Conservation Biology

Review

Using social-network research to improve outcomes in natural resource management

Julie E. Groce [1]*, Megan A. Farrelly,[2] Bradley S. Jorgensen,[3] and Carly N. Cook [1]

[1]School of Biological Sciences, Monash University, Wellington Road, Clayton, VIC 3800, Australia
[2]School of Social Sciences, Monash University, Wellington Road, Clayton, VIC 3800, Australia
[3]Monash Sustainability Institute, 8 Scenic Boulevard, Clayton, VIC 3800, Australia

Abstract: *The conservation and management of natural resources operates in social–ecological systems in which resource users are embedded in social and environmental contexts that influence their management decisions. Characterizing social networks of resource users can be used to inform understanding of social influences on decision making, and social network analysis (SNA) has emerged as a useful technique to explore these relationships. We synthesized how SNA has been used in 85 studies of natural resource management. We considered how social networks and social processes (e.g., interactions between individuals) influence each other and in turn influence social outcomes (e.g., decisions or actions) that affect environmental outcomes (e.g., improved condition). Descriptive methods were used in 58% of the studies to characterize social processes, and 42% of the studies compared multiple networks or multiple points in time to assess social or environmental outcomes. In 4 studies, authors assessed network interventions intended to affect social processes or environmental outcomes. The heterogeneity in case studies, methods, and analyses preclude general lessons. Thus, to structure and further learning about the role of social networks in achieving environmental outcomes, we created a typology that deconstructs social processes, social outcomes, and environmental outcomes into themes and options of social and ecological measures within each. We suggest shifts in research foci toward intervention studies to aid in understanding causality and inform the design of conservation initiatives. There is a need to develop clearer justification and guidance around the proliferation of network measures. The use of SNA in natural resource management is expanding rapidly; thus, now is the time for the conservation community to build a more rigorous evidence base to demonstrate the extent to which social networks can play a role in achieving desired social and environmental outcomes.*

Keywords: biodiversity conservation, environmental outcome, intervention, network metrics, social network analysis, social outcome, social process, theory of change

Uso de la Investigación en Redes Sociales para Mejorar los Resultados del Manejo de Recursos Naturales

Resumen: *El manejo y la conservación de los recursos naturales operan en los sistemas socio-ecológicos en los que los usuarios de recursos están inmersos en contextos sociales y ambientales que influyen sobre sus decisiones de manejo. La caracterización de las redes sociales de los usuarios de recursos puede usarse para informar al entendimiento de las influencias sociales sobre la toma de decisiones, y el análisis de redes sociales (SNA, en inglés) ha surgido como una técnica útil para explorar estas relaciones. Sintetizamos cómo el SNA se ha utilizado en 85 estudios sobre el manejo de los recursos naturales. Consideramos cómo las redes sociales y los procesos sociales (p. ej.: las interacciones entre los individuos) influyen uno sobre el otro y en cambio influyen sobre los resultados sociales (p.ej.: decisiones o acciones) que afectan a los resultados ambientales (p. ej.: mejoría en las condiciones). Se usaron métodos descriptivos en 58% de los estudios para caracterizar los procesos sociales, y el 42% de los estudios compararon múltiples sistemas o múltiples puntos en el tiempo para evaluar los resultados sociales o ambientales. En cuatro estudios los autores evaluaron las intervenciones en los sistemas con la intención de afectar a los procesos sociales o los resultados ambientales. La heterogeneidad*

*email julie.groce@monash.edu
***Article impact statement**: Testing network interventions and outcomes improves understanding of the role of social networks in natural resource management.*
Paper submitted October 23, 2017; revised manuscript accepted April 24, 2018.

DOI: 10.1111/cobi.13127

en los estudios de caso, los métodos y los análisis excluye a las lecciones generales. Así, para estructurar y aprender más sobre el papel de las redes sociales en la obtención de resultados ambientales, creamos una tipología que desensambla a los procesos sociales, los resultados sociales, y los resultados ambientales hasta volverlos temas y opciones de medidas sociales y ecológicas dentro de cada uno. Sugerimos cambios en los focos de investigación hacia estudios de intervención para apoyar en el entendimiento de la causalidad e informar el diseño de las iniciativas de conservación. Existe una necesidad para desarrollar una justificación y dirección más claras alrededor de la proliferación de medidas de sistemas. El uso del SNA en el manejo de recursos naturales se está expandiendo rápidamente; por lo tanto, ahora es el momento para que la comunidad de la conservación construya una base de evidencias más rigurosa para demostrar el alcance hasta el cual las redes sociales pueden tener un papel en la obtención de los resultados sociales y ambientales deseados.

Palabras clave: análisis de redes sociales, conservación de la biodiversidad, intervención, medidas de sistema, proceso social, resultado ambiental, resultado social, teoría del cambio

摘要: *自然资源的保护和管理是在社会生态系统中进行的, 在这个系统中, 资源利用者的管理决策受到其所在的社会和环境背景的影响。构建资源利用者的社会网络可以帮助理解影响相关决策的社会因素, 而社会网络分析已成为探索这些关系的一种有效方法。本研究整理了社会网络分析在 85 个关于自然资源管理研究中的应用。我们分析了社会网络和社会过程 (如个体间的互动) 是如何相互影响并反过来影响社会结果 (如决策和行动), 从而影响了环境结果 (如环境改善) 。在这些研究中, 有 58% 的研究使用描述性方法来描述社会过程, 而 42% 的研究比较了多个网络或多个时间点来评估社会或环境结果。有 4 项研究评估了旨在改变社会过程或环境结果的网络干预。但由于案例研究、方法和分析的差异, 我们很难得到一致性的经验。因此, 为了构建和进一步了解社会网络对实现环境结果的作用, 我们建立了一个分类体系, 将社会过程、社会结果和环境结果分解为各自社会和生态测度的主题和选项。我们建议将研究重点转向干预研究, 以帮助理解因果关系, 并为保护措施设计提供信息。而目前还需要为增加网络测度确立更明晰的理由和指引。社会网络分析在自然资源管理中的应用正在快速普及;因此, 保护团体是时候建立起更严格的证据基础, 来证明社会网络在实现社会和环境结果的目标中能够发挥多大的作用。* ***【翻译: 胡怡思; 审校: 聂永刚】***

关键词: 生物多样性保护, 环境结果, 干预, 网络指标, 社会网络分析, 社会结果, 社会过程, 变革理论

Introduction

Effective and sustainable management of natural resources by communities or private individuals is an essential factor in reducing the loss of biodiversity, complementing or enhancing protected areas, and enabling landscape-scale conservation approaches that target important natural ecosystems (Gutiérrez et al. 2011; Stolton et al. 2014). Natural resource management (NRM) can be viewed as functioning within social–ecological systems (Berkes & Folke 1998), with resource users or managers embedded in broader social, political, and environmental contexts that influence their management decisions (Chaffin et al. 2016). To encourage individuals to conserve biodiversity, mechanisms and programs have been developed that range from regulatory restrictions imposed on resource use to voluntary strategies adopted by willing resource users (Rydin & Falleth 2006; Kamal et al. 2015). Given the extent of private lands in many countries and the pressing need to sustainably manage common-pool resources, there is much scholarly interest in what influences individual or collective motivations and decisions to engage in conservation initiatives (Knowler & Bradshaw 2007; Chaffin et al. 2016).

Whether complying with existing norms of resource use or participating in new conservation initiatives, individuals need the necessary awareness, attitude, and capacity to implement those actions (Honig et al. 2015). This involves learning about new management options (Pannell et al. 2006), forming attitudes about the best options for their situation (Lawrence & Dandy 2014), shifting their management practices (Stroman & Kreuter 2015), and committing to conservation approaches long term (Dayer et al. 2018). Acquiring information, improving capacity, and changing attitudes can come about through social interactions, such as communication with family or neighbors (Borgatti & Halgin 2011). Thus, the decision of whether to take on and commit to a conservation initiative is influenced in part by the social networks of the individual (Kittredge et al. 2013).

The ways in which an individual's behavior can be influenced by their relationships with others has generated interest in understanding social networks; many disciplines seek to identify how these networks might be leveraged to promote desirable behaviors (Wasserman & Faust 1994; Valente 2012). To analyze relationships, social network analysis (SNA) examines who is connected to whom in a system, how they are connected, and to what extent those connections enable the movement of ideas and information or influence the beliefs and behaviors of the individuals comprising it (Valente & Davis 1999; Borgatti & Halgin 2011). In SNA concepts from graph theory are used to construct networks in which nodes often symbolize actors (e.g., individuals,

organizations) and ties between the nodes symbolize ways in which actors are connected (e.g., friendship, movement of materials [Borgatti et al. 2009]). Networks can be visualized from the perspective of individuals (actors) and their connections, known as egocentric networks, or visualized as whole networks, where the position of individuals are viewed relative to each other (Wasserman & Faust 1994). Network structure can then be described by calculating various metrics that characterize individuals, subgroups, or the network as a whole (commonly used metrics described in Supporting Information).

Social network analysis expanded initially in the fields of psychology, anthropology, and sociology (Prell 2012), and while arguably a theory in itself (Borgatti & Halgin 2011), SNA has also offered a lens through which other concepts and theories can be further analyzed, such as social capital (Burt 2000) and diffusion of innovations (Valente & Davis 1999). It has been applied across many disciplines, including public health (Latkin & Knowlton 2015), economics (Wilkinson 2006), and education (Cela et al. 2015), and increasingly within the context of NRM (e.g., fisheries, forestry) and governance (e.g., comanagement of resources) as a way to understand learning and collaboration toward sustainable resource use (Bodin & Prell 2011). Crona et al. (2011) describe several theories that apply within natural resource governance and management, such as social learning, social influence, social movements, and social capital. Social interactions are fundamental to these theories; thus, "SNA can be used [for example] as a tool to identify actors for participatory processes, [or] it can serve as an analytical tool to understand an ongoing collaborative resource governance process or why an adaptive co-management initiative has stalled" (Crona et al. 2011:48). This enhanced understanding would ideally lead to improved management or governance processes.

Analyzing network structure in other fields has generated insights into how networks influence social processes and outcomes (Borgatti & Halgrin 2011). This and other work within NRM and social–ecological systems can be described through a theory of change in which network characteristics and social processes that influence each other can, in turn, influence social outcomes that affect environmental outcomes (Fig. 1). A social process is an approach or activity that involves interactions between people or organizations (e.g., communication [Bardis 1979]) that can be influenced by and serve to form the structure of a social network. That is, social processes can influence network structure (e.g., through the formation of new connections [Snijders et al. 2010]) and network structure (e.g., presence of subgroups) can likewise influence social processes (e.g., information transfer). Social outcomes result from social processes and could be a decision or change in behavior (e.g., participating in a conservation program) or an achievement or level of

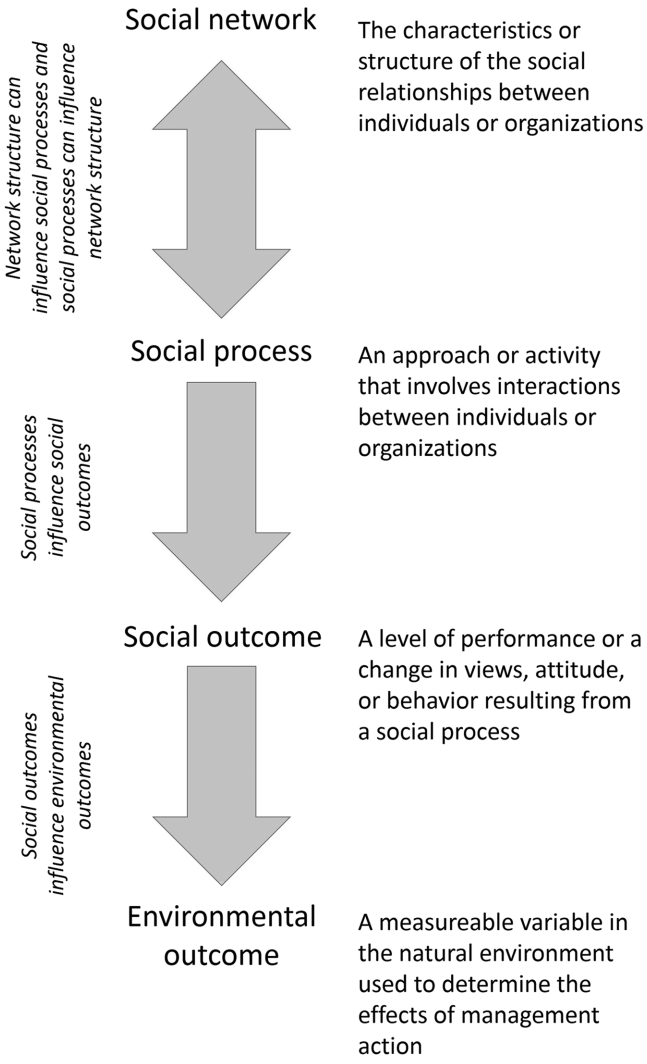

Figure 1. A conceptual diagram of a theory of change that links social networks, processes, and outcomes. Direction of arrow indicates direction of influence. Social networks may influence or be influenced by social processes (e.g., communication), leading to social outcomes (e.g., change in behavior) which may then influence environmental outcomes (e.g., fewer invasive species).

performance (e.g., access to funding [Borgatti & Halgin 2011]). These social outcomes are sometimes more akin to what the conservation-science literature describes as outputs (e.g., number of kilometers fenced [Hockings 2003]); however, we preserve the terminology used in the network-theory literature to avoid confusion (Borgatti & Halgrin 2011). Social outcomes that result in a desirable activity being conducted should ultimately lead to desirable environmental outcomes (Eklund & Cabeza 2017) (Fig. 1).

At the core of our theory of change is the concept that network structure is associated with particular

social processes or outcomes, which paves the way for exploring how changes to the network may influence those outcomes (Valente 2012). There is evidence from other fields that network interventions—purposeful changes to social networks—can be used successfully to influence social processes and shape social outcomes (e.g., decreasing intentions to smoke [Valente et al. 2003], increasing social participation [Howarth et al. 2016], and improving local-level adaptation to climate change [Serrao-Neumann et al 2013]). In a health context, a social outcome of lower rates of smoking is motivated by a desired health outcome (Valente et al. 2003), whereas in the context of NRM or biodiversity conservation, the desired outcome is a positive change in environmental or ecological condition (Koontz & Thomas 2006). For example, the decision by landowners to enroll in a conservation program, influenced in part by their interactions with others (a social process), and landowners' implementation of the actions prescribed in that program (a social outcome) ideally enhance species abundance on the property (an environmental outcome) (Fig. 1).

Given the evidence from other fields that social network data can be used to design interventions that shift attitudes and behavior toward desired outcomes (Valente 2012; Latkin & Knowlton 2015), we investigated how social networks have been studied and used in NRM to better understand or achieve desired social and environmental outcomes with the goal of the conservation of natural resources. Through an extensive search and review of social network research in the context of the NRM and conservation literature, we assessed how the existing body of research is positioned, relative to our theory of change, to inform conservation efforts. To structure the diversity of concepts and approaches found in this literature, we devised a typology that organizes themes and outlines possible measures to address key elements within this theory of change. With the recent expansion in SNA research, this review is timely to consolidate learnings, reveal knowledge gaps, and provide direction for research that is needed to advance concepts of social networks in environmental management and biodiversity conservation.

Methods

We searched the published literature to identify studies that used SNA (the calculation of metrics to quantify elements of network structure) in the context of the conservation and management of natural resources, particularly by private individuals or through collective action to manage communal resources. Our aim was to review the use and findings of SNA in NRM to determine what lessons can be drawn from this literature about the influence of social network characteristics on social and environmental outcomes and whether the lessons could inform initiatives to promote more effective biodiversity conservation by individuals with the direct ability to conduct on-the-ground management.

Search and selection criteria

Using Scopus and Web of Science online databases, which encompass natural and social sciences, we searched articles published in all years through 15 January 2018. We scanned for search terms used in article titles, abstracts, and keywords. We used *social network* and *network analysis* as key search terms because *social network analysis* tended to overly restrict the results. Several terms covering various resource conservation and management situations helped balance the breadth and precision of search results. Specifically, we searched for "*social network**" AND each of the following terms in turn: *biodiversity*, *conservation*, "*eco** *mange**", "*eco** *service**", "*natural resource manage**". We then searched for "*social network**" AND *enviro** AND each of the following: *agri**, *agro**, *fish**, *forest**, *marine*, *rangeland*, *soil*, *water*, *wood**. We searched "*network analysis**" AND each of the following terms in turn: "*eco** *manage**", "*eco** *service*", "*natural resource manage**". We then searched for "*network analysis**" AND *social* AND each of the following: *agri**, *agro**, *biodiversity*, *conservation*, *fish**, *forest**, *marine*, *rangeland*, *soil*, *water*, *wood**. Finally, we searched for "*egocentric network*" to capture any remaining relevant articles.

Natural resource management is a broad field with numerous research foci and scales of inquiry, and the study of social networks within NRM is similarly diverse. To enable comparison among or generalizations across studies given the wide range of objectives and methods used in the literature, we retained studies from the search results if they met all of the following criteria: used social network analysis (qualitative or quantitative) as part or all of the data analysis to better understand a population of interest; provided sufficient methodological details; and represented people or organizations in the network nodes, some or all of whom were local-level actors with direct ability to manage resources. Additionally, we focused on natural resource governance, management, or conservation, with the aim of improving biodiversity conservation or sustainable resource use. This criterion served to exclude studies on resource management for the primary purpose of increasing productivity or financial capacity and a range of other research foci such as energy consumption or food security.

Data extraction and synthesis

We synthesized the reviewed articles at 2 levels. Broadly, we included all relevant articles and produced an

overview of the research field that includes progress toward validating the theory of change (Fig. 1) and use of network interventions. To that end, we extracted details from the 85 studies including publication year, location, conceptual framework, data-collection methods, network features, and general conclusions. We categorized the studies according to broad method (i.e., whether authors described the structure of one or more networks or subgroups using network measures [descriptive]), whether networks were compared across multiple people, groups, or subgroups that displayed different processes or outcomes (compare across groups), or whether 1 or more networks or subgroups were compared across multiple periods (compare across time). Using the theory of change (Fig. 1), we then classified studies as addressing social process, social outcome, or environmental outcome. Although few authors used these specific terms, the intentions were discerned from the stated goals or analyses (e.g., to what were the researchers trying to correlate network characteristics). Although all studies included aspects of social process (e.g., in measuring interactions between people), within the theory-of-change classification, we were particularly interested in the proportion of studies that moved beyond social process in the analysis. To provide further distinction in the types of social processes examined in the studies, we categorized all studies into 4 themes based on study objectives and analyses: flow of information or resources, social learning, social influence, and collaborating. These themes help distinguish among appropriate measures in the typology discussed later.

The variability in study design and analyses across the reviewed studies resulted in a wide array of network metrics calculated and prevented meta-analysis of SNA findings. However, for a subset of sufficiently similar studies, we undertook a finer-scale analysis in which we summarized the network metrics used to characterize the network. Studies within a management context and focused on private or communal resources were included in the subset (Supporting Information).

Typology of processes and outcomes

Relative to the theory of change, we created a typology that deconstructs social processes, social outcomes, and environmental outcomes into themes and options of measures within each. The goal of this typology was to ease classification of the types of themes discussed in the literature and provide illustrative examples and possible measures that could help researchers identify or better target the element of the theory of change their studies address. This is not intended to be an exhaustive list; rather, we offer suggestions of how the themes could be quantified for analysis and provide guidance for researchers new to the subject.

Results

Our searches initially returned 4,781 articles (number of articles per search term in Supporting Information). We retained 572 articles based on reading the titles and abstracts. Further reading confirmed 85 articles were relevant, and we retained these for data extraction and synthesis. The 85 reviewed articles (full list, extracted data, and categorizations in Supporting Information) were published from 1992 to 2018; 86% were published during or after 2010, indicating SNA is a relatively nascent research area within conservation and NRM fields of study. Research was conducted in 35 countries on local- to international-scale issues related to marine, coastal, or terrestrial resources. Network theory was the primary framework for one-quarter of the studies, whereas the remainder used SNA as an analytical tool within other frameworks, such as diffusion of innovations or social capital. Therefore, SNA was often one of several analytical tools used within a study. Analyzes occurred for single whole networks (55% of studies), 2 or more distinct whole networks (31%), or multiple separate egocentric networks (14%).

Actors (types of nodes) included individuals in direct control of on-the-ground work or decisions (e.g., farmers, fishers) and organizations or other stakeholders in positions to influence resource use and management by creating policy or programs but that were not themselves direct managers. Forty-seven percent of studies focused on direct-only actors, whereas 53% of the studies included both direct and indirect actors. Questions used to elicit information on the number and type of connections between actors (network ties) varied considerably. Three of the more common types of ties can be generalized as exchange of information or knowledge (29% of studies), communication (24%), and collaboration (15%). The number of connections within a network was determined by various methods or combinations of methods. Most approaches relied on an individual's ability to freely recall their interactions, with or without prompts by the researcher, whereas others used rosters as a recognition method. The number of ties were either all inclusive or bounded by an upper limit ("list up to 5 people . . . ") or period ("within the past 2 years . . . ") or they were reduced according to the strength of connections (e.g., limiting analysis to strong ties). Network data in most studies were collected through commonly used qualitative or mixed method approaches, such as semistructured interviews, participant observations, or focus groups, to aid interpretation of the network connections and context.

Most studies (64%) used SNA to characterize a type of social process, whereas fewer studies attempted to link SNA results with social outcomes (29%) or environmental outcomes (7%; Table 1). Six of the 54 studies classified as characterizing social process did so within a system that

Table 1. Examples from reviewed studies of social processes (grouped into one of 4 themes), social outcomes, and environmental outcomes.

Social-process theme[a]	*Example research findings*[b]
Flow of information, knowledge, or resources (13 studies)	
social process ($n = 8$)	Relative to local farmers, migrant farmers have larger networks, more connections across distinct community groups, and more knowledge about proenvironmental management practices, which makes them well-positioned to exchange information about such practices (Isaac et al. 2014).
social outcome ($n = 4$)	Communication patterns in a fishing community show deep-sea fishers occupy central positions in the knowledge network, but their lack of awareness of declining fish stocks in the area means ecological information is not being passed through the network, which may explain the community's lack of collective action to rectify their unsustainable use of resources (Crona & Bodin 2006).
environmental outcome ($n = 1$)	Rates of shark bycatch suggest one ethnic group of fishers are using better shark bycatch avoidance behaviors than other groups, but the lack of information sharing between groups appears to limit the diffusion of such behaviors to other groups (Barnes et al. 2016).
Social learning (11 studies)	
social process ($n = 4$)	Scientists and managers who work on fish- and fire-management issues show a lack of social interaction, illustrated by the limited number of ties between the groups, which may limit the opportunity for generation of new knowledge, learning, and innovation (Fischer et al. 2014).
social outcome ($n = 6$)	The networks of landholders who adopted the practice of field-edge habitat plantings had ties to other landholders and agencies that provide technical support, whereas networks of nonadopters included only one of those groups, suggesting the importance of multiple learning pathways (Garbach & Long 2017).
environmental outcome ($n = 1$)	Comparing several cultural groups living off rainforest habitat suggests sustainable use of resources (based on measures of forest ecosystem function) correlate with social networks that include people who are important sources of social support and knowledge (Atran et al. 1999).
Social influence (25 studies)	
social process ($n = 13$)	Stakeholders in a forest-management planning process show a disconnect between their perceived level of influence and actual power as determined by their communication activity (i.e., the number of incoming and outgoing ties of each stakeholder in the network [Paletto et al. 2016]).
social outcome ($n = 9$)	Stakeholders' opinions about land management are less influenced by their particular organizational affiliation or category (e.g., conservationist vs. farmer) and more by whom they speak with on a regular basis (Prell et al. 2010).
environmental outcome ($n = 3$)	Cooperation within local networks and access to new ideas through external connections are needed for successful adoption of agricultural practices that improve land use and diversity (Isaac & Matous 2017).
Participating, cooperating, collaborating (36 studies)	
social process ($n = 29$)	Social network analysis illustrates collaborative connections among coastal-management practitioners and suggests that decentralized networks with well-positioned individuals who can facilitate information and resource exchange may strengthen the process of ecosystem-based management (Smythe et al. 2014).
social outcome ($n = 6$)	Assessing ecosystem-based management outcomes stemming from different planning processes shows that collaborative networks with similar overall network characteristics can achieve different outcomes and networks with different characteristics can achieve similar outcomes. Thus, different causal pathways can contribute to accomplishing desirable ecosystem-based management (Bodin et al. 2016).
environmental outcome ($n = 1$)	Labor-exchange networks help maintain close connections among swidden farmers, which limits establishment of new settlements in pristine areas and slows overall rates of deforestation (Downey 2010).

[a] *Number in parentheses is number of reviewed studies categorized per theme or outcome.*
[b] *Full citations and remaining studies are listed in Supporting Information.*[*****]

was considered successful or unsuccessful in some manner (e.g., lack of collective action). However, because no clear description or supporting evidence was provided for this potential outcome measure, they remained in the social-process category. Relative to general method (Fig. 2), 58% used descriptive methods, primarily to characterize social processes (47 studies; e.g., described structure of social networks to understand flow of information) or social outcomes (2 studies; e.g., describe a single network that reached a particular outcome as a group). Fewer studies (34%) compared across separate networks or subgroups within a single network (Fig. 2), the majority of which attempted to correlate network metrics with different social (e.g., land-use decisions [Kittredge et al. 2013]) or environmental outcomes (e.g., species richness of trees [Isaac 2012]) (Table 1). Seven studies characterized networks across >1 period to assess network dynamics (Fig. 2), 4 of which used participant recall to determine network connections for the earlier periods and 3 of which collected data at each period.

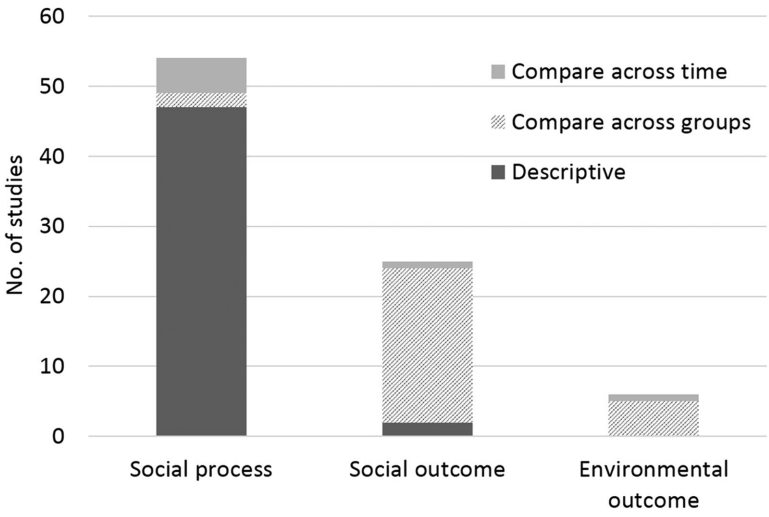

Figure 2. Number of reviewed studies (n = 85) in each method category (descriptive, compare across groups, compare across time) grouped by their focus on social process, social outcome, or environmental outcome.

Only 4 studies assessed networks before and after an intervention, such as establishing a bush-fire planning procedure (Brummel et al. 2012) and providing mobile phones to Ethiopian farmers to examine the impact on information-seeking activity (Matous & Todo 2015). Although interventions were rarely evaluated, many authors (39 studies) commented on how altering the networks may improve structural characteristics (e.g., increased connectivity) and thus possibly the outcomes. Suggested alterations included establishing new projects (Berdej & Armitage 2016) involving influential individuals as stakeholders in management decisions (Prell et al. 2009) or actively creating new connections among existing network nodes (Vance-Borland & Holley 2011).

Thirty-nine studies (46%) addressed both a management context and privately owned (e.g., famers, 24 studies) or common pool (e.g., fishers, 15 studies) resources. Network metrics in this subset varied (Table 2). We distinguished between egocentric or whole networks (because the metrics differed) and the 4 social-process themes in Table 1. For whole networks, we also grouped metrics by whether authors provided information about general connectivity in the network, insights into overall structure (e.g., cohesion, existence of subgroups), or information on the positions of actors relative to others. Studies in which egocentric network analysis was used, which characterized separate networks of multiple individuals, consistently investigated the influences of network size or type of alter against process or outcomes (Table 2). Type of alter includes attributes of the people or organizations to which an individual is connected. Eleven of these egocentric studies compared network metrics between different social or environmental outcomes. Studies in which a whole network-analysis approach was used reported on or tested 36 different network measures collectively (Table 2). Eleven of these studies compared measures between networks or subgroups that displayed different outcomes yet were still quite variable in the approaches and measures used (Supporting Information). Relatively common metrics included network density (indicates the extent to which all actors are connected), calculations of ties within versus between groups (indicates tendency towards group closure), betweenness centrality (indicates actors who can control the flow of information), and network size and type of alter (Table 2). These common metrics are also reflected in the full set of reviewed studies. Network size, type of alter, and network density were used in 78%, 66%, and 48% of studies, respectively (Supporting Information). Although the individual research contexts generally explain the diversity of measures used, the variability we observed in this subset, along with inconsistent use of terms and definitions (e.g., variable nomenclature, written description rather than mathematical formulae), made it difficult to identify patterns that could assist in highlighting the most informative network measures.

Discussion

Social network analysis has gained prominence in NRM research in recent years and is seen as a "flexible tool that provides a different and useful perspective on complex social dynamics in relation to environmental management" (Salpeteur et al. 2017:4). We sought to synthesize how SNA has been used in NRM studies and its relevance to the decisions and actions of private individuals or communities in conserving natural resources. This body of literature has grown rapidly over the past 10 years and has captured a diverse range of case studies with equally diverse objectives, methods of data collection, nodes and ties of interest, network metrics, outcome variables, and analytical approaches. Although this case-study approach offers a rich set of baseline data and contexts, the lack of an overarching methodological framework limits the advancement of learning beyond context-specific scenarios.

Table 2. Network metrics used in studies ($n = 39$) examining the management of resources by private individuals or communities.

		Themes related to social processes				
Network level	*Network metrics*[a]	*flow of information or resources*	*social learning*	*social influence*	*collaboration*	*Total no. of studies*
Egocentric network[b]	ego-network size (degree)		2	10		12
	type of alter[c]		2	10		12
	tie strength[d]			4		4
	density			3		3
	efficiency			1		1
	cliques			1		1
	2-step neighborhood			1		1
Whole network[e]						
Measures related to connections	network size[f] (reported)	3	2	2	6	13
	network density		6	2	2	10
	average degree	1		2	3	6
	average path length		1		2	3
	network diameter		1		1	2
	double 2-step paths		1			1
	geodesic distance	1				1
	line connectivity		1			1
	network centralization			1		1
	tie strength[d]				1	1
Measures related to community structure and/or subgroups	type of alter	5	7	5	6	23
	ties within vs between groups[g]	4	3	1	2	10
	no. of components			2	3	5
	modularity	3		1	1	5
	reciprocity		2		2	4
	transitivity		1	1	2	4
	block models (cutpoints)		1		1	2
	cycles (dyads, triads)		2			2
	hierarchy				2	2
	network efficiency				2	2
	clustering coefficient				1	1
	core, periphery				1	1
	factions			1		1
	k core				1	1
	network betweenness				1	1
	network heterogeneity				1	1
Measures related to actor positions	betweenness centrality	1	2	5	2	10
	degree centrality	1	1	5	1	8
	closeness centrality		1	2	1	4
	eigenvector centrality[h]			3		3
	indegree centrality		1		2	3
	outdegree centrality		2		1	3
	brokerage roles	1		1		2
	key-player measures			1		1
	leverage centrality			1		1
	pair dependency			1		1

[a] *Metrics defined in Supporting Information.*
[b] *Egocentric networks characterize separate networks of multiple individuals. Examination of egocentric networks occurs in 12 studies (11 private resource ownership, 1 communal resource ownership). Of these 12 studies, 2 are categorized as social learning and 10 as social influence (no studies categorized as flow of information or resources or collaboration).*
[c] *Includes measures of diversity, heterogeneity.*
[d] *Does not include articles in which tie strength is used as a means to exclude certain ties from the analysis.*
[e] *Examination of whole networks occurs in 27 studies (13 private resource ownership, 14 communal resource ownership). Of these 27 studies, 5 are categorized as flow of information or resources, 7 are categorized as social learning, 7 are categorized as social influence, and 8 are categorized as collaboration.*
[f] *Includes counts of nodes and ties.*
[g] *Includes various measures, such as external-interal (E-I) index and cross-boundary exchanges.*
[h] *Includes a single use of alpha centrality (Díaz-José et al. 2016).*

To consolidate theory about how social networks can influence attitudes and behaviors (Borgatti & Halgin 2011), we developed a theory of change that links social networks and social processes as a precursor to social outcomes, which in turn can influence environmental outcomes (Fig. 1). This connects the concept of one's actions being influenced by others in their networks (Borgatti & Halgrin 2011) with the concept of one's actions then influencing environmental outcomes (e.g., Eklund & Cabeza 2017). This theory of change provided a valuable framework with which to assess how well the current literature supports the theoretical basis for focusing on SNA within NRM. Using the theory of change, we distinguished among the reviewed studies where the objectives focused primarily on interactions between people (social processes), on the decisions or actions made by individuals because of those interactions (social outcomes), or on further associating network metrics with environmental measures (environmental outcomes). Although elements of this theory of change were often discussed or implied in the studies, there has been little attempt to validate the causal relationships implied, leaving a large gap in demonstrating whether network interventions can be used to promote desired outcomes in resource conservation and management.

Using social network analysis to address social process

The dominant focus in the reviewed studies was on social processes, which is understandable given that is the immediate link to social networks. Processes examined in the studies could be grouped into the themes of information flow, social learning, social influence, and aspects of collaboration (Table 1). The authors of these process-oriented studies often used SNA to establish baseline information about and assess social connections within social-ecological systems. In particular they looked for potential strengths or weaknesses in the network or explored the value of SNA as a tool to understand the connections among actors. Many examined resource-governance processes, such as communication among key actors, in line with the concept that promoting an effective governance system will support conservation outcomes (e.g., Berdej & Armitage 2016). Yet a descriptive approach still leaves unanswered the question of whether changes in governance influence the attitudes and behaviors of those who directly use the resources (i.e., social outcomes) or influence the quantity or quality of the resource itself (i.e., environmental outcomes [Koontz & Thomas 2006]).

The majority of process-oriented studies used descriptive methods to visualize the links between individuals and organizations of interest (Fig. 2), often in only a single network. Some studies looked at differences in subgroups within a network (e.g., Barnes-Mauthe et al. 2013) or compared network characteristics with randomly generated networks (e.g., Maciejewski et al. 2016) to further understand connections within the system. This descriptive approach is an essential starting point in understanding the diversity in network structures across different contexts and gathering baseline information of a particular system, but it offers little in the way of contrasting network characteristics where processes differ. Several studies, however, compared network data for 2 or more temporal points (Fig. 2) to either assess network dynamics over time (e.g., García-Amado et al. 2012) or understand the effect of an intervention on connecting otherwise unconnected individuals (e.g., Brummel et al. 2012).

Using social network analysis to understand social outcomes

Nearly one-third of the studies addressed specific social outcomes relative to network characteristics and associated social processes (Fig. 2). They addressed social outcomes such as acquiring new ecological knowledge (Crona & Bodin 2011), manufacturing traps that are more environmentally friendly (e.g., Cavalcanti et al. 2013), or enrolling in a conservation program (e.g., Kittredge et al. 2013). Assessing social outcomes requires additional data beyond that of network connections in a single context that is sufficient to demonstrate that a clearly defined and measurable outcome was or was not attained (e.g., adopting a management practice or not). Data are needed from more than 1 network or from more than 1 period to contrast outcomes across different contexts (e.g., Sandström & Lundmark 2016). The majority of studies that centered on social outcomes used comparative methods to determine whether correlations existed between network characteristics and differing outcomes (Fig. 2), in which they contrasted separate networks, subgroups within a single network, or separate groups of egocentric networks. Although the results were informative within the individual case studies, the heterogeneity we observed in research objectives, methods, and use of network metrics (e.g., Table 2) made it challenging to generalize the findings. Furthermore, although new knowledge or adopting best management practices were assumed to have a positive relationship with environmental outcomes, this was rarely tested and often not made explicit, leaving the reader to infer the possible links.

Using social network analysis to understand environmental outcomes

Demonstrating the link between network structure and environmental outcomes in the theory of change requires yet another data set, one that explicitly includes environmental measures, possibly a longer time series of measurements to capture lags in ecological change, and sufficient data to disentangle factors influencing the change (Koontz & Thomas 2006). Only 6 studies measured

environmental variables (Table 1) that were then related to network characteristics of farmers, forest owners, and fishers in both private and communal systems (details in Supporting Information). These studies used comparative methods to test for associations between individual or group behavior and environmental outcomes. Even within this small number of studies there was a diverse array of methods and contexts that limit generalization of findings. Nonetheless, they offer examples of correlating social networks with environmental outcomes and provide some test of the theory of change.

Recommendations for improving the value of SNA research

The limited use of interventions (e.g., before-and-after studies) among the reviewed studies precluded our learning about the causal relationships in the theory of change and learning how to design successful network interventions, as has been done in other fields such as health programs (Latkin & Knowlton 2015). Conservation science is often criticized for failing to evaluate the outcomes of ecological interventions and therefore missing the opportunity to learn about how to improve effectiveness (Ferraro & Pattanayak 2006), and it would be regrettable to repeat this pattern with network interventions. We suggest taking advantage of opportunities to learn from conservation programs (e.g., collecting data before and after the intervention) aimed at creating the social outcomes hypothesized to improve environmental outcomes (Fig. 1). Likewise, the large number of reviewed studies that suggested particular changes to network structures, as a means to possibly improve connections and outcomes, provide a great opportunity to follow up and test these hypotheses. Research focus can be directed to where critical network attributes are already known from previous SNA research (e.g., testing the use of influential individuals on program uptake [Prell et al. 2009]). We also encourage researchers to assess multiple periods after an intervention to consider the longevity of changes observed. We appreciate that experimental interventions in social networks will have limitations (e.g., due to cultural sensitivities [Matous & Todo 2015]), but in many cases experimental designs are feasible, such as implementing before-and-after studies where interventions (via organizational outreach or implementing conservation programs) are already planned. In action research, another option, researchers become involved purposefully in change by engaging with people or groups and creating space for social learning and problem solving (Patton 2002). For example, Westerink et al. (2017) actively created connections between farmers and public officials that built trust among the groups and led to the creation of adaptive management agreements intended to improve biodiversity and water quality. Although time- and effort-intensive, knowledge gains will be worthwhile, and journals could encourage the publication of these studies, rather than more descriptive studies of social processes.

Longitudinal studies with data collected at multiple periods would also improve understanding of how networks may evolve over time or whether changes in social processes or outcomes are sustained after the intervention has occurred. Descriptive studies of a single point in time provide important baseline information about existing relations among people or entities that can be used for targeting interventions (Valente 2012). However, this static representation fails to capture the shifting nature of networks, in which interactions and relationships form or end over time (Matous & Todo 2015). Many authors of the reviewed articles recognized that the lack of longitudinal studies is a significant gap in the existing literature that must be remedied to better understand causality (Crona & Bodin 2011), effectiveness of interventions (Kocho-Schellenberg & Berkes 2015), network evolution (Sandström & Lundmark 2016), and lasting changes in behavior or other outcomes (Cavalcanti et al. 2013).

Our assessment of SNA metrics used within the studies reveals a clear need to critically assess the value of the diversity of metrics used. Although we found that a small number of metrics are commonly used in NRM contexts, the diversity of metrics used across studies precludes generalizations. We also found that the lack of clear justification and description of metrics calculated (i.e., reporting equations) in many studies made it difficult to assess whether the diversity arose from meaningful differences or variable terminology. Although this diversity provides enormous flexibility in the ways networks can be assessed, it is important to evaluate whether the evolution of analytical methods and network metrics is the result of a positive and natural advancement or a product of lack of clarity and the proliferation of SNA software packages. This is particularly important for whole network approaches, where there is greatest flexibility in the types of metrics that can be calculated. We see a need to develop clearer guidance within NRM and conservation research about the most appropriate and meaningful network metrics to test in studies with different contexts and objectives. Therefore, reporting standards are required to ensure studies provide a clear justification for the metrics used in a study and how they were calculated to avoid confusion associated with trends in nomenclature and genuine progress in the development of new metrics as the field continues to mature.

With the aim of assisting researchers to orient their studies in relation to the theory of change, we devised a typology (Table 3) of processes and outcomes to distinguish the wide array of research avenues and where a study fits in relation to testing the validity of this theory of change. We hope our recommendations will encourage authors to conduct studies that build the evidence base on which conservation practitioners can design effective interventions in social–ecological systems. An example

Table 3. Typology of themes within social process, social outcome, environmental outcome.*

Theme	*Example**	*Possible measures*
Social process		
flow of information, knowledge, or resources	distribution of information among individuals accessing funding opportunities	number of sources of information to which an individual is connected number of direct and indirect pathways between an individual seeking funding and someone who is a source of funding
social learning	engagement and sharing among individuals	
gaining insights into others' beliefs or actions	proportion of connections in a network where individuals have identified each other (reciprocated) as links number of different types of people or organizations to which an individual is connected	
social influence	individuals who can exchange information with multiple types of people or organizations individuals with potential to initiate change in a group	identify individuals with the largest numbers of connections to people in different groups proportion of people in a network to whom one individual is directly versus indirectly linked
collaborating (including participating, cooperating)	involvement in a management planning process coordinating activities with a common goal	identify individuals with the lowest number of connections to the rest of the group (e.g., terminal nodes) proportion of people in a network to whom one individual is directly or indirectly linked
Social outcome		
choice (e.g., adoption of or change in behaviors, attitudes, or beliefs)	change in attitude change in land management practices	responses from 2 or more periods to attitudinal questions by individuals socially connected to each other responses of individuals from 2 or more periods about their adoption of new management practices
performance (e.g., achievement or access to resources)	management performance access to funding	reported satisfaction of individuals after implementing a management activity number of funding grants received by an organization
Environmental outcome		
species level	change in demographics change in behavior	rates of juvenile mortality across 2 or more breeding seasons number of daily foraging events for a period of time
community level	change in species diversity change in resource availability	species richness and species evenness at 2 or more periods presence of ephemeral water sources at 2 or more periods
landscape level	change in landscape connectivity change in dispersal patterns	habitat patch size and inter-patch distances at 2 or more periods number of successful dispersal events at 2 or more periods

Examples of specific topics of interest for each theme. Content influenced by Noss (1990), Schusler et al. (2003), Bodin and Crona (2009), Borgatti and Halgin (2011), and Prell (2012).

of the type of studies required can be seen in Crona et al. (2017), whose theory of change in the context of understanding leadership and social capital in fisheries systems links network measures with social and environmental outcomes and provides clear explanations of variables, metrics, and evaluation of those outcomes. Because myriad other factors (e.g., individual characteristics, culture, climate) also contribute to changes in behavior or changes in ecological condition (Ostrom 2009), it will require a large and targeted evidence base to clearly demonstrate the role of social networks in influencing social and environmental outcomes. Such an evidence base can only be built through the types of studies we outline above.

Reviews of SNA in other research areas (e.g., online education [Cela et al. 2015], HIV prevention or treatment [Ghosh et al. 2017], project management [Zheng et al. 2016]) are not immune from similar shortcomings to the SNA research we reviewed. The relatively recent increase in the use of SNA is generating insights about social interactions, but there is often more emphasis on process-related benefits rather than outcomes (Zheng et al. 2016). Information on network characteristics are rarely used to design interventions or test whether interventions improve outcomes (Cela et al. 2015), and the lack of longitudinal studies limit causal determinations (Zheng et al. 2016). Another consistent trend among fields is the heterogeneity of objectives, methods, and analyses

among studies, which precludes meta-analysis and generalizations (e.g., Ghosh et al. 2017). Given that the use of SNA is nascent in the field of environmental management and conservation, learning the lessons from other fields should enable this research area to bypass many of the potential pitfalls and advance rapidly toward providing valuable evidence to design more effective conservation programs.

Conclusion

Studies of SNA within NRM have improved understanding of the important role key individuals can play in transmitting ideas and information through a network and potentially in influencing the decisions and actions of others. Descriptive studies and focus on social processes have advanced the knowledge base, but as the field continues to develop it is important to validate causal relationships and build the evidence base for the links between observations about network structure and desired outcomes. More targeted research in the future could yield important insights into how to structure conservation programs aimed at engaging resource users to ensure they achieve desired social and environmental outcomes that can be sustained over the long term. The bulk of SNA research in NRM is <10 years old and expanding rapidly, so now is an opportune time to review progress, identify strengths and weaknesses in the existing evidence base, and find ways to enhance the ability for the conservation community to learn from future research. This review is not intended as a critique of individual studies. Rather, we have identified ways to build a more rigorous evidence base to demonstrate the extent to which social networks can play a role in achieving desired environmental outcomes.

Acknowledgments

We thank Monash University's School of Biological Sciences and School of Social Sciences for supporting this research. We also thank several anonymous reviewers whose valuable comments helped to improve the clarity and strength of the article.

Supporting Information

Commonly used network metrics (Appendix S1), number of document returns from database searches (Appendix S2), and details and categories of the 85 reviewed studies (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

Bardis PD. 1979. Social-interaction and social processes. Social Science **54:**147–167.

Barnes-Mauthe M, Arita S, Allen SD, Gray SA, Leung PS. 2013. The influence of ethnic diversity on social network structure in a common-pool resource system: implications for collaborative management. Ecology and Society **18:** https://doi.org/10.5751/ES-05295-180123.

Berdej SM, Armitage DR. 2016. Bridging organizations drive effective governance outcomes for conservation of Indonesia's marine systems. PLoS ONE **11**(e0147142) https://doi.org/10.1371/journal.pone.0147142.

Berkes F, Folke C. 1998. Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge, United Kingdom.

Bodin Ö, Crona BI. 2009. The role of social networks in natural resource governance: What relational patterns make a difference? Global Environmental Change-Human and Policy Dimensions **19:**366–374.

Bodin Ö, Prell C. 2011. Social networks and natural resource management: uncovering the social fabric of environmental governance. Cambridge University Press, Cambridge, United Kingdom.

Borgatti SP, Halgin DS. 2011. On network theory. Organization Science **22:**1168–1181.

Borgatti SP, Mehra A, Brass DJ, Labianca G. 2009. Network analysis in the social sciences. Science **323:**892–895.

Brummel RF, Nelson KC, Jakes PJ. 2012. Burning through organizational boundaries? Examining inter-organizational communication networks in policy-mandated collaborative bushfire planning groups. Global Environmental Change **22:**516–528.

Burt RS. 2000. The network structure of social capital. Research in Organizational Behavior **22:**345–423.

Cavalcanti C, Engel S, Leibbrandt A. 2013. Social integration, participation, and community resource management. Journal of Environmental Economics and Management **65:**262–276.

Cela KL, Sicilia MA, Sanchez S. 2015. Social network analysis in e-learning environments: a preliminary systematic review. Educational Psychology Review **27:**219–246.

Chaffin BC, Garmestani AS, Gunderson LH, Benson MH, Angeler DG, Tony CA, Cosens B, Craig RK, Ruhl JB, Allen CR. 2016. Transformative environmental governance. Annual Review of Environment and Resources **41:**399–423.

Crona B, Bodin Ö. 2011. Friends or neighbors? Subgroup heterogeneity and the importance of bonding and bridging ties in natural resource governance. Pages 206–233 in Bodin Ö, Prell C, editors. Social networks and natural resource management: uncovering the social fabric of environmental governance. Cambridge University Press, Cambridge, United Kingdom.

Crona B, Ernstson H, Prell C, Reed M, Hubacek K. 2011. Combining social network approaches with social theories to improve understanding of natural resource governance. Pages 44–72 in Bodin Ö, Prell C, editors. Social networks and natural resource management: uncovering the social fabric of environmental governance. Cambridge University Press, Cambridge, United Kingdom.

Crona B, Gelcich S, Bodin Ö. 2017. The importance of interplay between leadership and social capital in shaping outcomes of rights-based fisheries governance. World Development **91:**70–83.

Dayer AA, Lutter SH, Sesser KA, Hickey CM, Gardali T. 2018. Private landowner conservation behavior following participation in voluntary incentive programs: recommendations to facilitate behavioral persistence. Conservation Letters **11:**e12394.

Eklund J, Cabeza M. 2017. Quality of governance and effectiveness of protected areas: crucial concepts for conservation planning. Annals of the New York Academy of Sciences **1399:**27–41.

Ferraro PJ, Pattanayak SK. 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. Plos Biology **4** (e105) https://doi.org/10.1371/journal.pbio.0040105.

García-Amado LR, Pérez MR, Iniesta-Arandia I, Dahringer G, Reyes F, Barrasa S. 2012. Building ties: social capital network analysis of a forest community in a biosphere reserve in Chiapas, Mexico. Ecology and Society **17:** https://doi.org/10.5751/ES-04855-170303.

Ghosh D, Krishnan A, Gibson B, Brown SE, Latkin CA, Altice FL. 2017. Social network strategies to address HIV prevention and treatment continuum of care among at-risk and HIV-infected substance users: a systematic scoping review. Aids and Behavior **21:**1183–1207.

Gutiérrez NL, Hilborn R, Defeo O. 2011. Leadership, social capital and incentives promote successful fisheries. Nature **470:**386-389.

Hockings M. 2003. Systems for assessing the effectiveness of management in protected areas. BioScience **53:**823–832.

Honig M, Petersen S, Herbstein T, Roux S, Nel D, Shearing C. 2015. A conceptual framework to enable the changes required for a one-planet future. Environmental Values **24:**663–688.

Howarth S, Morris D, Newlin M, Webber M, Newlin M. 2016. Health and social care interventions which promote social participation for adults with learning disabilities: a review. British Journal of Learning Disabilities **44:**3–15.

Isaac ME. 2012. Agricultural information exchange and organizational ties: the effect of network topology on managing agrodiversity. Agricultural Systems **109:**9–15.

Kamal S, Grodzinska-Jurczak M, Brown G. 2015. Conservation on private land: a review of global strategies with a proposed classification system. Journal of Environmental Planning and Management **58:**576–597.

Kittredge DB, Rickenbach MG, Knoot TG, Snellings E, Erazo A. 2013. It's the network: how personal connections shape decisions about private forest use. Northern Journal of Applied Forestry **30:**67–74.

Knowler D, Bradshaw B. 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy **32:**25–48.

Kocho-Schellenberg JE, Berkes F. 2015. Tracking the development of co-management: using network analysis in a case from the Canadian Arctic. Polar Record **51:**422–431.

Koontz TM, Thomas CW. 2006. What do we know and need to know about the environmental outcomes of collaborative management? Public Administration Review **66:**111–121.

Latkin CA, Knowlton AR. 2015. Social network assessments and interventions for health behavior change: a critical review. Behavioral Medicine **41:**90–97.

Lawrence A, Dandy N. 2014. Private landowners' approaches to planting and managing forests in the UK: What's the evidence? Land Use Policy **36:**351–360.

Maciejewski K, Baum J, Cumming GS. 2016. Integration of private land conservation areas in a network of statutory protected areas: implications for sustainability. Biological Conservation **200:**200–206.

Matous P, Todo Y. 2015. Exploring dynamic mechanisms of learning networks for resource conservation. Ecology and Society **20:** https://doi.org/10.5751/ES-07602-200236.

Noss RF. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology **4:**355–364.

Ostrom E. 2009. A general framework for analyzing sustainability of social-ecological systems. Science **325:**419–422.

Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F, Wilkinson R. 2006. Understanding and promoting adoption of conservation practices by rural landholders. Australian Journal of Experimental Agriculture **46:**1407–1424.

Patton MQ. 2002. Qualitative research and evaluation methods. 3rd edition. Sage Publications, Thousand Oaks, California.

Prell C. 2012. Social network analysis: history, theory, and methodology. SAGE Publications, London.

Prell C, Hubacek K, Reed M. 2009. Stakeholder analysis and social network analysis in natural resource management. Society and Natural Resources **22:**501-518.

Rydin Y, Falleth E. 2006. Networks and institutions in natural resource management. Edward Elgar Publishing Limited, Cheltenham, United Kingdom.

Salpeteur M, Calvet-Mir L, Diaz-Reviriego I, Reyes-García V. 2017. Networking the environment: social network analysis in environmental management and local ecological knowledge studies. Ecology and Society **22:** https://doi.org/10.5751/ES-08790-220141.

Sandström A, Lundmark C. 2016. Network structure and perceived legitimacy in collaborative wildlife management. Review of Policy Research **33:**442-462.

Schusler TM, Decker DJ, Pfeffer MJ. 2003. Social learning for collaborative natural resource management. Society and Natural Resources **16:**309–326.

Serrao-Neumann S, Di Giulio GM, Ferreira LC, Choy DL. 2013. Climate change adaptation: Is there a role for intervention research? Futures **53:**86–97.

Snijders TAB, van de Bunt GG, Steglich CEG. 2010. Introduction to stochastic actor-based models for network dynamics. Social Networks **32:**44–60.

Stolton SR, Kent H, Dudley, N. 2014. The futures of privately protected areas. Protected Area Technical Report Series No. 1. International Union for Conservation of Nature, Gland, Switzerland.

Stroman D, Kreuter UP. 2015. Factors influencing land management practices on conservation easement protected landscapes. Society & Natural Resources **28:**891–907.

Valente TW. 2012. Network interventions. Science **337:**49–53.

Valente TW, Davis RL. 1999. Accelerating the diffusion of innovations using opinion leaders. Annals of the American Academy of Political and Social Science **566:**55–67.

Valente TW, Hoffman BR, Ritt-Olson A, Lichtman K, Johnson CA. 2003. Effects of a social-network method for group assignment strategies on peer-led tobacco prevention programs in schools. American Journal of Public Health **93:**1837–1843.

Vance-Borland K, Holley J. 2011. Conservation stakeholder network mapping, analysis, and weaving. Conservation Letters **4:**278–288.

Wasserman S, Faust K. 1994. Social network analysis: methods and applications. Cambridge University Press, Cambridge, England.

Westerink J, Opdam P, van Rooij S, Steingröver E. 2017. Landscape services as boundary concept in landscape governance: building social capital in collaboration and adapting the landscape. Land Use Policy **60:**408–418.

Wilkinson J. 2006. Network theories and political economy: From attrition to convergence? Pages 11–38 in Marsden T, Murdoch J, editors. Between the local and the global: confronting complexity in the contemporary agri-food sector. Research in Rural Sociology and Development 12, Emerald Publishing, United Kingdom.

Zheng X, Le Y, Chan APC, Hu Y, Li YK. 2016. Review of the application of social network analysis (SNA) in construction project management research. International Journal of Project Management **34:**1214–1225.