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A social network analysis of actors involved in wild pig (*Sus scrofa*) management in Missouri

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Abstract

Wild pigs (*Sus scrofa*) cause significant damage to agriculture and native ecosystems and can transmit diseases to animals and people. Management responses designed to reduce population numbers are needed to mitigate these threats. Identifying networks of key actors, including the ways in which they interact, is valuable for purposes of better understanding opportunities or constraints that generate or impede effective management responses. The goal of our study was to understand the network of organizations, and the personnel working within them, that were active in wild pig management, research, or policy initiatives in Missouri during 2018–2020 by 1) identifying individuals and organizations involved in the network, 2) investigating the attributes of relevant personnel, 3) determining the structural patterns of the network, and 4) examining how the network structure could be optimized to improve communication and collaboration efforts. Results from a social network analysis identified 150 personnel affiliated with 26 organizations actively working on wild pig issues in Missouri. The network was largely homogenous based on respondents' attributes, had low density, and was relatively fragmented, small, decentralized with few ties per node, and separated with few brokers. We emphasize the importance of understanding the strengths and weaknesses of a

network's structure in facilitating effective collective action to manage wild pigs.

KEYWORDS
collective action, feral swine, graph theory, human dimensions, invasive species management, social relationships

Efforts to remediate challenging environmental problems, such as the proliferation of a damaging invasive species, may benefit from the engagement of a variety of actors from public and private sectors (Carlisle and Gruby 2019). Advantages associated with networks of diverse management and governance actors include the generation of knowledge to inform management decisions (Crona and Parker 2012) and the development of capabilities needed to better adapt to social and environmental changes (Folke et al. 2005). In addition, research has shown that the involvement of diverse actors in social networks may be more important than the presence of formal institutions when it comes to effective enforcement and compliance with environmental laws and regulations (Bodin and Crona 2009). With the various benefits that have been theoretically and empirically associated with diverse networks of actors, there has been increasing interest in examining the extent to which such networks exist and function in particular environmental domains. Here, we examine one such network within the context of a seemingly intractable problem, the elimination of non-native and invasive wild pigs (*Sus scrofa*) in the United States.

Since their introduction by Spanish explorers in the 1500s (Belden and Frankenberger 1977), wild pigs have been reported in 35 U.S. states (USDA 2019). With their continued expansion, as well as their social behaviors and opportunistic diet, they cause significant damage to both flora and fauna in ecosystems and agriculture (Seward et al. 2004, Campbell and Long 2009). In addition, wild pigs are key disease vectors, carrying and contributing to the transmission of numerous viruses, bacteria, and parasites that can infect wildlife, domestic livestock, pets, and humans (Bevins et al. 2014, Brown et al. 2018). While estimated costs of wild pig damage, including control costs, have been reported to reach billions of dollars (Pimental 2007, Elsey et al. 2012), the economic impact is likely much greater given inflation, unreported damages, and the continued growth of wild pig populations in the United States (McLean et al. 2021). It is evident there is a need for adequate management responses to mitigate threats by reducing population numbers (Bevins et al. 2014).

At the state level, public and voluntary sector entities (e.g., nonprofits) have implemented a variety of management plans, policies, and strategies to decrease the wild pig population and mitigate species' damage, including eradication efforts (e.g., shooting, trapping, use of a toxic bait) and restrictions on human activities associated with wild pigs (e.g., transportation of wild pigs, sport hunting; Centner and Shuman 2015, Grady et al. 2019). In Missouri, it is unlawful to release wild pigs, and hunting them on lands managed, leased, or owned by the state's Department of Conservation (hereafter MDC) is banned (MDC 2021). In addition to the MDC, other organizations, including those within the federal government (e.g., U.S. Forest Service [USFS], U.S. Department of Agriculture Animal and Plant Health Inspection Service [USDA APHIS]), foundations (e.g., LAD Foundation), and academic institutions (e.g., University of Missouri) are active in addressing wild pig issues in the state, including by conducting research, implementing policies, and assisting private landowners in reducing population numbers on their properties (Pierce and Martensen 2018, MDC 2021). The MDC, USFS, USDA APHIS, and LAD Foundation have come together to create the Missouri Feral Hog Elimination Partnership, which has worked to trap and remove wild pigs from the landscape with the goal of eradication in the state (MDC 2021). Due in part to the partnership, as well as more stringent state laws, wild pig populations in Missouri have become largely isolated, occurring in only about 4% of counties, and often only spreading due to human-mediated movement (MDC 2021). With the established collective effort, it is advantageous for relevant organizations to continue enhancing communication and collaboration efforts within and between organizations to eradicate wild pigs in Missouri.

In natural resource management, analysis of networks of key actors can help discern how social relationships might improve or impede initiatives to remediate challenging environmental problems. Moreover, the process of

identifying stakeholders and investigating their social structures are valuable steps in understanding ways to generate collective action (Bodin et al. 2006, Bodin and Crona 2009, Prell et al. 2009, Omondiagbe et al. 2017). To do so, social network analysis (SNA) can be used to measure, map, and analyze actor attributes (e.g., demographics, occupational position, attitudes), relations, and interactions (Tichy et al. 1979, Blanchet and James 2012), including how actors are positioned in a network and how social relationships create general network patterns (Wasserman and Faust 1994, Scott 2000). With SNA, a network consists of a number of nodes (also referred to as vertices) that are connected by ties (also referred to as links and edges). Generally, a node represents an individual or a group of individuals, and the ties are any social connection between them. Together, the nodes and ties reveal the structural dynamics of a social network that can be visualized via sociograms, as well as quantified and linked to various characteristics that affect network function.

Many studies have used SNA to reveal networks of actors involved in natural resource management and to investigate opportunities and impediments to collective action. For example, Cunningham et al. (2016) described the local actors and mapped their knowledge acquisition and diffusion regarding climate policy in the Shoalhaven region in Australia to better outline key implications of local community engagement. Alexandrescu et al. (2016) sought to identify stakeholders in a network relating to a brownfield site in Italy and to assess their social embeddedness in order to foster stakeholder involvement in regeneration processes. Similarly, Omondiagbe et al. (2017) sought to identify stakeholders, map their relationships via an SNA, and examine how the network structure could aid in collaborative efforts toward invasive species management in New Zealand. Similar studies have highlighted actors and their social relations, for example, regarding the governance of vernal pools in Maine, USA (Levesque et al. 2017) and changes in rural uplands in the United Kingdom (Prell et al. 2009) to enhance participatory and collaborative natural resource management efforts.

Social networks can be instrumental in generating certain advantages in the management of natural resources (e.g., learning and adaptation), and such networks can be examined with considerable analytical precision via the measures, characteristics, and social concepts provided by SNA (Ramirez 1999, Dougill et al. 2006, Lockie 2006). Concerning the reduction of wild pig populations in Missouri, identifying individuals and organizations involved, as well as using SNA to measure and evaluate the strength and weaknesses of the network structure can facilitate optimization of communication and collaboration efforts needed for effective management of this invasive species. Our research will be useful not only for governing agencies in Missouri, but also for other agencies and task forces (an alliance of technical and scientific leadership from state, federal, provincial, and private conservation partners working to reduce free-ranging populations of wild pigs in North America) looking to find ways to improve collaborative efforts in their own states. Moreover, there is a need for empirical research that analyzes and quantifies network characteristics to build on practical uses of SNA in natural resource governance contexts (Bodin and Crona 2009). In response to the need for more research in this area and its utility for enhancing future wild pig management plans in Missouri and in other states affected by wild pigs, the goal of our study was to explore and characterize the network of organizations active in wild pig management, research, or policy initiatives in Missouri during 2018–2020. More specifically, our objectives were to 1) identify individuals and organizations involved in wild pig management, research, or policy initiatives in Missouri, 2) investigate the attributes (e.g., demographics, occupational position, attitudes) of relevant personnel working within these organizations, 3) determine the structural patterns of the social network, and 4) examine how the network structure can be optimized to improve communication and collaboration efforts.

STUDY AREA

Missouri is located in the Midwestern region of the United States and was considered a high-priority state by the National Feral Swine Damage Management Program (NFSDMP) regarding the allocation of management funds during our study. Wild pigs can be found in an estimated 30 counties in Missouri (4% of all counties; MDC 2021). In general, their population is relatively small and dispersed across the state, however, some larger-sized groups can be

found in the Ozark and west-central regions. Before recent and ongoing efforts to reduce the wild pig population in the state, their proliferation occurred in the 1990s when recreational hunting of the species gained popularity. Over time, European wild boar were raised as an alternative to domestic swine and for hunting in captive facilities, and eventually, escaped or were intentionally released onto the landscape. Since then, the MDC has received complaints from landowners regarding wild pig damage on their property. In addition to the damage they cause on private land (e.g., consumption of crops), they have also caused significant damage to natural areas on public land (e.g., Mark Twain National Forest; Pierce and Martensen 2018, MDC 2021).

METHODS

The methodological framework that guided our data collection and analysis was borrowed from two approaches in the SNA literature: an ego-centric approach, which focuses on network actors and their local relationships (Marsden 2005), and a socio-centric or whole-network approach, which focuses on sets or interrelated actors in a bounded social collective (Marsden 2005). First, we imposed an ego-centric approach during data collection via snowball sampling (i.e., a technique in which existing subjects provide referrals to recruit new subjects until no new subjects are identified [Bryman 2008]) while setting network boundaries around those who were involved in wild pig management issues in Missouri during 2018–2020. Considering that snowball sampling can increase the primary sample and the representativeness of actors involved (Noy 2008), we took this approach to identify the full range of actors in our target network, both known and unknown. We then implemented a whole-network approach in which all individuals and their relationships that emerged from the first step were used to analyze the target network. Given our attempt to bound the target network and our implementation of a snowball sampling approach, we surmised that all possible actors were considered in the analyses (Alexandrescu et al. 2016). Indeed, it is common for whole-network studies to consider their target networks as bounded for analytical purposes (Prell 2012, Vittoria and Lubrano Lavadera 2014). Previous research has shown that both ego-centric and socio-centric approaches can provide complementary viewpoints on the same data (Marsden 2005). Beyond conducting macro-level analyses to determine the structure and positions at the level of the whole network, we also conducted relevant micro-level analyses to assess structural characteristics at the level of individual actors. Social network analysis is useful in bridging the successive micro- and macro-levels that are embedded within one another (Galaskiewicz and Wasserman 1994), which can provide central insights regarding shared meanings and multi-level interactions (e.g., individual and organizational interactions) within wider contexts in which social events occur (Racherla and Hu 2010, Scott 2013).

Following this approach, we first asked a small number of specialized informants (i.e., actors with a great deal of knowledge in the area of interest [Bernard 2017]) to identify organizations, both public and private, involved with wild pig management or policy issues in Missouri. Informants were selected following discussions with senior management staff from the USDA APHIS' NFSDMP. To supplement and refine the list of organizations identified via specialized informants, we conducted internet searches and reviewed reports from the NFSDMP, the National Wild Pig Task Force, and Missouri's task force. From there, two specialized informants with the MDC and USDA APHIS assisted us in building an initial list of individuals (names, email addresses, and affiliated organization names) currently active in wild pig management, research, or policy initiatives in the state. The goal of this step was to collect the names and email addresses of central personnel from each organization identified, as well as identify any additional personnel or organizations that may not have been initially identified.

Once the primary sample of personnel was determined, sample members were emailed and invited to participate in an online survey via Qualtrics online survey tool (Qualtrics, Provo, UT, USA). Participants were asked to provide their name, email address, affiliated organization, and names of other individuals (both within and outside of their organizations) with whom they had communicated about wild pig management, research, or policy within the past two years (2018–2020). We then followed a snowball sampling approach using names generated by the survey to send out additional survey invitations. We continued this process until the names identified in the survey

began to repeat (Sandström 2011), and no new names were mentioned (Bryman 2008). Questionnaires were only sent to individuals who were employed by or affiliated with an organization (i.e., self-employed individuals were excluded). The initial questionnaire distribution occurred on March 10, 2021, and two reminders were sent to each individual two-and four-weeks later. After the initial distribution, six additional distribution events occurred where questionnaire links were emailed to new individuals that were identified (n = 150 individuals; response rate 55%). As fewer individuals were identified, reminders were sent one-and two-weeks post initial contact for efficiency purposes and the questionnaire closed on September 10, 2021.

Before distributing the questionnaire, questions were tested and reviewed by a small, independent group of individuals (n = 11) familiar with the topic of wild pig management in Missouri and the United States more broadly. During the pre-testing stage, we asked respondents to provide feedback on the clarity of questions and response options, logic and flow of content, length and completion adherence, and technical quality of Qualtrics. The questionnaire was revised where appropriate based on the comments received. Once finalized, the questionnaire consisted of three sections: 1) background information (e.g., their primary field of work and work role), 2) relational information (i.e., data concerning the way in which two or more individuals were connected), and 3) demographic information (e.g., age, level of education; Supplementary Appendix A). To ensure the questionnaire was being completed by individuals within our target network, we asked the initial question: "Within the past 2 years, have you actively participated in any management, research, and/or policy initiatives related to wild pig issues in Missouri?" Only those who answered yes were prompted to continue (n = 66). For those who identified as being a part of our target network, we asked questions related to their relevant work background to get a better understanding of the breadth and depth of organizations and individuals involved. The questions included the name of the primary organization they worked for (or were affiliated with), organization type (e.g., the federal government, state government, nonprofit), organization's primary geographic focus (e.g., international, national, statewide), primary field of work (e.g., fish and wildlife, forestry, land use), work role (e.g., staff or faculty, contractor, volunteer), type of work (e.g., administration/management, analysis, fieldwork), years worked in their primary organization, and years worked on wild pig issues. Furthermore, to understand inter-organizational involvement (i.e., secondary organization affiliation), we asked respondents, "As it relates to your involvement in wild pig issues in Missouri, are you affiliated with any other organizations?" For those who said yes, we asked them to provide us with the organization's name. In doing so, we accounted for the possibility that a respondent could work or volunteer for multiple organizations involved in wild pig management issues in Missouri. Beyond investigating respondents' relevant work background and organization affiliations, we also asked about their attitudes and perceptions of wild pig management in Missouri to better understand how actors within identified organizations perceived the issue and their roles in the network. This included their level of agreement (on a scale of 1 = strongly agree to 7 = strongly disagree) with wild pig eradication in Missouri, and their perceived level of success (on a scale of 1 = very successful to 5 = not at all successful) of wild pig management in Missouri. Moreover, we asked about the perceived level of power (on a scale of 1 = a great deal to 5 = not at all) that they and their organization held in influencing wild pig management decisions in Missouri.

In the second section of the questionnaire, we collected relational information. We asked each respondent to list up to 10 different individuals whom they had communicated with about wild pig management, research, or policy within the past two years, along with their email address and the name of the organization they were primarily affiliated with (including both those within and those outside of their primary organization). We also asked who initiates communication the majority of the time to determine the directionality of the connection. When two respondents named each other as individuals whom they had communicated with, and both stated they initiated communications the majority of the time, connections were considered reciprocal and were therefore not directional. Moreover, to better understand the nature of relationships between individuals in the network, we investigated the extent to which collaborative efforts were taking place (e.g., the development of informal relationships, meeting regularly, and engaging in collective decision-making). We further asked respondents to characterize whether the individuals they identified were critical to the success of wild pig policy initiatives in Missouri. In the final section of the questionnaire, we included a list of demographic questions, including gender, age, and race or ethnicity.

Qualtrics was used to calculate descriptive statistics of background data and respondent attributes, and Gephi SNA software (Bastian et al. 2009, version 0.9.2) was used to analyze relational data and create relevant sociograms. Relational data was exported from Qualtrics, reformatted, and saved as a series of Microsoft Excel files (interactions, nodes, and edges) related to the communication and collaboration network levels. Each set of files was then imported into Gephi. Once in Gephi, communication and collaboration sociograms were built and network-level statistics for each graph were calculated including graph density, centralization, diameter, number of components, and modularity. In addition, node-level statistics were calculated, including degree centrality and betweenness centrality. For the communication graph, ties were interpreted as nondirectional ties prior to the calculation of statistics (Wasserman and Faust 1994).

Data from the demographic questions, background questions, and attitudinal questions were used to calculate the degree of homogeneity and thus get insight into network homophily (Somashekhar 2014). Homophily occurs when actors with similar attributes prefer to interact with one another (Friedkin 1998, Skvoretz et al. 2004). Attributes include status characteristics, which encompass both ascribed characteristics (e.g., age, race or ethnicity, sex or gender) and acquired characteristics (e.g., education, occupational position), as well as value characteristics involving association with others who think in similar ways (e.g., beliefs, attitudes) regardless of differences in status characteristics (Lazarsfeld and Merton 1954).

To gain insight into the network's density, graph density was calculated by taking the total number of ties in the network and dividing it by the number of ties in a complete network. Density is the proportion of possible ties in a network that actually exist and measures the degree to which all actors are tied to one another (Wasserman and Faust 1994). A density score of 1 signifies that all nodes in the network are tied to one another, and a density score of 0 signifies the network is entirely disconnected (Prell et al. 2009), with scores between 0 and 1 representing intermediate levels of connectedness/disconnectedness among nodes in the network. Like network density, reachability encompasses the accessibility to many individuals and measures whether actors within a network are connected, either directly or indirectly, to all other actors (Bodin et al. 2006). To get insight into the network's reachability, the diameter and number of components were calculated. The diameter is the longest path of ties between two nodes in a network. A component is a subnetwork within the greater network in which all nodes are tied to one another, either directly or indirectly. If a network contains more than one component, it is considered fragmented (Bodin et al. 2006).

To get an understanding of centrality, degree centrality scores for each node and the network's centralization score were calculated. At the node level, a high degree of centrality indicates that an actor has many ties compared to other actors, and at the network level, it indicates the tendency for a few actors to have many ties (i.e., degree of network centralization; Bodin et al. 2006). A centralization score of 1 signifies that the maximum number of ties possible converge on one node, and a score of 0 signifies an entirely connected network (i.e., all actors are connected to one another; Prell et al. 2009). Like density, centrality scores between 0 and 1 represent intermediate levels of this node characteristic. Lastly, to get insights on betweenness, betweenness centrality scores for each node and network modularity scores were calculated. At the node level, betweenness centrality is the degree to which each node contributes to minimizing the distance between nodes in a network and can be measured by how often a node appears on the shortest paths between nodes (Freeman 1979, Bodin et al. 2006). Actors with high betweenness centrality (i.e., brokers) contribute the most to connecting nodes that would otherwise not be directly tied (Burt 2003). At the network level, modularity is used to investigate betweenness and is a measure to quantify the degree of network separation into smaller groups, modules, or communities (Bodin et al. 2006).

RESULTS

A variety of public organizations including federal and state governments, universities, and groups within the voluntary sector including foundations, associations, and nonprofits were identified as active in wild pig management, research, or policy initiatives in Missouri during 2018–2020. This included 20 organizations that

respondents primarily worked for within state or federal governments (87%)–with the MDC and USDA APHIS being the two most represented organizations (56%; Table 1). Six additional organizations were also identified as being involved by at least one respondent via their secondary affiliation status. These organizations were exclusively voluntary sector entities, including the Conservation Federation of Missouri, Missouri Cattlemen's Association, Missouri Pork Association, Missouri Society of American Foresters, National Cattlemen's Association,

TABLE 1 Primary organizations identified as active in wild pig management, research, or policy initiatives in Missouri, USA, 2018–2020.

Organization name	Organization type[a]	Organization's geographic focus[a]	Percent of network
Missouri Department of Conservation	State government	Local, Statewide	31.21% (*n* = 44)
United States Department of Agriculture/ Animal Plant Health Inspection Service	Federal government	Local, Watershed, National	24.82% (*n* = 35)
United States Army Corp of Engineers	Federal government	Statewide, National, International	10.64% (*n* = 15)
United States Department of Agriculture/ Forest Service	Federal government	Local, Statewide, Regional or Multi-state, National	6.38% (*n* = 9)
National Park Service	Federal government	Watershed, Local, Regional or Multi-state	4.96% (*n* = 7)
LAD Foundation	Nonprofit	Local	3.55% (*n* = 5)
United States Fish and Wildlife Service	Federal government	Watershed, National, International	3.55% (*n* = 5)
Mississippi State University	Education/academic/ research	Regional or Multi-state, International	2.84% (*n* = 4)
University of Missouri	Education/academic/ research	Statewide	2.13% (*n* = 3)
United States Department of Agriculture/ Natural Resource Conservation Service	Federal government	National	1.42% (*n* = 2)
United States Department of Agriculture/ Office of General Counsel	Federal government	-	1.42% (*n* = 2)
Bird Conservancy of the Rockies	Nonprofit	-	0.71% (*n* = 1)
Missouri Department of Agriculture	State government	Statewide	0.71% (*n* = 1)
Missouri Department of Natural Resources	State government	Statewide	0.71% (*n* = 1)
Missouri Farm Bureau	Nonprofit	Regional or Multi-state	0.71% (*n* = 1)
National Wild Turkey Federation	Nonprofit	Regional or multi-state	0.71% (*n* = 1)
New Mexico State University	Education/academic/ research	International	0.71% (*n* = 1)
Noble Research Institute	Nonprofit	-	0.71% (*n* = 1)
Pennsylvania State University	Education/academic/ research	-	0.71% (*n* = 1)
United States Geological Survey	Federal government	-	0.71% (*n* = 1)

[a]Every response option selected by respondents is reported. Singular response options signify respondent consensus and empty cells are due to a lack of data.

and The Nature Conservancy. No private sector entities were identified as being involved in wild pig management issues in Missouri.

Approximately 73% of respondents were male, 87% were white, and 55% were between the ages of 45 and 64. Half of the respondents (49%) worked primarily in the fish and wildlife field, followed by 23% who worked primarily in the conservation field. A majority of respondents (95%) were staff or faculty in their respective primary organizations. Approximately 25% of respondents worked in administration/management, 26% worked in program coordination/project management, 26% worked in fieldwork, and 15% worked in research. A quarter of respondents (25%) worked 1–5 years in their primary organization, 22% worked 16–20 years, and there was an even distribution of respondents (14% each) who worked between 6–10, 11–15, and 21–25 years in their primary organization. Almost half of the respondents (46%) worked on wild pig issues between 1–5 years, followed by 25% who reported they had worked on wild pig issues between 6–10 years. Moreover, as it related to their involvement in wild pig issues in Missouri, 28% of respondents were affiliated with a secondary organization.

Regarding beliefs and attitudes, there was a near consensus concerning the goal of wild pig eradication in Missouri, with 91% reporting that they strongly agreed with complete removal. Among the 9% of respondents ($n = 7$) who did not strongly agree with complete removal, 2 were from state government organizations, 2 were from federal government organizations, and 3 were from education/academic/research organizations. There was also general agreement that wild pig management in the state had achieved some level of success, with approximately 57% believing it was somewhat successful and 43% believing it was very successful. Respondents differed in their perceived level of personal power in influencing wild pig management decisions in Missouri. While 29% indicated that they felt they had a moderate level of influence on wild pig management decisions, 42% felt they had little influence. Even so, respondents were confident in their perceived level of organizational power, with 72% stating they believed their primary organization had a lot (35%) or a great deal (37%) of influence. Lastly, out of all personnel identified by respondents, 79% were believed to be critical to the success of wild pig policy initiatives.

The communication aspect of the network (communication graph) included 141 personnel from 20 different primary organizations, connected by 241 ties of differing strengths (Figure 1A). The strength of ties is set, by default, with an edge weight equal to one in Gephi, and parallel edges are automatically merged to increase the weight. The collaboration aspect of the network (collaboration graph) included 125 personnel from 19 different primary organizations, connected by 211 ties of differing strengths (Figure 1B). Between the two graphs, we were able to calculate network-level measures (Table 2) and relevant node-level measures to get a better understanding of overall structural patterns.

Both the communication and collaboration graphs' density scores were low, indicating a high degree of network disconnection and fewer ties between nodes. Regarding reachability, the communication and collaboration graph's diameters were seven and eight, respectively, indicating that both levels of the network had relatively less access among individuals. Moreover, the communication graph had more than one component, indicating a fragmented network. We note that the high proportion of component subgroups is due to eight nodes not being connected to any other nodes (Figure 1A). On the other hand, the collaboration graph had only one component, indicating a completely connected network with no fragmentation.

The centralization scores indicated a somewhat decentralized network with more nodes having a few ties rather than a few nodes having many ties. The average number of ties per node in the communication graph and collaboration graph was 3.443 (SD = 4.248) and 3.376 (SD = 3.864), respectively, with most nodes in either graph having one tie. Concerning betweenness, the modularity scores highlighted a relatively high degree of separation into smaller communities, with the communication graph having 15 communities and the collaboration graph having eight. In the communication graph, nodes appeared on the shortest paths between nodes in the network an average of 175.579 (SD = 378.232) times and 182.920 (SD = 375.435) times in the collaboration graph, with most nodes in either graph lying on these paths zero times. Regarding the nodes with relatively higher degree centrality scores (≥ 756; 90th percentile) in the communication graph, there were 15

individuals who linked actors who would otherwise not be tied. These individuals included personnel from USDA APHIS (n = 7), MDC (n = 3), USACE (n = 2), NPS (n = 1), USDA FS (n = 1), and Mississippi State University (n = 1; Figure 1A). In the collaboration graph, there were 14 individuals with relatively higher degree centrality scores (≥723; 90th percentile) from, USDA APHIS (n = 7), MDC (n = 2), USACE (n = 2), NPS (n = 1), USDA FS

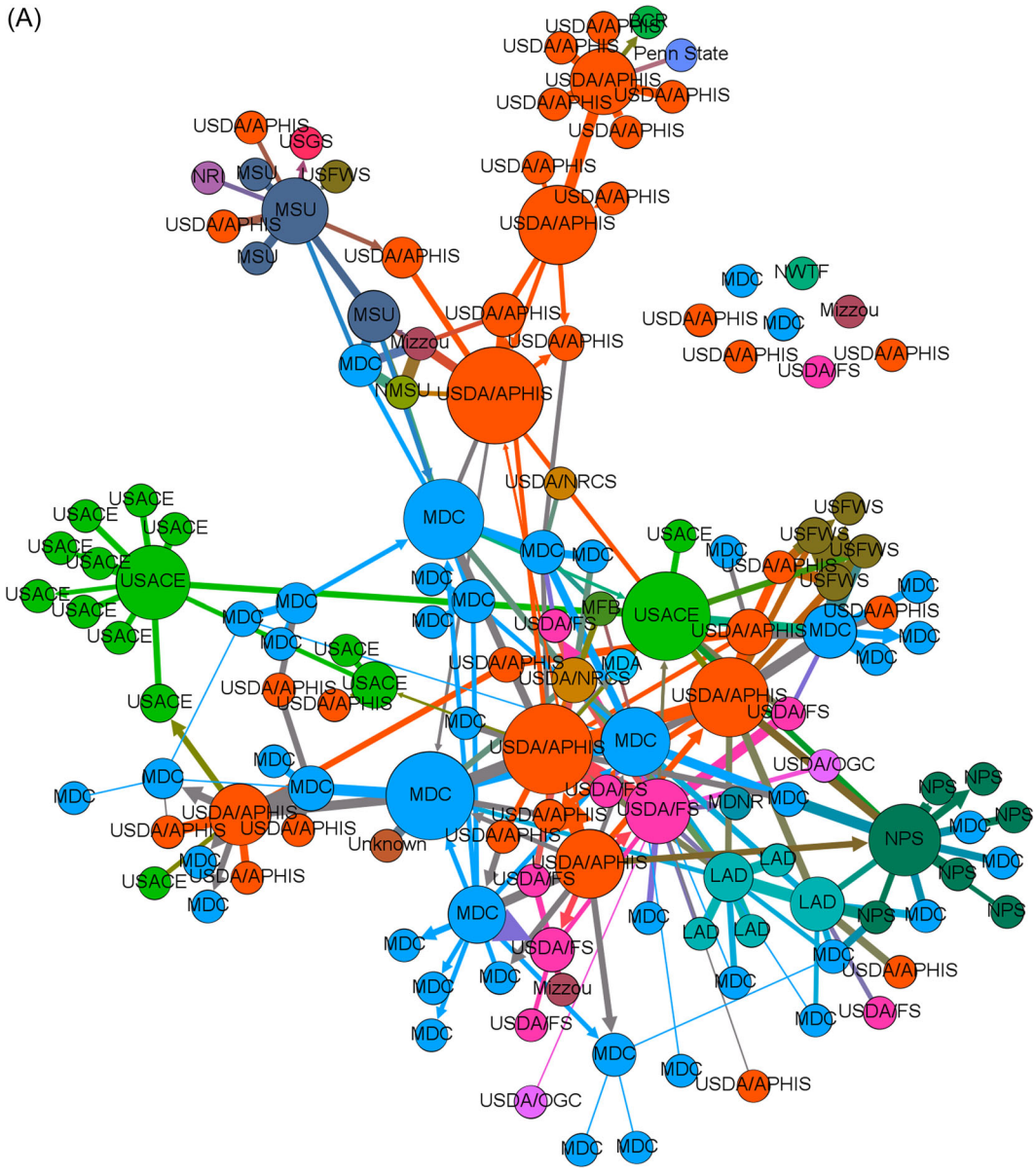

FIGURE 1 Network of primary organizations active in A) communication and B) collaboration efforts regarding wild pig management, research, or policy in Missouri, USA, 2018–2020. The size of the circles reflects the node's betweenness centrality, the thickness of the edges reflects the strength of the tie, and the colors of the nodes represent their primary organization (as also labeled). Edges with no arrows (i.e., undirected) show a reciprocal connection (Borgatti et al. 2009). In the communication graph (a), the edges with arrows show how communication was being directed, with arrows pointing from those who initiate communication the majority of the time to those who do not.

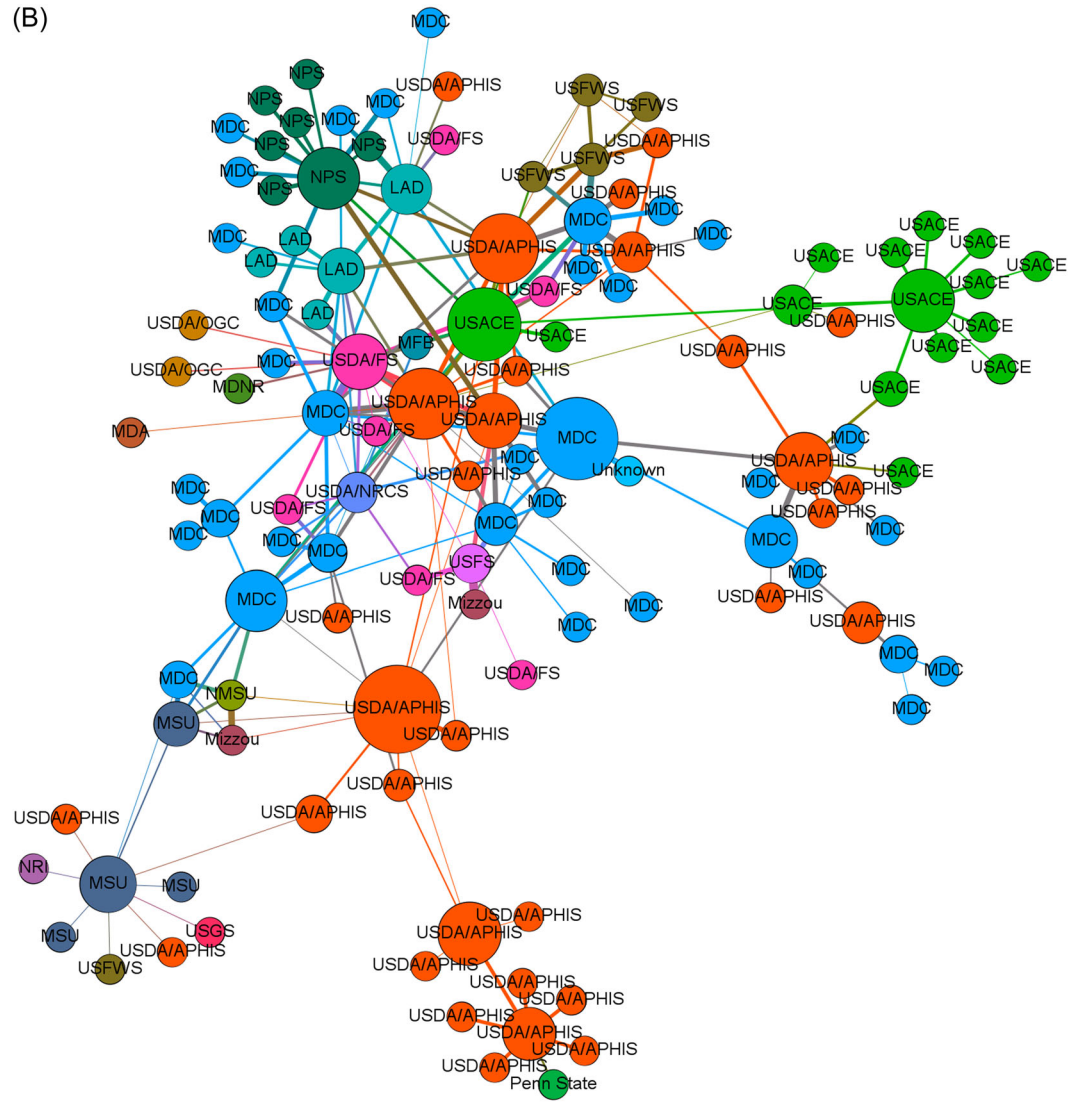

FIGURE 1 Continued

TABLE 2 Network-level statistics for communication and collaboration graphs that encompass the primary organizations, and personnel within them, that were identified as active in wild pig management, research, or policy initiatives in Missouri, USA, 2018–2020.

	Density	Reachability			Betweenness
	Graph density	Diameter	Number of components	Centrality Centralization	Modularity (Number of communities)
Communication graph	0.025	7	9	0.316	0.621 (15)
Collaboration graph	0.027	8	1	0.254	0.599 (8)

(n = 1), and Mississippi State University (n = 1; Figure 1B). Comparatively, there were few differences between the communication and collaboration levels of the network, suggesting a highly similar network of actors who were both communicating and collaborating with others.

DISCUSSION

To help governing bodies optimize initiatives to remediate challenging environmental problems, it is useful to identify relevant actors and investigate the social patterns that connect them. Our study provides a quantitative assessment of actors involved in wild pig management in Missouri. Using Missouri as a case study, we have successfully demonstrated the ability of SNA to reveal important insights into the relationships that have emerged between actors active in wild pig management, research, or policy initiatives in Missouri during 2018–2020. Our study revealed that actors from federal and state governments, voluntary sector entities, and universities were all involved in the network, though government actors accounted for most of the network. In terms of the network's structure and characteristics, we found that the network was largely homogenous in terms of respondents' attributes, had low density, and was relatively fragmented, small, decentralized with few ties per node, and separated with few brokers. Given the need to balance the different, and often opposing, structural characteristics of social networks to enhance the governance of natural resources (Bodin et al. 2006, Janssen et al. 2006, Prell et al. 2009), we discuss the strengths and weaknesses of the target network's structure in guiding collective action for effective management of wild pigs in Missouri.

While we took a common, whole-network approach regarding most of our analyses to describe characteristics of how social networks are connected (Marsden 2005, Prell 2012, Vittoria and Lubrano Lavadera 2014), we give caution to the generalizability of our network-level results and interpretations, as there may be some ambiguity in our network boundary. The characteristics used to describe the social network in this study included homophily, density, reachability, centrality, and betweenness. As evidence of homophily, the network can be seen as having a high degree of homogeneity in terms of respondents' attributes. The majority fell into similar organization types, fields of work, and primary work roles, and most had similar sociodemographic characteristics. Moreover, the majority of respondents held similar attitudes toward wild pig eradication in Missouri. The network was also largely dominated by government actors. Similar stakeholders tend to have a greater mutual understanding which allows them to better communicate complex and often implicit information (Prell et al. 2009). In addition, with a near consensus on the goal of wild pig eradication, there may be less conflict in achieving a socially desirable goal and greater cohesion and sense of purpose among network members (Johnson et al. 2003). Moreover, given the narrow focus of the network (wild pig management), it is not surprising that the majority of respondents fell into similar fields of work. However, to the extent the network lacks individuals with different types of knowledge (e.g., scientific/technical versus local-contextual), varied life experiences, and diverse points of view, it may not realize some of the advantages ascribed to optimal and well balanced social networks, such as the capacity to adapt policies and institutions to changing ecological and social conditions and the capacity for creating and sharing new knowledge (Crona and Bodin 2006, Newman and Dale 2007, Prell et al. 2009).

It is important to note that although respondents exhibited a relatively high degree of homogeneity on the variables we measured, there are important caveats. First, we relied primarily on government personnel to identify key informants for our study, and as such, our resulting primary and secondary samples may have had a disproportionate number of government actors including those from the organizations with which our specialized informants were affiliated (i.e., USDA APHIS and MDC). Second, the demographic characteristics and attitudes of respondents may not necessarily be reflective of the demographic characteristics and attitudes of personnel in their organizations more broadly, including other personnel involved in wild pig issues. As such, there may be a greater diversity of individuals and organizations in the network than is represented by our results. We nevertheless believe

it important to highlight the benefits of having diverse representation in the network, including more organizations drawn from the private and nonprofit sectors, individuals with varying work roles (e.g., volunteers), fields of work (e.g., social sciences), work focus (e.g., research) and demographics (e.g., females, multi-racial). This would be particularly advantageous given the need for collective action by multiple communities in the state to manage wild pigs on public and private lands.

In light of our finding that 42% of respondents felt they had little power in influencing wild pig management decisions in Missouri, we also highlight the potential benefits of empowering actors in the network. Empowering stakeholders can enhance collaboration in resource management contexts (Ernstson et al. 2009). Moreover, when networks exhibit power asymmetries, they may become dominated by a hegemony of ideas and interests that stifle dialogue and creative problem-solving (Carlisle and Gruby 2019).

Both the communication and collaboration graphs' density scores were low, indicating a higher degree of network disconnection and fewer ties between nodes. With higher network density, there may be more opportunities for collaboration among individuals within and across organizations and greater potential for collective action (Olsson et al. 2004, Hahn et al. 2006, Bodin and Crona 2009). However, a high degree of network density may result in the homogenization of experiences and knowledge (e.g., network actors may coalesce around similar management strategies) which in turn can reduce the potential for innovation (Oh et al. 2004, Bodin and Norberg 2005, Crona and Bodin 2006). In this case, an increase in density would likely benefit the network given that more social relations can increase trust among individuals and groups (Coleman 1990, Pretty and Ward 2001) and decrease the risk and cost of collaboration (Cohen et al. 2001, Burt 2003). Additionally, increasing the network's density could aid in the accessibility of information (Weimann 1982, Abrahamson and Rosenkopf 1997) and contribute to the development of social norms regarding acceptable management actions (Coleman 1990) to help reduce the wild pig population in Missouri. Increasing the network's density would also allow others to fill positions and continue to perform management functions if one or more actors were disconnected from the network (Janssen et al. 2006). This is particularly important considering the greater potential for disruption of the network if an actor were, for example, to take a different position outside of the network or retire.

Regarding reachability, the communication graph indicated a fragmented network due to eight completely disconnected nodes. These nodes represented individuals who were identified as being a part of the network during the development of the initial contact list, but they did not respond to our questionnaire, nor were they subsequently identified by other respondents as being part of the network. These individuals may have played minimal or infrequent roles in the periphery of the network (e.g., high-level executives) or were no longer part of the network (e.g., temporary staff) by the time the questionnaire was administered. However, we suggest that there are many more actors associated with these organizations who are intermittently or loosely connected, especially when considering the breadth and depth of personnel working within the key government organizations. We recommend that key actors consider the potential for fragmented subgroups and work to communicate and engage with organizations more broadly to maximize the efficiency of management initiatives. Connecting fragmented subgroups goes hand in hand with our recommendation to increase network density, as the graphs' diameters indicated a relatively low degree of reachability to others in the network. Increasing access to more people in a network can enhance knowledge transfer (Oh et al. 2004) and increase collective memory and experiences that are crucial in periods of unforeseen change and uncertainty (McIntosh 2000, Folke et al. 2003).

Regarding centrality, the centralization scores indicated a somewhat decentralized network with more nodes having a few ties rather than a few nodes having many ties. While there has been some evidence that shows a positive correlation between a higher degree of network centralization and collective action due to the positive effect central actors have on coordination (Sandström 2008), rapid response (Leavitt 1951), and diffusion of information (Prell 2003, Bodin et al. 2006), there is more evidence to show that highly centralized networks can lead to uneven distribution of power (Ernstson et al. 2009), may decrease heuristic learning (Leavitt 1951, Shaw 1981), and may not be sustainable given that they are less proficient in carrying out multifaceted initiatives (Bodin and Crona 2009). Considering these factors, as well as the well-developed stage in which the governing

organizations are working to control Missouri's wild pig population, it is likely beneficial that this network is in fact less centralized (Bodin and Crona 2009). In addition, it is also beneficial that there are more actors with few ties because it is probable that these social connections between actors are strong and are having a positive impact on the influence and connectivity of diverse segments of the network (Prell et al. 2009).

Lastly, concerning betweenness, the modularity scores highlighted a relatively high degree of separation into smaller communities, and the distribution of betweenness centrality scores highlighted the infrequency of brokers. The level of separation into smaller communities is likely advantageous, as a certain degree of modularity is needed to maintain heterogeneity of actors and knowledge which is important for innovation (Folke et al. 2005). It might also be likely that the relatively high degree of modularity is helping to maintain stronger links within organizations which are important for the transfer of tacit knowledge (Reagans and McEvily 2003). Nevertheless, we recommend central organizations and brokers stay vigilant to changes in trust between the various network communities and work to enhance trust whenever possible. Management of wild pigs, like any other natural resource that requires collective action, is facilitated by trust, and a high degree of modularity has the potential to hinder the growth of trust between groups (Borgatti and Foster 2003). Regarding the brokers found in our network, there were relatively few nodes with high betweenness degree centrality scores. While few brokers could challenge the connectedness of the network due to the increased likelihood of network fragmentation when these individuals no longer hold these roles (Borgatti and Foster 2003), we believe it is valuable that these brokers are employed by or affiliated with several different organizations (USDA APHIS, MDC, USACE, USDA FS, and Mississippi State University). With more than one organization maintaining brokers, more organizations are likely to gain access to different group-specific knowledge (Bodin et al. 2006), which is critical during times of crisis (Burt 2003). With their ability to connect groups, as well as increase mobility and diffusion of information (Bodin et al. 2006, Prell et al. 2009), we highlight the emotional burden brokers may carry when dealing with different ideas or groups (Krackhardt 1992, Prell et al. 2009) and recommend they get additional support so they can optimally perform (Long et al. 2013).

Moving forward, future research would benefit from expanding on the social network analysis of actors involved in wild pig management in Missouri and exploring additional approaches that were beyond the scope of this study. While we were able to identify and investigate relevant personnel and organizations, determine structural patterns, and examine the strength and weaknesses of the network, our understanding of the network and SNA's application in natural resource contexts can be improved by investigating more nuanced graph statistics in addition to taking different methodological approaches. For example, it would be practical to look more closely at node- and edge-level statistics, such as in-degree (the number of edges entering a node) and out-degree (the number of edges leaving a node; Freeman 1979), as well as investigating the strength of social ties ("…combination of the amount of time, the emotional intensity, and intimacy (mutual confiding), and the reciprocal services which characterize the tie" [Granovetter 1973; p.1361]). These additional metrics would provide more specific insights on, for example, the type, frequency, directionality, and significance of social relations.

Furthermore, we suggest looking at the network over time given social networks are constantly changing (Bodin and Crona 2009). It would be particularly interesting to see how the network's composition and function change in relation to any change in the wild pig population size in Missouri. We would expect to see a positive correlation between more optimized networks and success in wild pig removal (i.e., decreased number of wild pigs) and a negative correlation between less optimized networks and an increase in wild pig numbers. It would also be advantageous to explore this network starting from a different hierarchical level (e.g., non-governmental actors) (Alexandrescu et al. 2016) to identify any varying network configurations. Moreover, future research should identify key actors and conduct SNAs in other states with wild pig issues and compare the strength and weaknesses in network structures. If particular network structures could be linked to effective wild pig management initiatives, they could be applied to networks in other states to enhance their collective efforts. Lastly, we recommend future research consider combining quantitative (SNA) and qualitative approaches (e.g., interviews), not only to understand the outside perspective of the network (composition and function of social relations) but to also understand the inside perspective (content and perception of the network) via key actors (Edwards 2010).

It would also be advantageous for future research to address certain limitations found in our study. Even though our network boundary was defined by individuals and organizations acting within a geographical location and on a particular issue, we are aware that there is a certain level of measurement error and bias in our initial identification of personnel and organizations (Clarkson 1995, Varvasovszky and Brugha 2000). Indeed, there is an acknowledgment in the SNA literature that there are many ways to define or bound a network, and each inherently is unique in terms of its strengths and weaknesses (Marsden 1990). In this case, determining the network boundary was challenging given that the population from which we sampled was largely unknown (Prell et al. 2009). In addition, by working with governmental, specialized informants to build our initial list of actors, we potentially overlook additional actors, for example, non-governmental actors that were active in wild pig management, research, or policy initiatives in Missouri during the period of interest. However, we highlight the importance of this exploratory approach in illuminating additional parts of the network not initially recognized and in describing the strength and weaknesses of such a network to better inform wild pig management.

Another limitation of our study emerged when we found that there was some apprehension about taking part in our questionnaire because respondents were not comfortable providing others' names and email addresses or believed it was a phishing attempt. Beyond the explanation that was provided in the questionnaire, we responded to all direct inquiries and provided further clarification regarding the purpose of our approach and the confidentiality protocol in place. While we are unaware of how much this affected the willingness of personnel to be involved in the study, we understand that the network identified may not fully represent all personnel working on wild pig issues in Missouri. We are, however, confident that between our investigative approach and snowball sampling, we sufficiently outlined our target network boundary, identified key actors, and determined the roles and influence of the actors that were identified. To this point, out of all personnel identified, 79% were believed to be critical to the success of wild pig policy initiatives, indicating that the majority of personnel were likely playing key roles in the network. Nonetheless, we do recommend that more awareness is raised regarding future SNA projects, particularly when utilizing name-generating questionnaires to avoid any hesitation or confusion and to encourage questionnaire completion.

MANAGEMENT IMPLICATIONS

Even with the limitations raised, SNA is a useful methodological approach for understanding more than just individual attitudes and beliefs, but rather the connections that relevant stakeholders have and how those connections may impact wildlife management. Our findings provide practical information to help steer effective management efforts of wild pigs in Missouri and in other states affected by wild pigs. Given the complexity and difficulty of controlling wild pigs, the future success of management efforts will depend in part on identifying actors involved, as well as measuring and assessing their social relations. The results of our research can inform relevant actors on their network's strengths and weaknesses and provide guidance for enhancing, for example, social memory, heterogeneity, learning and knowledge transfer, adaptive capacity, and trust. Future research and development of management strategies for wild pigs that incorporate SNA results to optimize social network composition and function will be valuable in facilitating effective collective action to manage this species.

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DISCLAIMER

The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA, U.S. Government determination or policy.

CONFLICT OF INTEREST

The authors report no conflicts of interest.

ETHICS STATEMENT

This study was approved by the Institutional Review Board (IRB) of Colorado State University (protocol ID: 3222).

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

REFERENCES

Abrahamson, E., and L. Rosenkopf. 1997. Social network effects on the extent of innovation diffusion: a computer simulation. Organization Science 8:289–309.

Alexandrescu, F. M., E. Rizzo, L. Pizzol, A. Critto, and A. Marcomini. 2016. The social embeddedness of brownfield regeneration actors: Insights from social network analysis. Journal of Cleaner Production 139:1539–1550.

Bastian, M., S. Heymann, and M. Jacomy. 2009. Gephi: an open-source software for exploring and manipulating networks. Pages 361–362 *in* International AAAI conference on weblogs and social media, March 2009, San Jose, California, USA.

Belden, R., and W. Frankenberger. 1977. Management of feral hogs in Florida—past, present, and future. Clemson University, Georgetown, South Carolina, USA.

Bernard, H. R. 2017. Research methods in anthropology: Qualitative and quantitative approaches. Rowman & Littlefield, Landham, Maryland, USA.

Bevins, S. N., K. Pedersen, M. W. Lutman, T. Gidlewski, and T. J. Deliberto. 2014. Consequences associated with the recent range expansion of nonnative feral swine. BioScience 64:291–299.

Blanchet, K., and P. James. 2012. How to do (or not to do)… a social network analysis in health systems research. Health Policy and Planning 27:438–446.

Bodin, Ö., and B. I. Crona. 2009. The role of social networks in natural resource governance: what relational patterns make a difference? Global Environmental Change 19:366–374.

Bodin, Ö., B. I. Crona, and H. Ernstson. 2006. Social networks in natural resource management: what is there to learn from a structural perspective? Ecology and Society 11:1–8.

Bodin, Ö., and J. Norberg. 2005. Information network topologies for enhanced local adaptive management. Environmental Management 35:175–193.

Borgatti, S. P., and P. C. Foster. 2003. The network paradigm in organizational research: a review and typology. Journal of Management 29:991–1013.

Borgatti, S. P., A. Mehra, D. J. Brass, and G. Labianca. 2009. Network analysis in the social sciences. Science 323:92–895.

Brown, V., R. Bowen, and A. Bosco-Lauth. 2018. Zoonotic pathogens from feral swine that pose a significant threat to public health. Transboundary and Emerging Diseases 65:649–659.

Bryman, A. 2008. Social research methods. Oxford University Press, Oxford, UK.

Burt, R. 2003. The social capital of structural holes. Pages 148–189 *in* M. F. Guillen, R. Collins, P. England, and M. Meyer, editors. The new economic sociology: developments in an emerging field. Russell Sage Foundation, New York, New York, USA.

Campbell, T. A., and D. B. Long. 2009. Feral swine damage and damage management in forested ecosystems. Forest Ecology and Management 257:2319–2326.

Carlisle, K., and R. L. Gruby. 2019. Polycentric systems of governance: a theoretical model for the commons. Policy Studies Journal 47:927–952.

Centner, T. J., and R. M. Shuman. 2015. Governmental provisions to manage and eradicate feral swine in areas of the United States. Ambio 44:121–130.

Clarkson, M. B. E. 1995. A stakeholder framework for analyzing and evaluating corporate social performance. Academic Management Review 20:92–117.

Cohen, M. D., R. L. Riolo, and R. Axelrod. 2001. The role of social structure in the maintenance of cooperative regimes. Rationality and Society 13:5–32.

Coleman, J. S. 1990. Foundations of social theory. Belknap Press of Harvard University Press, Cambridge, Massachussetts, USA.

Crona, B. I., and Ö. Bodin. 2006. What you know is Who you know? Communication patterns among resource users as a prerequisite for co-management. Ecology and Society 11:1–7.

Crona, B. I., and J. N. Parker. 2012. Learning in support of governance: theories, methods, and a framework to assess how bridging organizations contribute to adaptive resource governance. Ecology and Society 17:1–18.

Cunningham, R., C. Cvitanovic, T. Measham, B. Jacobs, A. M. Dowd, and B. Harman. 2016. Engaging communities in climate adaptation: the potential of social networks. Climate Policy 16:894–908.

Dougill, A. J., E. D. G. Fraser, J. Holden, K. Hubacek, C. Prell, M. S. Reed, S. T. Stagl, and L. C. Stringer. 2006. Learning from doing participatory rural research: lessons from the Peak District National Park. Journal of Agricultural Economics 57:455–467.

Edwards, G. 2010. Mixed-method approaches to social network analysis. ESRC National Centre for Research Methods, School of Social Sciences, University of Manchester, Manchester, UK.

Ernstson, H., S. Sorlin, and T. Elmqvist. 2009. Social movements and ecosystem services—the role of social network structure in protecting and managing urban green areas in Stockholm. Ecology & Society 13:1–39.

Elsey, R. M., E. C. Mouton, Jr., and N. Kinler. 2012. Effects of feral swine (*Sus scrofa*) on alligator (*Alligator mississippiensis*) nests in Louisiana. Southeastern Naturalist 11:205–218.

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. Annual Review of Environment and Resources 30:441–473.

Folke, C., J. Colding, and F. Berkes. 2003. Synthesis: building resilience and adaptive capacity in social-ecological systems. Pages 352–387 *in* F. Berkes, J. Colding, and C. Folke, editors. Navigating social-ecological systems: building resilience for complexity and change. Cambridge University Press, Cambridge, UK.

Friedkin, N. E. 1998. A structural theory of social influence. Cambridge University Press, Cambridge, UK.

Freeman, L. 1979. Centrality in social networks conceptual clarifications. Social Networks 1:215–239.

Galaskiewicz, J., and S. Wasserman. 1994. Introduction. *In* S. Wasserman and J. Galaskiewicz, editors. Advances in Social Network Analysis: Research in the Social and Behavioural Sciences, Sage, Thousand Oaks, CA, USA.

Grady, M. J., E. E. Harper, K. M. Carlisle, K. H. Ernst, and S. A. Shwiff. 2019. Assessing public support for restrictions on transport of invasive wild pigs (*Sus scrofa*) in the United States. Journal of Environmental Management 237:488–494.

Granovetter, M. 1973. The strength of weak ties. American Journal of Sociology 78:1360–1380.

Hahn, T., P. Olsson, C. Folke, and K. Johansson. 2006. Trust-building, knowledge generation and organizational innovations: the role of a bridging organization for adaptive comanagement of a wetland landscape around Kristianstad, Sweden. Human Ecology 34:573–592.

Janssen, M. A., Ö. Bodin, J. M. Anderies, T. Elmqvist, H. Ernstson, R. R. J. McAllister, P. Olsson, and P. Ryan. 2006. A network perspective on the resilience of social-ecological systems. Ecology and Society 11:1–15.

Johnson, J. C., J. S. Boster, and L. A. Palinkas. 2003. Social roles and the evolution of networks in extreme and isolated environments. Journal of Mathematical Sociology 27:89–121.

Krackhardt, D. 1992. The strength of strong ties: the importance of philos. Pages 216–239 *in* N. Nohria and R. G. Eccles, editors. *Networks and organizations. Structure, form, and action*. Harvard Business School Press, Boston, Massachusetts, USA.

Lazarsfeld, P. F., and R. K. Merton. 1954. Friendship as a social process: a substantive and methodological analysis. Freedom and Control in Modern Society 18:18–66.

Leavitt, H. 1951. Some effects of certain communication patterns on group performance. Journal of Abnormal and Social Psychology 46:38–50.

Levesque, V. R., A. J. Calhoun, K. P. Bell, and T. R. Johnson. 2017. Turning contention into collaboration: engaging power, trust, and learning in collaborative networks. Society & Natural Resources 30:245–260.

Lockie, S. 2006. Networks of agri-environmental action: temporality, spatiality and identity within agricultural environments. Rural Sociology 46:22–39.

Long, J. C., F. C. Cunningham, and J. Braithwaite. 2013. Bridges, brokers and boundary spanners in collaborative networks: a systematic review. BMC Health Services Research 13:1–13.

Marsden, P. V. 1990. Network data and measurement. Annual Review of Sociology 16:435–463.

Marsden, P. V. 2005. Recent Developments in Network Measurement. Pages 8–19 *in* P. J. Carrington, J. Scott, and S. Wasserman, editors. Models and Methods in Social Network Analysis, Cambridge University Press, Cambridge, UK.

McIntosh, R. J. 2000. Social memory in Mande. Pages 141–180 *in* R. J. McIntosh, J. A. Tainter, and S. K. McIntosh, editors. The way the wind blows: climate, history, and human action. Columbia University Press, New York, New York, USA.

McLean, H. E., T. L. Teel, A. D. Bright, L. M. Jaebker, J. M. Tomecek, M. G. Frank, R. L. Connally, S. A. Shwiff, and K. M. Carlisle. 2021. Understanding tolerance for an invasive species: an investigation of hunter acceptance capacity for wild pigs (*Sus scrofa*) in Texas. Journal of Environmental Management 285:112–143.

Missouri Department of Conservation [MDC]. 2021. Feral Hogs in Missouri. <https://mdc.mo.gov/wildlife/invasive-animals/feral-hogs-missouri>. Accessed 15 Jan 2022.

Newman, L., A. Dale. 2007. Homophily and agency: creating effective sustainable development networks. Environment, Development and Sustainability 9:79–90.
Noy, C. 2008. Sampling knowledge: the hermeneutics of snowball sampling in qualitative research. International Journal of Social Research Methodology 11:327–344.
Oh, H., M.-H. Chung, and G. Labianca. 2004. Group social capital and group effectiveness: the role of informal socializing ties. Academy of Management Journal 47:860–875.
Olsson, P., C. Folk, and T. Hahn. 2004. Social-ecological transformation for ecosystem management: the development of adaptive co-management of wetland landscapes in southern Sweden. Ecological Society 9:1–26.
Omondiagbe, H. A., D. R. Towns, J. K. Wood, and B. Bollard-Breen. 2017. Stakeholders and social networks identify potential roles of communities in sustainable management of invasive species. Biological Invasions 19:3037–3049.
Pierce, R. A., and R. Martensen. 2018. Feral hogs in Missouri: damage prevention and control. Agricultural MU Guide, University of Missouri Extension, Columbia, Missouri, USA.
Pimental, D. 2007. Environmental and economic costs of vertebrate species invasions into the United States. Managing Vertebrate Invasive Species 38:2–8.
Prell, C. 2003. Community networking and social capital: early investigations. Journal of Computer-Mediated Communication 8. https://doi.org/10.1111/j.1083-6101.2003.tb00214.x
Prell, C. 2012. Social network analysis: history, theory, methodology. Sage, Los Angeles, London.
Prell, C., K. Hubacek, and M. Reed. 2009. Stakeholder analysis and social network analysis in natural resource management. Society and Natural Resources 22:501–518.
Pretty, J., and H. Ward. 2001. Social capital and the environment. World Development 29:209–227.
Racherla, P., and C. Hu 2010. A social network perspective of tourism research collaborations. Annals of Tourism Research 37:1012–1034.
Ramirez, R. 1999. Stakeholder analysis and conflict management. Pages 101–126 *in* D. Buckles, editor. Cultivating peace: conflict and collaboration in natural resource management. Princeton University Press, Ottawa, Canada.
Reagans, R., and B. McEvily. 2003. Network structure and knowledge transfer: the effects of cohesion and range. Administrative Science Quarterly 48:240–267.
Sandström, A. 2008. Policy networks: the relation between structure and performance. Department of Business Administration and Social Sciences, Lulea University of Technology, Lulea, Sweden.
Sandström, A. 2011. Social networks, joint image building, and adaptability: the case of local fishery management. Pages 288–321 *in* B. Organ, editor. Social networks and natural resource management. uncovering the social fabric of environmental governance. Cambridge University Press, Cambridge, UK.
Scott, J. 2000. Social network analysis: a handbook. Sage Publications, London, UK.
Scott, W. R. 2013. Institutions and organizations: Ideas, interests, and identities. Sage Publications, Newbury Park, California, USA.
Seward, N. W., K. C. VerCauteren, G. W. Witmer, and R. M. Engeman. 2004. Feral swine impacts on agriculture and the environment. Sheep & Goat Research Journal 19:34–40.
Shaw, M. E. 1981. Group dynamics: the psychology of small group behavior. Third edition. McGraw-Hill, New York, New York, USA.
Skvoretz, J., T. J. Fararo, and F. Agneessens. 2004. Advances in biased net theory: definitions, derivations, and estimations. Social Networks 26:113–139.
Somashekhar, M. H. 2014. Diversity through homophily? The paradox of how increasing similarities between recruiters and recruits can make an organization more diverse. McGill Sociological Review 4:1–18.
Tichy, N. M., M. L. Tushman, and C. Fombrun. 1979. Social network analysis for organizations. Academy of Management Review 4:507–519.
U.S. Department of Agriculture [USDA]. 2019. History of Feral Swine in the Americas. <https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/sa-fs-history>. Accessed 15 Jan 2022.
Varvasovszky, Z., and R. Brugha. 2000. How to do (or not to do)... a stakeholder analysis. Health Policy Plan 15:338–345.
Vittoria, M. P., and G. Lubrano Lavadera. 2014. Knowledge networks and dynamic capabilities as the new regional policy milieu. A social network analysis of the Campania biotechnology community in southern Italy. Entrepreneurship & Regional Development 26:594–618.
Wasserman, S., and F. Faust. 1994. Social network analysis: methods and applications. Cambridge University Press, Cambridge, Massachusetts, USA.
Weimann, G. 1982. On the importance of marginality: one more step into the two-step flow of communication. American Sociological Review 47:764–773.

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