discussion and a participatory wealth ranking (PWR) exercise. Participants for each focus group were selected from similar demographics to prevent conflict or dominating voices. This allows different perspectives or stories to emerge from each focus group, as more homogenous groups may limit social barriers to willingness to participate (Onwuegbuzie et al., 2009). Topics of discussion included a timeline of the environmental impact on the community, and demographic-specific climate impacts (such as impacts on farmers and impacts on women). Community perceptions of IPTs were also discussed, as well as perceptions on the major factors facilitating or obstructing access to engagement with the adaptive technologies. By engaging with these topics in a group environment, the discussions aimed to encourage group discourse and interaction to facilitate more detailed and descriptive sharing than in individual community member interviews. It also allowed us to identify areas of consensus and conflict on discussion topics. The second part of the focus group consisted of a PWR activity, following the framework of existing PWR methods in the literature (Coirolo & Rahman, 2014; Committee on Sustainability Assessment, 2015). PWR is typically a measure of relative poverty that allows community members to assess the community themselves, based on their own definitions of poverty (Zeller et al., 2006). Participants were asked to discuss households in terms of four categories of relative wealth: "wealthy," "moderately well-off," "poor," and "very poor." To assign households to each of these rankings, participants were first asked to form a consensus on the major indicators of each of these wealth categories, after which participants assigned each household to the relevant category. Household

social network connectivity and innovation engagement could then be compared with these wealth scores. Definitions of wealth categories as defined by community members can be found in Table 1.

Table 1. Participatory wealth ranking (PWR) categories. Wealth categories and key indicators as determined by community focus group participants.

Category	Key identifiers
Wealthy	Large landowners/farmers with over 1,000 decimals of land (100 decimals = approximately 1 acre), or households with a high status job, including large business owners, doctors, and government workers. Have highest education level, and often lease out land to other households.
Moderately well-off	Medium-scale farmers, most of which own or rent farmland in the range of 500–750 decimals. Some lease out land to other households. May have some household members engaged with small business, but are not large business owners.
Poor	Primarily farmers who own or rent some land, but very little. No more than 100–200 decimals. Dependence on wealthier households often necessary, for example as sharecroppers.
Very poor	Households which are either landless or own only house land. Farmers (sharecroppers) and non-agricultural laborers. No cash money typically, and high dependence on wealthier households.

Source: Author's summary of focus group discussion findings.

In addition to households within each para, we also included external organizations (such as NGOs or community organizations) identified by community members as playing an important role in introducing or otherwise supporting engagement with IPTs. Households, rather than individuals, within the community form the primary actors of interest to this research, based on the understanding that climate change adaptation decisions are typically made at the household rather than individual level (Thomas et al., 2007). Also, individual livelihood outcomes and resilience are strongly related to the overall household's livelihood strategy (Sallu et al., 2010). To obtain social network and household attribute data, a survey and social network questionnaire was conducted with every household within the network boundaries. Due to the study timeline overlapping with a busy harvest season, convenience sampling was utilized, selecting a representative from each household based on availability and willingness to participate. To obtain network data, each respondent was asked about which households or organizations have played an important role in adapting their household's livelihood to the changing environmental conditions. The network data focused on the ties important for adapting to or mitigating climate impacts, creating the basis for visualizing a "livelihood adaptation" network within the community. As adaptation strategies are not limited to innovation, the survey did not exclude "non-innovation" households. To help reduce recall error, the "roster recall" method of social network data collection, as described by Borgatti et al. (2018), was employed for generating household ties. Each household informant worked through a roster of all households in the community, identifying and characterizing all social ties that they considered important for their household's

ability to adapt to climate change. The primary advantage of this data collection method is a reduction in recall error by respondents, although using this method can become impractical with increasing sample sizes where the large number of actors in the network can become unwieldy. After a respondent completed a list of actors for the network question, a series of follow-up questions was asked about each actor, to define the attributes of each tie (such as "information" or "money"). Rather than using predetermined tie categories, this question was left open-ended for the respondent to define the type of interaction, in order to account for the possibility of important tie categories not predicted by the researcher. The direction of the tie was also categorized, allowing for the creation of a "directed" social network.

In addition to collecting social tie data, we surveyed general household attributes such as data on the household respondent, primary and additional livelihoods in the household, changes to household livelihoods as a result of the environmental impacts, and household engagement with and knowledge of innovative technologies. The household survey also included the Poverty Probability Index (PPI), a questionnaire developed by the Grameen Foundation and currently managed by Innovations for Poverty Action (IPA) as a tool to measure household or community poverty (Innovations for Poverty Action, n.d.). The questionnaire aims to estimate poverty levels with simple multiple-choice questions about household traits and assets. The PPI is cited in a number of applications in the non-profit and research field as an effective poverty measuring tool (Committee on Sustainability Assessment, 2015; Desiere et al., 2015), and in this context allowed for a secondary wealth measuring tool in addition to the participatory methods.

2.1. Data analysis

Applying survey and interview methods made it possible to combine qualitative community member insights with quantitative social network data. Interview and focus group data was primarily applied as qualitative descriptive information and used to provide background context about the study community. It was also used to corroborate findings from the SNA. Descriptive statistics of community demographic data, IPT engagement, and other household attributes were calculated from household survey data. For this analysis, network measures were calculated using the SNA program UCINET 6 (Borgatti et al., 2002). Node-level network measures analyzed included degree centrality (the household's direct connections to other actors) and betweenness centrality (the number of times a household lies on the shortest path between two other actors). Degree centrality was selected both due to its prevalence in the literature (Bodin et al., 2006; Cassidy & Barnes, 2012), allowing a greater degree of comparability, but also its relative robustness to various sampling conditions and errors compared to other network measures (Wang et al., 2012). Betweenness centrality allowed for a measure of indirect influence within the network, such as a critical actor controlling the flow of information from one part

of the network to another (who might not otherwise have a high degree centrality). As directed tie data was collected, in-degree centrality and out-degree centrality were also included in the analysis to allow for a more granular analysis of degree centrality. For example, it might be expected that innovation engagement relates to a higher number of incoming support ties. Node-level network measures were analyzed using the UCINET 6 routine "Network>Centrality>Multiple Measures."

3. Results

In this section, I discuss initial results gathered from one of the East Jelekhali study paras, Mondol, in order to frame the following discussion on insights from applying SNA. Within the Mondol study community, households had adopted four primary IPT categories as adaptations to local climate stresses, particularly salinity intrusion and rainfall variability, described in Table 2. Overall engagement rates with these innovations was quite high, with 87 percent of Mondol households engaged with at least one IPT. All households that engaged with the technologies reported positive benefits to the household, with the most reported benefits being increased income and food production. Figure 2 displays the livelihood adaptation network that was mapped in the Mondol community. Household interviews and focus groups in Mondol described the livelihood innovations as primarily being adopted in the aftermath of the devastating impacts of Cyclone Aila in 2009, when salinity intrusion and flooding in the community worsened.

Table 2. Innovative production technologies (IPTs) in Mondol para.

Innovation	Description
Saline-tolerant rice	Salinity-tolerant rice varieties which help offset production losses due to increased soil salinity, particularly in the dry "boro" growing season.
Homestead gardens	Historically not commonly practiced in Mondol, training on cultivation of saline-tolerant and high-yielding vegetable varieties was provided to households by local NGOs as a climate-adaptive livelihood strategy.
Multiuse fish ponds	As local climate conditions changed, some households started engaging in extensive carp aquaculture as a supplementary nutrition and income source in preexisting multiuse ponds also used for washing and bathing.
Hanging gardens	Through NGO training, households constructed low-cost bamboo frames and hanging nets via which vine-like vegetables such as cucumber and squash could be grown with reduced impact from waterlogging, and as a second layer of production over ponds or gardens.

Source: Author's summary of fieldwork results.

Network results help identify the social structures and processes facilitating engagement with innovative technologies in Mondol. The majority of respondents identified the knowledge and training on how to practice these IPTs as originating outside the community, from NGO training and workshops, rather than government intervention. This is corroborated by the Mondol network diagram

(Figure 2) which shows that eight NGOs were involved in the livelihood adaptation network, with NGOs 1 and 3 playing a particularly central role, for which the ties primarily consisted of formal training and microloans. In addition to formal training ties from NGOs, the network visualization also shows a dense network of support ties between households, which included informal household information sharing, moneylending, and labor exchange ties important for livelihood adaptation. Indeed, while NGOs were identified as the source of knowledge on the IPTs in Mondol, half of the households reported learning how to practice the innovations from neighbors, as knowledge diffused from households with direct NGO training ties to neighboring households.
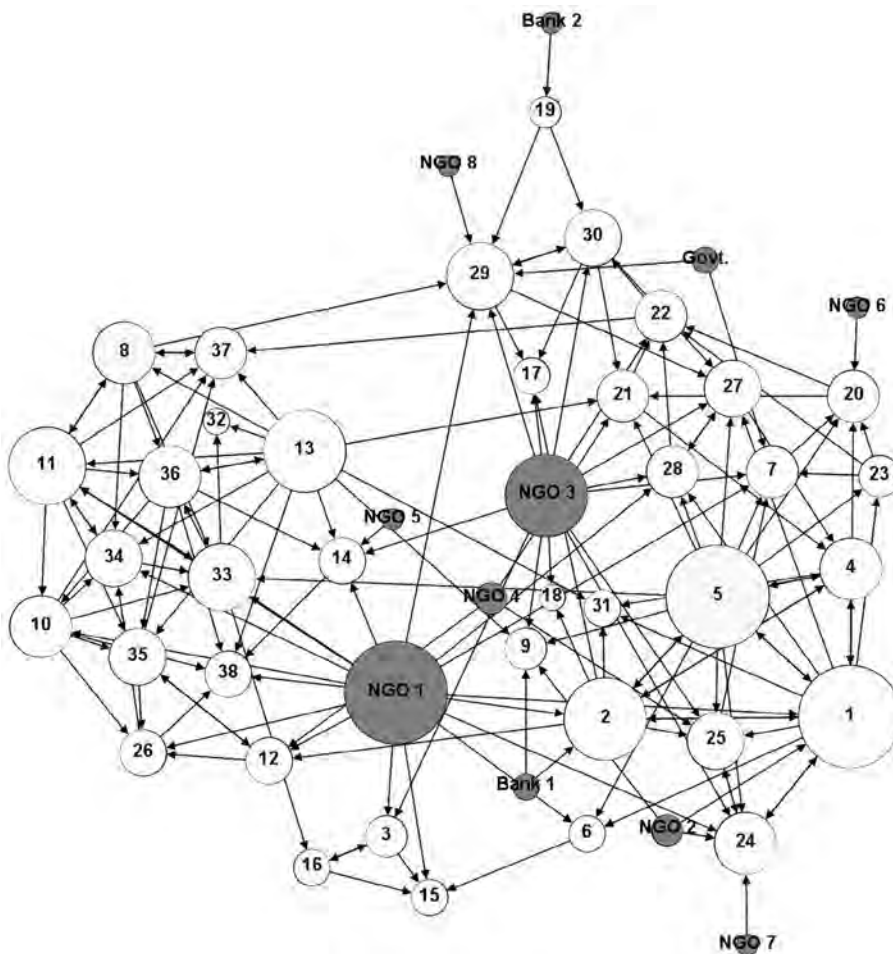
Figure 2. Mondol network of social ties important for livelihood adaptation to climate change.

Note: Households in white, external organization actors in gray. Size of node represents degree centrality. Numbers correspond to randomly assigned actor IDs.

Source: Author's representation.

Of particular relevance to this analysis were the node-level associations between innovation engagement and social network position. Different tie categories within a network are often analyzed as separate individual networks (Cassidy & Barnes, 2012), so separate component networks were mapped and analyzed for the three most frequently reported tie categories: information, money, and labor. Engagement with innovative technologies was analyzed as the number of innovative technologies being practiced within the household. Research shows a strong association between livelihood diversity and climate resilience (Cassidy & Barnes, 2012), and it was expected that households with greater connectivity within a social network of adaptive support ties would be more likely to have a greater diversity of climate-adaptive IPTs present, forming at least one indicator of household resilience. It might also be assumed that household wealth is a driving factor in household engagement with agricultural innovations, so associations between household wealth, as measured by both of our wealth-scoring methods, and innovation engagement were also analyzed.

An initial step in analyzing associations between network centrality and innovation engagement and wealth was in applying correlation coefficients. An example of these correlations for the Mondol study community is provided in Table 3. Results showed a significant relationship between innovation engagement and network position specifically in terms of in-degree centrality, which was significant in both the overall network (0.290, p = 0.030) and the information network (0.286, p = 0.033), suggesting a link between amount of incoming climate-adaptive information and access to innovative technologies. An additional relationship was found between network centrality and wealth, particularly with community-defined PWR wealth categories, where there was a significant relationship between wealth and both degree and out-degree centrality in all component networks. In Mondol, wealthier households tend to occupy more central roles within the community network, particularly acting as a primary source of outgoing social ties to neighboring community members. PWR wealth score was also found to be significantly positively correlated with household innovation engagement (0.284, p = 0.047).

Table 3. Correlation coefficients between network centrality and household traits.

	Innovation engagement	PPI	PWR
Degree—Information	0.119	0.056	**0.376**
Degree—Money	0.116	0.199	**0.265**
Degree—Labor	0.077	**0.264**	**0.241**
Degree—Overall	0.081	0.227	**0.412**
In-Degree—Information	**0.286**	−0.051	0.148
In-Degree—Money	0.006	−0.041	−0.169
In-Degree—Labor	0.134	0.153	−0.047
In-Degree—Overall	**0.290**	−0.023	−0.028

	Innovation engagement	PPI	PWR
Out-Degree—Information	−0.086	0.118	**0.409**
Out-Degree—Money	0.111	**0.264**	**0.509**
Out-Degree—Labor	−0.136	**0.257**	**0.341**
Out-Degree—Overall	−0.078	**0.236**	**0.469**
Betweenness—Information	0.069	0.079	**0.397**
Betweenness—Money	0.11	0.095	0.19
Betweenness—Labor	−0.011	0.158	0.185
Betweenness—Overall	−0.072	0.164	0.243

Note: Kendall's tau-b correlation coefficients. Bold results are significant at or below $p = 0.1$. PPI = Poverty Probability Index scores. Higher scores represent lower risk of poverty. PWR = Participatory Wealth Ranking scores. Higher scores represent higher wealth.

Source: Author's summary of fieldwork results.

To determine the role of household in-degree centrality and PWR wealth on innovation diversity, permutation-based regression analysis was applied. While traditional inferential regression tests draw on assumptions that data is derived from a random sample with a certain distribution, SNA deals with datasets that represent an entire population (Borgatti et al., 2018). In addition, traditional inferential tests assume that observations are statistically independent, while social network data is by nature non-independent, as the existence of ties for one node necessitates at least one other node having a tie as well (Krackhardt, 1988). Social network data, therefore, is not particularly compatible with such traditional statistical methods, at least in terms of assigning confidence to results. As described by Borgatti et al. (2018), permutation testing allows investigation of the likelihood that significant network findings were due to random chance alone, by comparing observed correlations to the distribution of correlations that would be obtained if the variables were truly independent. To analyze regression results of Mondol, the permutation testing utility in UCINET 6 was applied ("Tools>Testing Hypotheses>Node-level>Regression"), which computes classic linear multiple regression results, and estimates significance through random permutations (Hanneman & Riddle, 2005). The results of this method for the Mondol community are provided in Table 4, where in-degree centrality (In-degree) and PWR wealth scores (Wealth) were investigated as independent variables and innovation engagement as the dependent variable. In total, 10,000 random permutations were run. For more in-depth reading on applications of permutation tests in social networks, see Chapter 8 of Borgatti et al. (2018) and Boyd et al. (2006). Butts (2008) describes SNA with the "sna" R package, including permutation testing.

Table 4. Network regression permutation test results. Probability based on randomization tests.

Correlation Matrix					
	Wealth	**In-degree**	**Innovation**		
Wealth	1.000	−0.068	0.293		
In-degree	−0.068	1.000	0.330		
Innovation	0.293	0.330	1.000		
Determinant = 0.99544232					
Model Fit					
R²	**Adjusted R²**	**F Value**	**Probability**		
0.209	0.161	4.361	0.022		
Regression Coefficients					
Independent	**Unstandardized coefficient**	**Standarized coefficient**	**Proportion as Large**	**Proportion as Small**	**Proportion as Extreme**
Intercept	0.144	0.000	0.000	0.000	0.000
Wealth	0.339	0.327	0.032	0.968	0.062
In-degree	0.250	0.352	0.017	0.983	0.034

Source: Author's summary of permutation test results.

The correlation matrix shows once again that wealth and in-degree are positively correlated with innovation diversity (but not particularly correlated with each other). The R^2 value is 0.209, which was higher than similar models run using only wealth or in-degree alone as the independent variable. In permutation testing, the probability value represents the likelihood that the results are due to random chance alone. In this case, the probability is highly significant (one-tailed $p = 0.022$), suggesting that the findings are not due to random chance. Controlling for other variables, the standardized coefficients show that both household in-degree and wealth are positively and significantly related to household innovation diversity, with in-degree having a slightly larger effect (0.352, $p = 0.017$) than wealth (0.327, $p = 0.032$). By using this permutation testing method, I can establish some support for the case study hypothesis, in this case that households with a higher in-degree centrality in the local livelihood adaptation network are more likely to be engaged with a higher number of climate-adaptive innovations. While there are certainly a multitude of factors at play in determining household engagement with innovations as climate adaptations, these results provide an important first step in establishing a link between social networks and household climate adaptation via innovative livelihood strategies.

4. Lessons learned from study tools

4.1. Network questionnaire and household survey

Network-based surveys can often be a tiresome experience for both translator and respondent, as repetitive questions are continually asked about each social tie reported by the respondent. Additionally, in the roster recall method an entire list of network actors must be referenced one by one with the respondent. Survey-based network design can thus unsurprisingly be prone to a number of types of errors during data collection (Scott & Carrington, 2011). Attempts were made to reduce the burdensome nature of such surveys on both the research team and respondents. Questions about social ties were kept only to the critical relevant topics necessary for the research, to reduce the time requirements to describe each social tie. Some researchers emphasize that the placement of network questions in a survey may affect outcomes. For example, cognitively intensive network questions asked at the end of an already intensive survey might increase non-response error (Borgatti et al., 2018). By pretesting our surveys within the study area, however, our team found that first collecting household survey data before asking network questions resulted in greater respondent engagement. As the household survey gradually introduced research topics individually, such as local climate change impacts or IPTs, translators could gauge the respondent's understanding of the topics before we moved to the network questions. By that time, the respondent also had a clearer idea of the categories of ties being solicited by the network questionnaire.

The network questionnaire as designed included prompts asking for not only beneficial ties but obstructing ties as well. While such ties were not expected to be reported between households due to the sensitive nature of discussing such topics with outsiders, its inclusion was considered important due to the potential of obstructing ties from government, NGO, or other outside actors. This question was de-emphasized during surveys, however, when it became obvious that respondents were generally uncomfortable discussing obstructive ties. In general, it is important to assess the sensitivity and potential risk of network questions to respondents, as network data is often not truly anonymous. Further discussion on ethical issues in SNA can be found in the literature (Borgatti & Molina, 2003; Kadushin, 2005). It is worth noting the importance of careful planning and respondent prompting in cataloging the reported social ties by each respondent in a survey-based design. In our case study, a household roster was used and a random number assigned to every household. Households were primarily reported by the name of the head of household by respondents, but there were many cases of heads of households with the same names or respondents reporting ties to someone other than the head of household. The time-intensive nature of a roster-based household survey could result in frequent reporting errors due to such inconsistencies, and frequent return trips were made to households in this case study to verify answers.

4.2. Interviews and focus groups

As fieldwork dates overlapped with a busy harvest season, time allotted to lengthy interviews and focus group discussions was limited. Local farmer insight into the environmental changes on agricultural livelihoods heavily informed the background context of the study and helped to inform further questions or discussion topics to add to household surveys. Focus group discussions in the community were particularly successful. Careful attention was paid in trying to group respondents based on similar demographics, and to reduce the likelihood of participants deferring toward a more dominant voice in the discussions. The research team attempted to ask questions that promoted discussion and consensus-making among the focus group participants. This often resulted in participants engaging the researchers with their own inquiries. This was also successful during our PWR (participatory wealth ranking) exercise, where respondents formed a consensus on the wealth category of each household after a short discussion.

4.3. Fieldwork insights

Of further value to this study were informal visits and walkthroughs of the study community. These visits proved important for several reasons. Spending time in the community before or after surveys allowed for community members to engage the researchers at their own discretion with questions or inquiries. Some key informant interviews and critical topics within the community were uncovered this way, where our presence in the community outside of surveys allowed for more informal interactions and conversations. In addition, walks through the community with locals proved the best way to learn about the different IPTs present in the area. Observing various innovations with a community member allowed for a more natural discussion on the technologies and their relevance to the community. Further discussion on transect walks as a participatory study tool can be found in Kanstrup et al. (2014).

The importance of including local perspectives and research expertise when conducting research in a study community as a foreigner should always be emphasized. The fieldwork team in this study consisted of the author, from a foreign institute, and three local graduate-level students with research experience. This team acted not only as data collectors and translators but contributed a local cultural context, perspective, and awareness that could not be provided by the lead foreign researcher. Local researchers also helped to initially approach and disarm respondents, establishing a friendly and conversational tone. Emphasis was placed on not only providing direct translations of responses, but also picking up on tone and social cues that might further inform the response. This was particularly important in our case study due to the sensitive nature of network questions, where slight differences in researcher tone or phrasing might elicit different social tie

responses from the respondent. Translations of network surveys were worked on collaboratively as a study team, and initial household surveys were conducted as a group to ensure consistency, before translators split up to survey independently. We also attempted to keep translations and questions conversational and avoided heavy usage of formal scientific terminology. Frequent meetings throughout the field day and at the end of day allowed the team to discuss any issues or topics of interest that warranted addressing.

5. Conclusion

This case study review demonstrates that applying SNA in the field carries its own set of challenges, along with beneficial insights. Survey-based network analysis methods themselves can often be exhausting for both researcher and respondent, with potential impacts on data quality. The cultural and community context and the nature of the researcher–respondent relationship must also be taken to account when attempting to elicit ties of a potentially sensitive nature. There needs to be an emphasis on discussing the potential lack of anonymity in social network results, and what that might mean for the respondent. In East Jelekhali, SNA allowed us to explore the potential role of household social networks on access to innovative technologies which have become a primary means of livelihood adaptation in climate-impacted coastal regions of Bangladesh (Saha et al., 2016). In this case, ties to NGOs provided formal training and moneylending to support household engagement with these activities. However, equally important were informal ties between households, through which the knowledge and training on these IPTs diffused and crucial labor and money exchanges provided support. Analysis of network data showed that of the variables collected, in-degree centrality was most significantly associated with innovation engagement in households, suggesting further need to explore the role of social network position in climate adaptation and resilience. While this study analyzed associations between various household traits and network measures, determining causality in SNA is difficult to unravel, as discussed in detail by Doreian (2001). These results provide an initial step in establishing a relationship between network position, socioeconomic traits, and innovation engagement within a rural agricultural community, but the study does not attempt to fully uncover all causal mechanisms present.

The results of this study suggest potential for further methodological development of SNA. While applications of SNA provide some insight into potential relationships between network centrality and livelihood adaptation, causal forces in social networks are difficult to investigate with such cross-sectional studies. In that respect, future scholarly SNA investigations need to emphasize developing ethical and practical social experiment methodologies to truly and accurately capture the nature of these complex networks and move the field of SNA research forward. Adding a temporal

component to a community network analysis, such as investigating the adaptation networks soon after an environmental disaster and after adaptive strategies have disseminated through the community, might also paint a clearer picture of the relationships identified in this study. Static social network diagrams do not adequately demonstrate the dynamic nature of networks and social ties, and a study incorporating time-series network data might elucidate how networks evolve over time. I also emphasize the inclusion of participatory methods where appropriate, ideally allowing for active participation of locals in steering and shaping the research goals and questions, particularly in intercultural contexts where such methods can develop a greater understanding between researcher and participants (Schiffer & Hauck, 2010). Social network methods such as net-mapping (Schiffer & Hauck, 2010), which was not included in this study due to unexpected time limitations, may be highly valuable in this regard, allowing for group participatory consensus-making on the selection of relevant actors and measuring perceptions of influence of various network actors. While there has been a rapid growth in SNA research in the literature in recent years, the potential, and challenges, of applying network research in the field has not yet been fully explored. Hopefully, these insights can inform other new researchers on potentially common challenges to social network field design and methodology, and instigate new ideas in applying SNA toward livelihood adaptation research.

In the context of climate vulnerable regions such as rural coastal Bangladesh, we have investigated the potential link between community social network position and engagement with innovative technologies as adaptation measures which have provided broad quality-of-life improvements in areas severely impacted by saline soils. However, while these innovations play an important role in providing food security and income to agricultural livelihoods, innovation engagement is itself a very limited definition of climate change adaptation. Numerous climate change-induced factors which agricultural innovations cannot account for are shaping the vulnerability of rural livelihoods, ranging from the direct physical damage and flooding of increasing severe storm events (including the recent devastation of Cyclone Amphan in May 2020) to illness from water contamination (Shameem et al., 2014). As researchers, further applications of network analysis may help understand climate adaptation processes at levels beyond the scale of community-level household networks. As shown in Mondol, NGOs in Bangladesh are often playing a leading role in disaster response and climate adaptation projects, with over 40 NGOs actively registered as of 2020 in Khulna Division alone (Bangladesh National Portal, 2021). At a regional scale, SNA may provide a valuable research tool to explore communication, coordination, and areas of potential synergy within NGO social networks in Bangladesh to improve NGO response to climate disasters. Additionally, rural to urban migration is an increasing response to coastal climate disasters in Bangladesh (N. Huq et al., 2015). Migration brings with it inherent risks

and vulnerabilities, both for those migrating and the family members left behind, and SNA of both of these groups might allow for a better understanding of climate migration outcomes.

Acknowledgments

I would first like to thank the community of East Jelekhali, whose people were gracious and friendly in sharing their knowledge and time with us. I would also like to thank Abir Hassan, Baizid Mahmud, and Karimun Nessa, from Khulna University who conducted all the Bengali-language data collection for this study, for their dedication and friendship. Finally, my thanks to Eike Holzkämper and Marion Glaser from the Leibniz Centre for Tropical Marine Research as well as Samiya Selim from the Center for Sustainable Development, University of Liberal Arts Bangladesh, for their support, advice, and supervision.

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Meeting the Challenge of Learning for Sustainability Through Policy Networks

Adam Douglas Henry[1]
School of Government & Public Policy, University of Arizona, United States of America

Abstract

Decision-making for sustainability is often confounded by the complex and ideologically divisive nature of policy issues surrounding coupled natural and human systems. However, some policy actors are more successful than others in learning to deal with these challenges. This study examines the extent to which variation in learning by organizations in the policy process is explained by an organization's position within a larger policy network. Mechanisms of interest include bridging and bonding social capital, which is hypothesized to promote learning, and network segregation, which is hypothesized to impede learning. Hypotheses are tested using statistical models applied to organizational network positions and perceptions of learning outcomes in three regional land use planning processes in California, USA. Results underscore the importance of bonding social capital and network expansiveness in promoting learning within complex issue domains. Certain forms of segregation are an important barrier to learning.

Keywords: network segregation, regional planning, social capital, social network analysis, sustainability science.

Introduction

A central challenge in the study of human ecology is to understand how to promote *learning for sustainability* within the policy process. Learning for sustainability refers to the process by which social actors develop a better knowledge of complex problems at the boundary of coupled natural and social systems and deploy this knowledge to better manage salient issues (Henry, 2009; Parson & Clark, 1995; Social Learning Group, 2001).

Learning within the policy process is an important and distinctive form of learning. It is within the process of public policy-making that problems are defined, solutions formulated, and action is taken through the creation of new policies or programs. Thus the fate of many sustainability problems depends upon learning by "policy actors,"

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1   Corresponding author: adhenry@arizona.edu.

a term that refers to the many people and organizations that participate in the policy process and that represent a variety of interests within the public, private, and non-profit sectors.[2] These policy actors not only expend resources to pursue learning goals, but also hold power to enact meaningful change (Weible & Sabatier, 2017).

This study asks: How does an actor's position within a policy network influence their capacity to learn for sustainability? "Policy networks" refers to the myriad ways in which policy actors interact with and relate to each other, including formalized collaborations as well as informal information sharing. Networks are endemic to the policy process (Victor et al., 2016; Weible & Sabatier, 2017). Policy actors face a fundamental need to coordinate with others to expand their resources, knowledge, and power, all of which are critical learning resources. However, despite a broad understanding that networks are important to learning for sustainability (Bidwell et al., 2013; Henry & Vollan, 2014; Masuda et al., 2018), there exists at least two important gaps between the current theoretical understanding of learning mechanisms, and empirical research on how these mechanisms operate in actual social systems.

First, it is widely believed that network actors who are linked to more diverse resources, knowledge systems, and worldviews are better equipped to deal with complex problems and develop innovative solutions to these problems (Bidwell et al., 2013). Theoretical agent-based modeling work supports this view (Hong & Page, 2004), however there is relatively little empirical evidence regarding the association between network segregation (an inverse measure of diversity) and learning (Henry & Vollan, 2014). At the same time, the assumption that network segregation inhibits learning is implicit in many policy theories and underlies many organizational practices (Henry, 2016).

Second, the embeddedness of actors within larger systems is understood to influence learning, however there is a relative lack of empirical evidence on the precise nature of these connections. For instance, Armitage et al. (2018) study the influence of "enabling conditions" on learning, such as the types of activities policy actors engage in or the overall level of conflict in the system. Heikkila and Gerlak (2013) review many contextual factors that help explain learning, including process design and underlying social dynamics. Networks offer a useful measure of how actors are embedded in larger systems; certain network positions create access to social capital, while other positions may impede learning. While there is an emerging body of research on how networks create social capital and in turn enable learning (Stewart & Tyler, 2019), further work is needed to understand how and why network position matters for learning.

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2   This research views policy actors as organizations (and thus organizations are the "learning actor"); however, the theory and hypotheses examined below are applicable to learning by individuals as well.

This paper narrows the gap between theory and evidence through an examination of two theoretically-prominent mechanisms by which networks influence learning: through the creation of bridging and bonding social capital (Burt, 2000; Lin, 1999), and through the reduction of network segregation (Freeman, 1978b). These mechanisms are studied in the context of regional land use planning in three regions of California, United States of America (USA). Regional planning is a prototypical issue of sustainable development. Regional planning is fundamentally concerned with the problem of how to deal with rising populations and corresponding demand for infrastructure and services, while protecting Earth's local and global life-support systems. Actors involved in planning are continually engaged in various forms of learning, including belief updating through social interaction (Friedkin & Johnsen, 2011; Marsden & Friedkin, 1993), diffusion of innovations (Strang & Soule, 1998; Valente, 1995), and the synthesis of information for problem-solving (Hong & Page, 2004).

While there exist many pathways to learning, the fundamental goal of learning by policy actors is to craft solutions to manage, and perhaps even solve, policy problems. This research makes use of perceptual measures as a proxy for learning— that is, the extent to which policy actors believe that various forms of learning have taken place. While the empirical focus is on regional planning, the methods and general approach are also applicable to a wide variety of other policy domains that deal with complex human/environment interactions, placing this research firmly within human ecology and the field of sustainability science (Clark & Dickson, 2003; Kates, 2011).

Social capital and learning

Social capital refers to the benefits that a person accrues from maintaining positive social relationships with other people. Just as cash in one's pocket is a form of capital that may be used when needed (e.g., when a person's home is flooded and they must pay for repairs), relationships with people is another form of capital that may be used in difficult times (e.g., when a person's home is flooded and they must ask others for a temporary place to live).[3] Social capital is thought to be supported by a "virtuous triad" of trust, reciprocity, and social networks (Sabatier et al., 2005). Research on social capital has led to a rich tradition known as social capital theory, which has informed thinking about how network structures relate to fundamental social processes such as the evolution of cooperation and trust (Burt, 2000; Krackhardt, 1999; Lin, 1999; Simmel, 1950).

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3   Of course, there are important differences between financial and social capital. Financial capital is gone once spent, however social capital is potentially replenished and perhaps strengthened over time as it is spent. Thank you to an anonymous reviewer for this insight.

Given that relationships are a central feature of social capital, social network analysis provides a useful set of conceptual tools to both operationalize different forms of social capital and study its effects on learning. The following sections consider how the position of a particular policy actor (named *Ego*) reflects their available social capital, which in turn influences Ego's capacity for learning. Figure 1 depicts a hypothetical network with Ego as the focal actor; here, Ego has direct linkages with five other actors named *A*, *B*, *C*, *D*, and *E*—these actors are referred to as Ego's *alters*, and together they comprise Ego's *network neighborhood*.
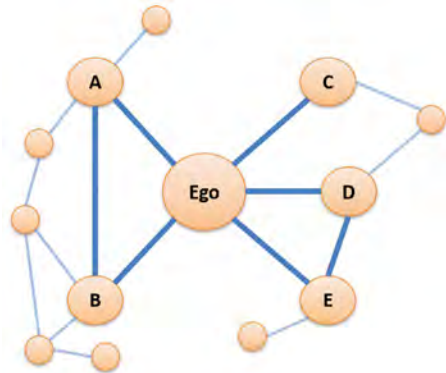
Figure 1. Hypothetical network with Ego as the focal learning agent.
Source: Author's representation.

Resources of various types flow within policy networks; information is exchanged, advice is given or received, and collaborators are sought out. These resources are raw ingredients for learning as organizations synthesize and apply information, knowledge, and expertise of various forms.

Occupying a central position in a network is useful for learning because it offers access to more of the social capital resources that the network has to offer. However, networks are also complex objects without a single natural center. Numerous concepts have been developed to assess whether an agent occupies a central network position (Freeman, 1978a; Wasserman & Faust, 1994). One of the simplest and most widely used concepts is *expansiveness*, or *degree centrality*. A node's expansiveness is the number of linkages emanating from that node to other network actors. In Figure 1, for example, Ego has a degree centrality of five since Ego is linked to five alters.

Having high expansiveness can be beneficial for learning, since this centrality measure signals the overall amount of resources an agent has direct access to (that is, learning resources that exist within one degree of separation of Ego). Having many collaborators, for instance, can increase an organization's pool of expertise, which allows them to perform innovative analyses, or implement programs that benefit wider target audiences. In general, it is likely that actors occupying network positions with high expansiveness are more likely to learn due to having greater access to raw information resources that are necessary conditions for innovation and problem-solving:

H_1 (expansiveness hypothesis): Network positions with high degree centrality tend to promote learning.

Bonding and bridging social capital

While expansiveness may increase the potential for successful learning, access to information is a necessary but not sufficient condition for learning to take place (Heikkila & Gerlak, 2013). The influence of network resources on learning depends on how relationships are structured among multiple agents, not just the overall number or density of relations (Bodin & Crona, 2009). In other words, it is not just an organization's direct connections that matter for learning—it is how an organization is embedded within larger configurations and the network as a whole.

Social capital theory focuses on a tension between two distinct types of social capital, known as "bridging" and "bonding" forms of social capital. Bonding social capital is viewed as social capital that increases the cohesion of one's own community, while bridging social capital is viewed as social capital that creates access to outside communities. The distinction between bridging and bonding social capital is discussed in lucid reviews by Burt (2000) and Lin (1999), and is explored in numerous empirical applications (Berardo & Scholz, 2010; Henry, Lubell, & McCoy, 2011; Scholz et al., 2008).

Policy actors frequently rely on both forms of social capital in their day-to-day activities. For instance, bonding social capital is created when people form or strengthen ties with coworkers in an organization or research group; that is, those people who one must interact with on a regular basis. Bonding social capital may be viewed as a form of organizational capacity since groups with higher levels of bonding social capital are more likely to trust one another, cooperate effectively, and generally put the goals of the collective before their individual self-interest. Bridging social capital, on the other hand, is created when actors form or strengthen ties with others outside of their regular professional world. These types of relationships, famously labeled "weak ties" by Granovetter (1973), create a unique form of capital that comes from having access to different groups and the varied resources, such as information, skills, or perspectives, that exist within these groups.

Bridging and bonding forms of social capital are thought to be reflected in certain types of network structures. The conceptual starting point is the connected triad—groups of three actors where no single actor is isolated from the other two (Simmel, 1950). Bonding social capital is thought to be reflected in "closed triads," where all pairs of actors are connected (Berardo & Scholz, 2010; Burt, 2000). For instance, the triad connecting actors A, B, and Ego in Figure 1 is a closed triad. Closed triads have the property that each pair of actors are both directly and indirectly tied such that "friends" are also "friends of friends." When a particular actor is part of many closed triads (relative to the total number of connected triads they are a part of), that actor is said to occupy a highly *clustered* network position. This reflects bonding social capital in the sense that clustered positions arise from actors making investments

in relationships within their group. The creation of closed triads may be due to the spread of positive reputations, or the many opportunities that members of the same group have to form ties because of their close proximity or shared activities.

Bridging social capital, as noted above, is social capital derived from linkages that provide access to disparate communities. In contrast to bonding social capital and closed triads, bridging social capital is thought to be reflected in the existence of "open triads," or connected triads where one pair of actors is not connected (Berardo & Scholz, 2010; Burt, 2000). In Figure 1, for instance, actors A, Ego, and C form an open triad. Ego stands at the apex of this particular open triad, and thus occupies a brokerage position between actors A and C—that is, in order for a resource, such as information, to flow from A to C, the information must first pass through Ego.

Bonding social capital, clustering, and learning

Occupying clustered network positions high in bonding social capital may enhance Ego's potential for learning because these structures potentially strengthen relationships and promote greater levels of trust and reciprocity in the network (Henry & Dietz, 2011; Henry, Lubell, & McCoy, 2011; Scholz et al., 2008; Simmel, 1950). Suppose, for instance, that Figure 1 represents information-sharing relationships and Ego finds actor E to be a particularly trustworthy source of information. The fact that actors D and E share information sends a signal to Ego that D's information is also legitimate and trustworthy through the "transitivity" of trust—that is, Ego is more likely to trust a given actor if they have a positive relationship with a third actor that Ego already trusts.

This underscores the importance of trust in making network ties an effective vehicle for learning. The positive relation between clustering, bonding social capital, and learning is illustrated also by work emphasizing the importance of non-hierarchical information exchange and collaboration on belief change and innovation. For instance, the literature on the impact of discussion on political choices suggests that hierarchical information exchange structures (such as when one individual broadcasts a message to many passive agents) are less effective in promoting the adoption of new ideas than are information exchange structures that allow for discussion after a message has been broadcasted (Kerr & Kaufman-Gilliland, 1994). In the policy process, hierarchical information exchange networks are primarily beneficial for those few central actors who can more efficiently influence the policy choices of a broad range of network actors. Evidence from the field suggests that innovation rarely occurs within such structures (Innes & Booher, 1999). Rather, the primary benefit of information exchange relationships is that they provide a platform for agents to mutually synthesize knowledge and ideas. These considerations lead to the hypothesis that embeddedness in clustered structures has a positive influence on learning:

H$_2$ (bonding social capital hypothesis): Highly clustered network positions tend to promote learning.

Bridging social capital, network brokerage, and learning

A prominent idea in the study of social networks is that actors occupying boundary-spanning network positions are generally better off, because they can act as brokers between disparate and fragmented groups (Burt, 2004). Figure 1 illustrates a case where Ego occupies a high-brokerage position, because the groups of nodes to the left of Ego (including alters A and B) and to the right of Ego (including alters C, D, and E) would be disconnected if Ego did not span the boundary between them. In terms of triadic structures, Ego's brokerage role is reflected in the fact that they stand at the apex of many open triads.

Occupying this brokerage role may enable learning because Ego is able to draw information from more diverse viewpoints (Burt, 2004). This view relies on the additional assumption that connected actors tend to share similar knowledge systems because many opportunities exist for learning within their clustered portion of the network. In Figure 1, for instance, Ego's linkage with both A and B is redundant—in this case B will most likely have the same information as A. Thus, Ego maximizes access to fresh information by seeking collaborations outside of clustered triads. Having a position with high brokerage is desirable because it allows Ego to sample many different paradigms and beliefs regarding the best way to tackle policy problems.

> H_3 (bridging social capital hypothesis): Network positions high in brokerage tend to promote learning.

H_2 and H_3 (Bonding and Bridging social capital hypotheses) are competing views because Ego's embeddedness in clustered structures, such as the interactions between Ego and alters E and D, is at odds with Ego's position as a broker. In order to maintain this brokerage position, for example, no linkages may be formed between nodes A, B and C, D, E. Such a linkage would increase Ego's triadic embeddedness, but would also obviate Ego's role as a boundary-spanner.

H_3 is limited in that it presumes that learning is largely an individual process that relies solely on having access to many different ideas and knowledge systems. Ultimately, whether H_2 or H_3 is more strongly supported should depend on Ego's intentions. Ego can facilitate information flow or block it; an actor with high brokerage can therefore learn more broadly or more selectively than actors with low brokerage.

Network segregation, diversity, and learning

A second mechanism through which networks influence learning is *network segregation*, meaning that relationships among policy participants tend to exist primarily among those actors with shared or similar characteristics (Freeman, 1978b).

Network segregation is frequently observed in real-world networks, takes on a variety of forms, and is generally thought to impede learning. Three particularly important forms of network segregation in policy systems relevant to sustainability include (Schneider et al., 2003):

1. *Belief-oriented segregation*, meaning that networks tend to create more connectivity among organizations with shared systems of policy-relevant beliefs.
2. *Functional domain segregation*, meaning that networks tend to create more connectivity among organizations operating within similar policy issues such as natural resources management, energy, or transportation.
3. *Governmental sector segregation*, meaning that networks tend to create more connectivity among organizations operating within similar sectors or governmental jurisdictions such as the national, regional, or municipal level.

As noted above, policy scholarship puts heavy emphasis on the role of network segregation as a barrier to learning (and network "diversity" or "integration" as a positive driver of learning). At the same time, however, there is a paucity of research on the association between learning and network segregation, the contextual factors that might cause this association to vary, and the mechanisms that link these two concepts. It is therefore useful to develop additional hypotheses of how various forms of segregation matter for learning.

Belief-oriented segregation and learning

Many policy networks are structured through a process of belief homophily, meaning that network actors tend to form ties with others that share similar systems of beliefs (Sabatier & Jenkins-Smith, 1993; Weible et al., 2011). Belief homophily is a powerful force in generating segregated networks (Henry, Pralat, & Zhang, 2011) and is believed to be a result of fundamental cognitive biases that cause policy actors to systematically interpret disconfirming evidence in a way that confirms their prior beliefs (Dandekar et al., 2013; Innes, 1978; Lord et al., 1979; Munro & Ditto, 1997; Munro et al., 2002). This process, known as biased assimilation, tends to erode trust among policy actors with divergent beliefs as they tend to interpret evidence in different ways (Leach & Sabatier, 2005). The result is an organization of policy networks that are globally diverse, but homogenous within local neighborhoods.[4]

Despite the negative effect of biased assimilation on networking between ideologically dissimilar policy actors, it is still common for actors to seek information and advice from sources they do not necessarily agree with. There are several reasons why this may happen. First, more information is usually better than less information,

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4   This perspective is a central component of the Advocacy Coalition Framework (ACF; Sabatier & Jenkins-Smith, 1993; Weible et al., 2011). The ACF is a prominent theoretical perspective on the policy process that focuses on the role of belief systems in driving political conflict in policy issues with high technical complexity and ideological polarization.

especially from the point of view of boundedly rational actors who routinely operate with imperfect information. Second, there may not be enough information sources to give policy actors the option to seek information from ideologically similar sources. Third, it is usually advantageous to understand one's competitors, and going to them for information is a useful way to better understand their strategies and resources.

For these reasons it is hypothesized that belief-oriented segregation reduces the propensity to learn:

H_4 (belief segregation hypothesis): Occupying a network position that is segregated in beliefs tends to inhibit learning.

Functional domain segregation and learning

Segregation across functional domain is problematic in the sense that it inhibits the synthesis of knowledge and decision-making authority on discrete problems that are closely coupled, such as issues of land use versus transportation (Cervero, 2002, 2003) or the sustainable provision of food, clean water, and renewable energy (Tilman et al., 2009). Network segregation works against the cross-disciplinary cooperation that is widely believed to be necessary to manage complex and interlinked policy problems. As a result, networks that segregate actors working in disparate functional domains are hypothesized to impede learning:

H_5 (functional domain segregation hypothesis): Occupying a network position that is segregated in functional domains tends to inhibit learning.

Governmental sector segregation and learning

Effectively dealing with complex policy issues requires collaboration across sectors (such as between governmental and nongovernmental organizations) and vertical levels within the governmental sector (such as between local, state, and federal governmental organizations). Empirical research supports the proposition that this type of integration supports positive learning outcomes. For instance, research on governmental innovations in water sustainability across three countries suggests that innovations are more likely to be adopted when they have the support of policy actors operating within two or more levels of government (Daniell et al., 2014).

Governmental sector segregation will work against the cross-scale and cross-level interactions that are believed to be critical to the effective management of complex policy problems (Cash et al., 2006). Interaction across governmental sector produces resources—such as information—that are relevant to the needs and problems faced by policy actors (Mitchell et al., 2006). Scope of information is one determinant of relevance. Many policy systems focusing on issues at the local or regional scale use information produced primarily at the state or federal level, as is the case with

Marine Protected Areas in California (Weible & Sabatier, 2005). Local knowledge systems are sometimes ignored or marginalized within policy processes, making sustainable outcomes far more difficult to achieve (Cash et al., 2003).

These considerations lead to the hypothesis that network segregation across governmental sector inhibits learning:

> H_6 (vertical segregation hypothesis): Occupying a network position that is vertically segregated tends to inhibit learning.

Methods

The above hypotheses are tested using survey data from policy actors in regional land use planning processes in three metropolitan regions in California, USA, including Sacramento, San Diego, and Riverside County. While the issue of central concern is land use, processes also tend to include adjacent policy issues such as transportation planning and natural resources management. Transportation planning is particularly relevant as there exists formal regional governments in the USA that are tasked with the formation and implementation of transportation plans, which are required to be integrated with local land use plans. The three study regions in question correspond to transportation planning regions, where there also exists a substantial amount of coordination among local governments on land use concerns.

Archival sources were used to identify actors from a wide diversity of organizations, including organizations from the public, private, and non-profit sectors, as well as a diversity of governance processes such as those related to transportation, land use, and natural resources. The archival sources used, all publicly available, include state-maintained lists of planning professionals, local government websites, as well as records of comments made on environmental impact statements.

Potential respondents were recruited by email to participate in an online survey.[5] Individuals who did not respond to this invitation (after three follow-up reminders) were asked to participate in a computer-assisted telephone interview (CATI) instead of the online survey. Overall, 514 survey responses were obtained from policy participants in the three regions, for an overall response rate of 34 percent.[6]

Although the survey sampled individuals, organizations are treated as the unit of analysis. Individual survey respondents were asked questions in the context of their professional activities within their organization; these responses were then aggregated to the organizational level by averaging the responses of affiliated

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5   A copy of the survey instrument is available from the author upon request.
6   This includes a total of 291 respondents from Sacramento (response rate 42%), 116 respondents from Riverside (response rate 25%), and 107 respondents from San Diego (response rate 30%).

respondents. Organizations in the final sample represent a diverse set of interests from across the public, private, and non-profit sectors. Organizations include local governments, state and federal agencies, interest groups, and business and industry groups, among others.

While respondents are drawn from three relatively distinct regional policy processes, the empirical analysis pools data from the three regions in order to examine average effects of network position on learning.

Network measurement

Network relationships were measured by asking survey respondents to nominate organizations they collaborate with (collaboration network), organizations that they go to for information or advice (information network), and organizations that they trust in the context of regional planning processes (trust network).

The structure of the regional collaboration, information, and trust networks are then estimated at the level of organizations and stakeholder groups based on connecting individual responses with the organizations they represent. Organizations A and B are assumed to be linked within the network if at least one respondent affiliated with Organization A or B nominated the other organization in a given network question. All ties are assumed to be equally influential in their effect on learning. Thus the networks estimated from the survey data are both undirected and unvalued.

Measured networks are depicted schematically in Figure 2. Policy networks within the three regions are relatively large (including many actors) and dense (with many relationships interconnecting these actors), thus it is difficult to see clear trends from looking at the graphics alone. However, there are a few noteworthy patterns. First, collaboration networks tend to be far more dense than either trust or information networks in the same region. This is expected in the case of information networks given that information is one type of collaboration. However, this is somewhat unexpected in the case of trust. In these systems, there are many instances of organizations that nominate each other as collaborators, but not necessarily as *trusted* collaborators.

Another interesting pattern is that the degree centrality of a node in the collaboration network (represented as the size of the node in Figure 2) does not necessarily translate into being a central actor in the trust or information networks. That is, some actors that are central information hubs are not central collaboration hubs. This shows that policy networks may have quite different structures within the same system depending on the relation of interest, and underscores the need to test the same set of hypotheses using different operationalizations of a policy network.
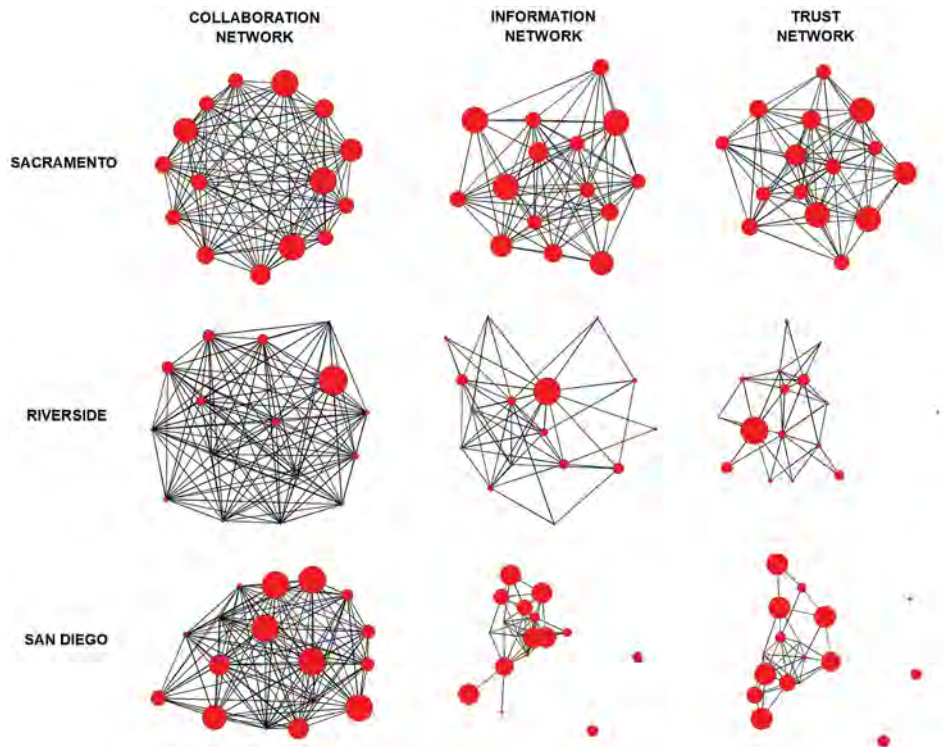
Figure 2. Measured policy networks in three regional processes.

Note: Network nodes represent organizations; links represent the specified relationship. Only the 15 most central actors in each network are shown. For comparability, node sizes are scaled according to the expansiveness of the organization in the collaboration network.

Source: Author's summary of survey results.

Hypothesis testing approach

Hypotheses of how local network positions influence learning are tested by fitting regression models using individual organizations in the policy network as the unit of analysis; in this case, perceptions of learning are taken as dependent variables, and characteristics of actors' position within the network are taken as independent variables. Variables measured for each organization include:

Learning (the dependent variable). This variable reflects overall perceptions of the probability of success of the regional planning process, including "the likelihood that current land use and transportation planning processes will improve regional problems in your area," and "the frequency with which regional land-use and transportation planning generates innovative policies in your area." A total of 12 similar items were scaled together to generate a measure of perceived learning ($\alpha = 0.80$). Perceptions of learning are not an ideal measure of learning as a theoretical variable, however perceptions of learning are likely to be at least correlated with

actual decisions and innovations that would count as learning, and may even be a necessary condition for learning to take place. The use of a perceptual measure of learning also allows for a test of null results. That is, if a given factor influences perceptions of learning then that factor may or may not influence actual learning; on the other hand if a given factor does not even influence perceptions of learning then it is very unlikely to have any effect on learning as policy or behavioral change.

Belief-oriented segregation. Seven distinct measures of policy-relevant beliefs were measured in the survey, including three distinct beliefs regarding the perceived severity of regional planning problems, the appropriate role of the various stakeholders in the decision-making process, environmentalism, economic conservativism, and support for smart growth planning theory. The average belief distance between organizations is defined as the Euclidean distance between the average belief score in these seven dimensions between a given pair of organizations.

Functional domain segregation. Participation in policy-making venues—which is congruent to the theoretical notion of functional domains discussed above— is measured for each respondent by asking the frequency with which they engage in various policy-relevant activities, including city planning, transportation planning, and natural resources planning, among other common venues of local governance. The degree of fragmentation in terms of cross-domain interactions is then measured as the Euclidean distance of the frequency of organizational pairs' participation in these various functional domains, or decision-making venues.

Governmental sector segregation. Segregation in terms of sector and vertical level of government is measured by the proportion of actors that a particular organization is connected to that are not in the same sector. The organization sector attribute takes on four possible values, including: regional or local (including regional Councils of Government or city/county governments), state, federal, and nongovernmental actors.

Collaborative institutions. A control variable is included that captures the degree to which an organization participates in regional collaborative institutions. Following a global trend in policy processes surrounding sustainability (Pretty, 2003), the regions studied here have all implemented a collaborative policy process (Lubell et al., 2010). These processes seek to engage a broad array of stakeholders in the policy process and promote a broad range of interactions thought to resolve barriers to learning (Sabatier et al., 2005). While this mechanism should theoretically operate through networks (that is, a collaborative process will enhance learning due to the changes it causes in one's network), the effect of collaborative participation controlling for networks is explicitly tested by including a variable capturing whether a majority of organizational representatives participate in the regional collaborative process.

Results

Table 1 summarizes model results when the network positions of organizational actors are viewed as independent variables influencing on perceptions of learning. Reported model results are from ordinary least squares (OLS) regression with robust standard errors.[7]

Table 1. Perceptions of learning by individual network actors across three California regions.

	Collaboration networks		Information networks		Trust networks	
Variable	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Social capital effects						
Degree centrality	0.010 ***	0.012 ***	0.015 **	0.015 **	0.017 ***	0.020 ***
	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)	(0.005)
Clustering coefficient	0.555 *	–	0.569 *	–	0.275	–
	(0.277)		(0.279)		(0.236)	
Betweenness centrality	–	–0.003 #	–	–0.002 #	–	–0.003 #
		(0.002)		(0.001)		(0.002)
Network segregation effects						
Avg. belief distance	–0.161 **	–0.155 **	0.026	–0.066	–0.110	–0.085
	(0.060)	(0.060)	(0.076)	(0.077)	(0.071)	(0.076)
Avg. venue distance	0.216 ***	0.198 ***	0.120 #	0.152 *	0.097 *	0.092 *
	(0.049)	(0.044)	(0.065)	(0.059)	(0.046)	(0.046)
Percent cross-level ties	–0.963 ***	–1.019 ***	–0.898 ***	–0.607 *	0.107	–0.173
	(0.227)	(0.199)	(0.275)	(0.240)	(0.274)	(0.278)
Collaborative institutions						
Majority participation	0.116	0.114	0.056	0.106	0.020	–0.013
	(0.075)	(0.075)	(0.093)	(0.091)	(0.084)	(0.085)
Constant	2.860	3.369	2.909	3.192	2.678	3.041
R^2	0.201	0.196	0.145	0.128	0.117	0.095
N (organizations)	239	243	132	146	200	211

Note: Stars indicate significance levels: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$. Hash mark (#) indicates $p<0.1$. Models 1 and 2 are alternative model specifications for each network type, introduced due to the strong correlation between clustering coefficient and betweenness centrality.

Source: Author's summary of results.

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7   All statistical analysis was performed in *Stata*, Release 12.

Social capital effects

In terms of social capital effects on learning, the hypothesis that degree centrality has a positive influence on learning outcomes (H_1, expansiveness hypothesis) appears to be supported across all models. That is, organizations with more collaborators, more information, and more trust are consistently reporting higher levels of perceived learning in these policy systems.

The effects of clustering and brokerage are somewhat less consistent. Since clustering and brokerage (measures of bonding and bridging social capital, respectively) are closely correlated, the problem of multicollinearity is managed by using two different model specifications (labeled Models 1 and 2) for each network. Model 1 includes clustering coefficient, and tests the effect of bonding social capital (H_2). Model 2 includes betweenness centrality, and tests the effect of bridging social capital (H_3). Betweenness centrality is an oft-used empirical measure of brokerage, and represents the number of shortest "geodesic" paths between pairs of actors that flow through a given organization. Betweenness centrality is thus a measure of the extent to which an actor creates connectivity between disparate communities in a network.

H_2 (bonding social capital) is supported in the context of collaboration and information networks. That is, occupying a position high on bonding social capital—such that one's alters also tend to be connected with each other—appears to increase learning. Higher betweenness centrality (brokerage) seems to lead to smaller levels of learning in all three network contexts. This is a weak relationship but appears to be consistent across different network types. Thus H_3 (bridging social capital) is not supported, and in fact the effect moves opposite to the hypothesized direction.

Network segregation effects

It is important to note that all the segregation concepts are operationalized in terms of "distance" measures, meaning how different on average an Ego organization is from their alters. Segregated positions will have smaller distance measures, while larger distance measures suggest more integrated, less segregated, positions. Thus, the network segregation hypotheses H_4, H_5, and H_6 are predicting positive coefficients—that is, higher distances (less segregation) should produce greater perceptions of learning.

Results for segregation are surprising. Belief-oriented segregation and vertical segregation appear to increase learning (greater diversity decreases learning, as seen in the negative coefficients). Moreover, this effect is strongly significant in certain cases.

In terms of belief-oriented segregation (H_4), it appears that segregation only matters within collaboration networks, yet here it matters in the opposite direction as expected. In other words, greater belief-oriented segregation in a collaboration

network appears to promote learning rather than inhibit learning. Following the logic of biased assimilation and belief homophily discussed above, this effect may be due to the difficulty of maintaining productive relationships with others holding divergent belief systems. Learning may be easier when one does not have to wrestle with belief and value conflict that often characterizes sustainability policy issues. Thus, H_4 (belief segregation) is clearly not supported.

Of the segregation hypotheses, only H_5 (functional domain segregation) operates as expected. Across all networks, results show that having more diversity in one's network in terms of functional domain (measured by venue participation) leads to higher perceptions of learning.

Similar to the result for belief-oriented segregation, it appears that sector segregation (for instance, when local governments work primarily with other local governments) is actually good for learning perceptions. This is contrary to H_6 (governmental sector segregation). This may be because working with actors at a similar level of government assures that resources shared (such as information) are salient to one another's needs—thus, it may be advantageous to work with others who are primarily interested in issues at the same scope as issues you work in.

Finally, and controlling for these factors, participation within local collaborative processes does not appear to have a direct effect on perceptions of learning. As noted above, this may be because the benefits of collaborative institutions derive primarily from their influence on the network structures, which in turn are the proximate determinants of learning in these policy systems.

Discussion

The results shown here illustrate that networks may have a counterintuitive and surprising effect on learning. Despite the widespread belief that bridging social capital, or "brokerage" positions enhance learning, this study finds an opposite effect. In the context of the regional planning processes studied here it appears that more clustered networks high in "bonding" social capital tend to promote greater learning. Of course this should not be expected to be universally true—the effect of bridging versus bonding social capital will certainly be dependent upon contextual factors such as the amount of risk organizations incur when deciding to coordinate with other actors in the region (Berardo & Scholz, 2010; Dietz & Henry, 2008; Scholz et al., 2008).

The analysis of network segregation shows that segregation likely matters, however the way in which it matters depends upon the network being studied as well as the attribute on which networks are segregated. It is encouraging that functional domain segregation operates as expected—that is, tends to impede learning. This is consistent

with a prominent belief that organizations benefit from creating connections that create diversity in expertise and knowledge systems (Bidwell et al., 2013). This belief is manifest in the strategies of many organizations that invest in the development of collaborative, boundary-spanning institutions in order to better manage complex problems and promote innovation (Henry & Vollan, 2014; Hong & Page, 2004).

At the same time, these results should temper the belief that diversity always promotes learning. Belief-oriented segregation may promote learning when it takes ideological conflict out of the equation. Governmental sector segregation may promote learning outcomes when it promotes the exchange of information that is more relevant to one's local needs. The exact mechanisms require further research, however the general lesson is that network segregation is not always going to be bad for learning and related outcomes, such as problem-solving and policy innovation.

Another interpretation of the observed positive relationship between network segregation and learning is that policy actors are comfortable in segregated networks. Without the need to collaborate with other actors who are very different, the transaction costs of participation in the policy process are kept low. This may facilitate less conflictual and "easier" decision-making, which for some respondents may translate to a positive perception of learning. It is the more conflictual processes—that force actors to question known processes and conventional beliefs—that may be needed to provoke deep learning.[8]

As with all scientific research, this study has limitations. The most important limitation concerns the operationalization of learning as perceptions about the policy process and the capacity of one's organizations to achieve learning outcomes. This view of learning still provides useful insights about how networks influence learning, since perception and actual learning outcomes are likely to occur together.

At the same time, future research should use measures of learning that are direct and multidimensional. A "direct" measure will be a measure of actual change in the beliefs or behaviors of policy actors, for instance the adoption of new policies (Berger et al., 2020) or the transmission of practices from one organization to another (Valente, 1995). A "multidimensional" measure will be one that accounts for the many forms of learning that occur within social and policy systems, including belief updating versus behavioral change, or individual learning processes such as trial-and-error policy experimentation versus social learning processes such as the diffusion of innovations between policy actors (Henry, 2016). Future research should seek to test theoretically-grounded hypotheses of learning using a variety of learning measures, in the context of different policy processes, and at varying levels of analysis such as the individual level, organizational level, and system level.

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8   Thank you to an anonymous reviewer for this insight.

Conclusion

Developing better theories of learning is crucial to the design of institutions that help us to successfully manage complex and ideologically divisive problems of sustainable development. Given the central role that networks play in learning, theories should explicitly consider the mechanisms by which one's position in a network explains variation in the potential for learning, as well as actual learning outcomes.

This paper contributes to such theoretical development by clarifying specific mechanisms through which networks are hypothesized to influence learning outcomes. These mechanisms are derived from prominent theories of social capital and network segregation, which are often invoked in the discussion of networks. However, there are few empirical tests of the hypotheses that social capital and network segregation matter for learning in sustainability. This is in part due to the difficulty of measuring learning—while this study uses an imperfect measure of learning *perceptions*, such a measure still enables an initial test of core hypotheses and allows identification of potential null effects.

Empirical tests show that social capital, as measured by overall numbers of connections, has a strong and consistent positive effect on learning in the regional planning processes studied here. Bonding social capital, in the form of occupying clustered network positions, also tends to promote learning. Bridging social capital, in the form of occupying positions of high brokerage, does not appear to influence learning. The effect of network segregation on learning depends upon the attributes on which the network is segregated as well as the type of network tie. Belief-oriented segregation in collaboration networks tends to impede learning, while belief-oriented segregation in information networks has no discernible effect. These results are contrary to the widespread belief—reflected in both theory and in practice—that creating more diverse, boundary-spanning networks will always improve the capacity of actors to learn.

This study fits into a larger research program seeking the development of a more comprehensive, inclusive, and synthetic theory of learning for sustainability (Henry, 2009). More research is needed on how network positions influence learning outcomes, accounting for a variety of different issue contexts as well as a variety of different forms of learning. Research on learning will also need to account for the dynamics of network evolution. A complete theory of networks and learning will not only explain how network structures influence outcomes, but also how networks self-organize in ways that may impede learning and how certain institutions might generate networks that enhance learning. Design principles for these institutions need to be grounded in solid, tested theory regarding the learning for sustainability.

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Book Review

Spatial Ecology and Conservation Modeling: Applications with R

By Robert Fletcher and Marie-Josée Fortin

Reviewed by Louis Donelle[1]

The last few decades of ecological research were marked by a growing recognition of the importance of space in shaping ecological patterns and processes. This is not only reflected by the emergence of subfields like landscape ecology and metapopulation/ metacommunity, but also by the development of an array of statistical methods and models for spatial analysis. Such progress has resulted in the release of several books, software, and packages on how to perform spatial statistics in a vast range of disciplines ranging from environmental studies and conservation biology to ecology, geography, and landscape ecology. Nonetheless, the study of spatial processes and their ecological consequences remains an intricate task and the growing number of statistical tools to do so can be overwhelming. By linking spatial ecology concepts with spatial statistics approaches, *Spatial Ecology and Conservation Modeling: Applications with R* by Robert Fletcher and Marie-Josée Fortin provides an overview of the issues often faced by ecologists and conservation practitioners when dealing with spatial analysis. The book will help scientists and practitioners learn the right tools to conduct their research, identify the challenges they face with their datasets, and circumvent those challenges by linking spatial analysis to ecological processes. As such, Fletcher and Fortin's book is an extremely valuable introduction to spatial ecology and both basic and more advanced methodological tools to conduct spatial analyses in R.

Because space is much more complex than simple geographical coordinates, the first half of the book focuses on quantifying spatial patterns and features. Scale being one of the prominent and pervasive issues in spatial ecology, it is only natural for it to be the topic of the opening chapter. As they do for every chapter, Fletcher and Fortin first introduce the key concepts and approaches to understanding the topic at hand, and then illustrate the topic's importance in ecological studies by providing ecological examples. For instance, rather than only explaining scale dependence in abstract terms, the authors provide several examples where the ecological conclusion

1   Louis Donelle, Department of Ecology and Evolutionary Biology, University of Toronto, Canada. louis.donelle@ gmail.com.

changed with the scale at which the data was analyzed, stressing the importance of selecting the appropriate scale for the ecological question of interest. Once the key concepts are explained, the readers are provided with hands-on ecological examples in R to help familiarize them with the R code (and packages) required to address the issue at hand (e.g., scale dependence), but also to demonstrate how to interpret and understand the R output. Such a learning-by-doing approach allows readers to go beyond the examples provided in the book and to replicate the analysis in a way that is tailored to their own research, to provide answers to their own specific ecological questions.

The book also focuses on issues related to land cover data and point data analysis. As these two types of data present drastically different challenges, best tackled by their own sets of statistical approaches, they are presented in their respective chapters where the most common metrics are showcased along with different null model strategies and modeling techniques. Once again, the book goes beyond the plain mathematical definition of the metric by bridging the gap between spatial statistics and ecological interpretation. This first half of the book ends on the most challenging issue in spatial statistics: spatial dependence, as stated in Tobler's first law of geography, "everything is related to everything else, but near things are more related than distant things." While this is partly why spatial ecology is so rich and interesting, it also violates the assumption of independence that is required for most standard statistical tests. Fortunately, there are multiple methods to quantify and account for such spatial dependence. On this particular issue, the book strikes a good balance: providing just enough information on the different methods in order for the reader to understand them and decide which is more appropriate for their specific goals, without going into heavy statistical definitions. By the end of the first part of this book, the reader will have developed a fair set of tools to deal with spatial data, and should have a good idea of when to use them.

Building on the methodological tools of the first part, the second part focuses on common areas of investigation in spatial ecology. The authors first review the most common approaches to model species distribution and animal movement, highlighting the benefits and pitfalls of the different approaches using applied examples. Though the book does not address more advanced issues directly in the examples, it presents them at the end of the chapter, thereby directing the reader to the relevant literature on these issues. Such a strategy is used throughout the book, allowing the authors to strive for breadth without sacrificing depth in the topics covered. The authors then spend an entire chapter discussing connectivity, as it is one of the key concepts in conservation. They present a great diversity of metrics and modeling approaches, ranging from patch-level to landscape-level connectivity and from simple to more data-intensive approaches. This chapter on connectivity then sets the context for the chapter on spatial populations. Although metapopulation theory accounts for the bulk of this chapter, the

authors also discuss spatial demography concepts such as source–sink dynamics. As data on spatial populations can range from simple occupancy data (presence–absence) to more complex abundance data (with or without different life stages), the book showcases several approaches, each suited for different types of data and/or different ecological questions (e.g., population synchrony, metapopulation viability). The book caps things off with spatially structured communities, where biogeography and metacommunity concepts are discussed. It is only natural that this topic comes at the very end, as it integrates several concepts from previous chapters (e.g., metapopulation, species distribution models). Though only the most common approaches are presented, the book provides the reader with a very strong basis that will allow them to explore and understand more advanced approaches.

By first introducing the fundamental topics in spatial statistics and then linking spatial statistics with spatial ecology, this book provides an accessible overview of spatial ecology, but also a great practical guide. Indeed, the learning-by-doing approach of the book leaves the reader with a ready-to-use toolset to investigate spatial ecology questions. Although this book is an introduction by design and little prior statistical training is required, spatial ecologists with more training would also benefit from the broad view of spatial ecology that it puts forward. Such breadth distinguishes this book from other recent publications like Gergel and Turner's *Learning Landscape Ecology* (2017), which strives for an in-depth coverage of technical and methodological tools used in landscape ecology. Fletcher and Fortin's book is relevant for graduate students, researchers, and practitioners addressing ecological, environmental, and conservation issues as well as land management, though the first section would be equally relevant for social scientists, as it provides an overview of spatial statistics. As we are entering the Anthropocene, such a book is an essential read to anyone interested in studying anthropogenic impacts on ecological systems, as human activities are inherently spatial.

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Contributors

Mariana Martins de Andrade is an oceanographer with a master's degree in biological oceanography. She works with marine conservation, sustainability, and public policies, researching participatory processes and the science–management interface. Her work supports scientific communication initiatives and the implementation of the 2030 Agenda and the United Nations Decade of Ocean Science for Sustainable Development in Brazil.

Örjan Bodin is an associate professor at the Stockholm Resilience Centre at Stockholm University. He is studying different challenges and opportunities in managing natural resources, and much of his research bridges the natural and social sciences.

Antonio Bodini is an ecologist interested in the analysis of complex systems through network modeling. Using network analysis he has explored patterns of growth and development in natural and urban ecosystems to obtain insight about ecosystem response to stress and trajectories for the sustainability of human ecosystems. His current research is dealing with policy and management scenario analysis applied to ecological and socioecological systems.

Marina Ribeiro Corrêa is a biologist and master's candidate in environmental sciences, and in 2019–2020 was a visiting researcher at the Leibniz Centre for Tropical Marine Research (ZMT) in Bremen, Germany. Her research interests are in coastal management, sustainability, socioecological systems, and the science–management interface. Besides research, she works in projects focused on ocean sustainability, participatory processes, and scientific communication.

Louis Donelle is a PhD student and Vanier Scholar in the Department of Ecology and Evolutionary Biology at the University of Toronto.

María Mancilla García is a researcher at the Stockholm Resilience Centre in Sweden. She works on relational approaches to the study of social–ecological systems. Her work ranges from applying process-relational philosophy to the analysis of social–ecological systems as complex adaptive systems to conducting empirical studies on water governance and fisheries governance in Latin America and Africa.

Marion Glaser is a social scientist and human geographer. She teaches at the University of Bremen, and leads the Social–Ecological Systems Analysis working group at the Leibniz Centre for Tropical Marine Research (ZMT) in Bremen, Germany. Her research analyzes the integrated dynamics and governance of coastal and marine social–ecological systems, focusing on the potentials of network analysis,

transdisciplinary approaches, and on the theory and practice of contextualized, multisite, and cross-scale sustainability analysis. Her recent focus has been on conflict and equity in the marine and coastal realm.

Philipp Gorris is a social scientist at the Institute of Geography and the Institute of Environmental Systems Research (IUSF), Osnabrück University (UOS) in Germany. His work centers on natural resource governance, sustainability transformations, and resilient economies. He is particularly interested in how collaborative approaches to resolving natural resource problems can be designed to develop environmentally sustainable and socially just policies through inclusive governance. He has carried out research on this topic in various countries around the world.

Adam Douglas Henry is a distinguished scholar and professor of environmental politics at the University of Arizona. His interests occupy the intersection of public policy, sustainability science, and computational social science. Henry's work applies network analysis to the study of the policy process in domains such as energy policy, urban water management, and invasive species management, among others.

Eike Holzkämper is a PhD student in the field of human geography, with a focus on the analysis of social–ecological systems through the lens of social networks. Recognizing the growing importance of data science, she is constantly developing her knowledge in this field. Her research interests lie at the intersection of coastal–marine environmental governance and transformations towards sustainability. She has conducted and collaborated in several projects related to natural resource governance in the tropics.

Ben Nagel is a doctoral candidate in political science with Jacobs University and the Leibniz Centre for Tropical Marine Research (ZMT) in Bremen, Germany. His current research examines natural resource governance and sustainability challenges from an interdisciplinary social–ecological systems perspective. Ben previously completed his Master of Science degree with the International Studies in Aquatic Tropical Ecology (ISATEC) program at the University of Bremen.

Daniel Filipe da Silva Pereira is a recent doctoral graduate whose work revolved around the development and application in silica of the loop analysis algorithm. In his doctoral degree he developed an R package for loop analysis, with an emphasis on the importance of the strength of interactions and pathways connecting variables. He also worked in applying these new methodologies to the study of a multi-stressor system, the Caspian Sea, in order to unveil the mechanisms behind its evolution.

Barbara Schröter is a political scientist and researcher in the Governance of Ecosystem Services working group at the Leibniz Centre for Agricultural Landscape Research (ZALF) in Müncheberg, Germany; and at Lund University, Centre for Sustainability Studies (LUCSUS), Lund, Sweden. Her research focus is on

governance structures, actors, and institutions in social–ecological systems. She is particularly interested in social networks, nature-based solutions, civil society engagement, and environmental justice.

Theresa Schwenke is a doctoral student in the Social–Ecological Systems Analysis working group at the Leibniz Centre for Tropical Marine Research (ZMT) in Bremen, Germany. Her background is in marine biology, focusing on the chemical defense of macroalgae and the bioacoustics of Antarctic pinnipeds. For her PhD, she specializes in the structure and dynamics of social–ecological networks and their connection to environmental governance.

Marco Scotti is a community ecologist interested in the development and application of new tools for modeling interactions between humans and nature. During his career, he has collaborated with social and political scientists by performing interdisciplinary studies based on network analysis. His current research focuses on the impacts that climate change and the overexploitation of resources have on the structure and functioning of socioecological systems.

Alexander Turra is a biologist with a master's and PhD degree in ecology from Campinas State University, Brazil. He is a professor of coastal management at the Oceanographic Institute at the University of São Paulo, Brazil, and the UNESCO Chair on Ocean Sustainability.

Luciana Yokoyama Xavier is an oceanographer, with a master's and PhD degree in oceanography from the University of São Paulo (USP), Brazil. She is a postdoctoral researcher at the Oceanographic Institute at USP (2018–present), and has been a visiting researcher at the Leibniz Centre for Tropical Marine Research (ZMT) in Bremen, Germany (2019–2020), supported by the São Paulo Researcher Foundation (FAPESP). Her research interests are in coastal management, participatory management, marine protected areas, social learning, and transdisciplinarity. She is a member of the Brazilian League of Women for the Ocean.

Aims and scope

Human Ecology Review (HER) is a semi-annual journal that publishes peer-reviewed interdisciplinary research on all aspects of human–environment interactions (Research in Human Ecology) and reviews books of relevance to the journal's subject matter and the interest of its readers. HER will not publish manuscripts that are purely biophysical nor ones that are purely sociocultural and it will not publish manuscripts that are monodisciplinary or specialisations to a specific discipline. Authors are strongly encouraged to make clear their manuscript's connection to an understanding of human ecology and human ecological scholarship more broadly.

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The Society for Human Ecology is based in the USA. Please use American spelling throughout and convert all measurements to SI units. Style followed is that of the *Publication Manual of the American Psychological Association* (APA style; www.apastyle.org). The dictionary used is Merriam-Webster.

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References

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Sample references

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