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ABSTRACT

Effective natural resource management (NRM) often depends on collaboration through formal and informal relationships. Social network analysis (SNA) provides a framework for studying social relationships; however, a deeper understanding of the nature of these relationships is often missing. By integrating multiple analytical methods (including SNA, evidence ratings, and perception matrices), we were able to investigate the nature of relationships in NRM social networks across five service types (e.g., technical advice, on-ground support) in our case study region, Daly catchment Australia. Only one service type was rated as highly associated with free choice in establishing relationships: technical advice/knowledge. Beneficial characteristics of NRM organizations, such as *collaborative* and *transparent*, were associated with the presence of freely chosen relationships between organizations. Our results suggest a need to improve our understanding of organizational roles and characteristics, in particular for use in applied NRM contexts, such as network weaving or disseminating information.

Introduction

Effective long-term natural resource management (NRM) depends, among other things, on effective collaboration through formal and informal relationships (Ostrom 1990; Pretty and Smith 2004; Barnes et al. 2016). In this context, collaboration refers to actors (i.e., individuals or groups, such as organizations) that together, through various types of social interactions, aim to achieve different NRM goals. The patterns in which actors collaborate can be described and analyzed as social networks (Borgatti et al. 2009; Prell 2012). Social network analysis (SNA) thus provides a framework for understanding how actors come together to form social networks, and what causes and consequences the structural characteristics of these networks bring about (Borgatti et al. 2009; Prell 2012; Bodin, Sandström, and Crona 2017).

The use of SNA in applied research for NRM has been increasingly advocated to integrate stakeholders into the design and implementation of NRM activities, including those aimed at conserving biodiversity (Guerrero et al. 2013; Mills et al. 2014). Key considerations are that natural resources are often common pool (Ostrom et al. 1999) and are embedded in regional governance systems including multiple jurisdictions (Mills et al. 2014); thus, management of these resource requires design and implementation of actions by diverse stakeholders that are not always connected or willing to collaborate. Accordingly, SNA can help to understand how different patterns of collaboration may enable or constrain NRM from planning to implementation, for example, through developing shared goals, knowledge exchange, coordinating and improving collective action, and facilitating group learning, among others (Bodin and Crona 2009; Reed et al. 2009; Henry and Vollan 2014; Bodin 2017). Examples of applied SNA research in NRM include identifying stakeholders who can coordinate management actions at different scales (Guerrero, McAllister, and Wilson 2015); diffusing knowledge across the network (Hubacek et al. 2006; Crona and Bodin 2010; Isaac 2012); identifying well-connected stakeholders to engage with (Prell, Hubacek, and Reed 2009; Mbaru and Barnes 2017); and informing "network weaving" (i.e., catalyzing new networks or building on existing ones through the creation of new connections) to develop or strengthen links among stakeholders (Hubacek et al. 2006; Vance-Borland and Holley 2011).

While the use of SNA to inform NRM is growing, some researchers have identified a need to develop a deeper understanding of the nature of the social relationships, or "ties," captured within the mapped social networks (Prell, Hubacek, and Reed 2009; Mills et al. 2010; Guerrero et al. 2013). Current applications of SNA in NRM have made largely implicit assumptions that (1) actors have a level of choice, or agency (Emirbayer and Goodwin 1994; Robins, Bates, and Pattison 2011; Guerrero, Bodin, et al. 2015), in establishing social ties; and (2) actors engage with other actors because they perceive that the relationship will be beneficial (Grootaert and van Bastelaer 2001). If these assumptions are not fulfilled, an important question emerges: can the desired NRM outcomes be achieved from collaborations in instances when actors do not have choice in establishing the relationship and/or they do not consider the relationship to be beneficial? For example, actors can be obliged to have a relationship with another actor (e.g., a pastoralist collaborating with a grazing association) (see also Sayles and Baggio 2017). In this example, the pastoralist may have limited agency if there is only one association to work with; thus, the interpretation of such collaboration (e.g., as an effective conduit for knowledge exchange) and its broader effects on NRM outcomes can be questioned. Similarly, building on existing social networks to design and implement NRM on the basis of the observed collaborative ties between actors, without understanding perceptions of the relationships and actors within the network, may not lead to the desired outcomes.

We propose that understanding the level of agency, factors that influence the establishment of relationships in social networks, and nature of relationships is critical when using and interpreting SNA in NRM. The goal of our study is to use multiple methods to examine collaboration among organizations participating in NRM and the underlying level of agency and implicit perceptions of actors to describe the nature of their relationships. We focus on organizational collaboration, defined as two organizations working together to undertake NRM activities (e.g., improving grazing land management, controlling weeds); therefore, in our SNA, we record social ties as "collaborative ties" based

on organizations providing and/or receiving different types of NRM services from one another. The services we considered are common services that were identified by NRM organizations in the study region and are as follows: technical advice and knowledge, information and data management, on-ground support, funding and material resources, and legal advice and permitting (Table 1).

To achieve our primary goal of exploring the nature of relationships in social networks, we (1) develop a set of criteria to assess the level of agency in establishing social ties for five different NRM related services; (2) map the social networks for the five services and assess the centrality of organizations within each of these networks; (3) use perception matrices, as a complementary tool to SNA, to elicit actors' perceptions of organizational characteristics; and (4) use information derived from the above three methods to identify organizational characteristics that are related to the formation of collaborative ties and their potential relationship to agency. We hypothesize that if the ties identified in the SNA are driven by individuals' agency, then the organizations perceived as having beneficial characteristics relevant to the service type should have more collaborative ties than organizations that offer the same services but are perceived as having less beneficial characteristics. If, however, the organizations with collaborative ties are construed negatively, then ties are less likely to be the result of agency and could indicate limited availability of alternative service providers or mandatory relationships. The methods presented here can be used to provide a richer understanding of the nature of relationships within social networks and can allow researchers to improve their interpretation of social networks in applied NRM contexts, such as network weaving or using networks to disseminate information.

Methods

Case Study

Our study focused on organizations actively participating in NRM in the Daly River catchment, Northern Territory (NT), Australia (Figure 1). The catchment supports ecological and cultural values of national significance, which are threatened by overgrazing, altered fire regimes, and invasive species (Woinarski et al. 2007). The catchment is also a high priority for development at a Territory and Federal level, with interest increasing around its horticultural possibilities, potentially pitting development against conservation (Adams and Pressey 2014; Adams et al. 2016). The catchment is a focus for several organizations, including government agencies, environmental nongovernmental organizations (NGOs), Indigenous organizations, and industry-based bodies (e.g., farming and grazing associations). Good NRM outcomes thus require effective collaboration among diverse organizations. The Daly catchment is a representative case of many regions, where there are multiple, potentially conflicting, demands for natural resources and NRM planning and implementation involves collaboration among diverse types of organizations.

Data Collection

Focus Groups

We conducted two focus groups with the aim of identifying organizations involved in NRM in the Daly and the types of services provided by organizations that would result in collaborative networks. There were 12 focus group attendees (the same people attended both sessions) and included researchers, managers, and policy makers working in northern

Table 1. Definition of five service types, associated requirements, service prevalence, and strength of evidence of agency (Low, Moderate, High).

| Service	Definition	Associated requirements	Percentage organizations providing service	Strength of evidence of agency
Technical advice/ knowledge	Provisioning of expertise. This can be through guidance or recommendations related to general knowledge of subject or specific technical approaches. For example, an organization might provide guidance on how to manage a weed by requesting general knowledge on the species traits such as flowering period or technical advice on how to administer chemical spray	No identified requirements	93%	High
Information/data management	Provisioning of data sets or information on a subject (e.g., through synthesis reports). This includes data storage and licensing services as well as being a source of information through distribution of reports and other documents. For example, an organization might provide spatial data under license for recorded presences of a weed	Information may be general and held by many organizations with no requirements. Data are typically held by those organizations that have collected the data or are legislatively required to hold data. As such, an organization may be required to collaborate only with those organizations to obtain data	67%	Moderate
On-ground support	Provisioning of support associated with on-ground action. For example, an agency might provide support in designing weed management strategies or provide the labor required to implement a weed management program	On-ground support is typically provided by organizations with specific natural resource management roles (government or NGOs) and their jurisdiction or expertise might be highly specialized. As such, an organization will likely need to work with organizations with the relevant expertise for the relevant activity (e.g., weed management) or with jurisdiction in the area of interest (e.g., a national park)	53%	Moderate
Funding/material resources	Provisioning of financial support or other material resources for an activity. For example, an organization might provide financial grants to support weed management as well as an equipment loan program to make spray equipment available to landholders on a periodic basis	Funding and material support is often made available through government funds or non-profit organizations. As such, an organization is typically required to apply to these organizations (government or NGOs)	23%	Low
Legal advice/ permitting	Provisioning permits required to undertake an activity or legal advice relating to an activity. For example an organization may be the regulatory agency for weed management and as such issues permits to grow or transport restricted species and provides legal advice to landholders regarding their legislative obligations to manage listed species	Legal advice and permitting is typically associated with statutory bodies required by law to enforce relevant acts and management plans. As such, an organization is typically required to apply to these organizations for relevant permitting and legal advice	23%	Low
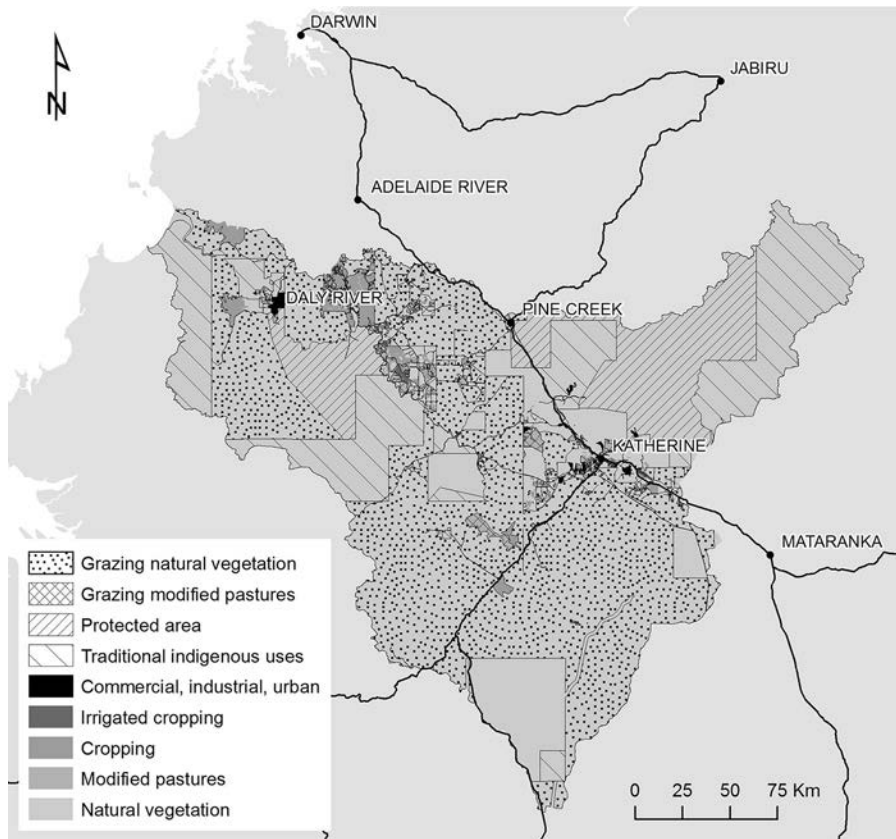
Figure 1. Map of Daly Catchment, Northern Territory Australia. Major towns and land uses are shown.

Australia (four focus group attendees work directly in the Daly catchment). These focus groups informed the design of the SNA survey, including the scope of the questions and the list of organizations and service types included in the analyses. NRM organizations were defined as those organizations with a mandate to prevent or mitigate the environmental degradation associated with climate change, water scarcity, inappropriate land development, invasive species, and/or unsustainable fishing, farming and grazing practices. The focus group identified 36 organizations participating in NRM projects in the Daly catchment including Indigenous organizations, government agencies, research organizations, environmental NGOs, and industry-based bodies. The focus groups identified five types of services that organizations typically provide for NRM projects: technical advice/ knowledge, information/data, on-ground support, funding/material resources, and legal advice/permitting (see Table 1 for definitions of service types).

Participant Recruitment
We used a purposive sampling strategy to recruit participants, inviting at least one participant (but up to three) from each identified organization based on their role (i.e., they were directly involved in NRM projects within the Daly catchment), and level of embeddedness in their organization (i.e., they had authority to represent and/or act on behalf of their organization). Participants were identified during the focus groups or

through direct inquiries to the organization. We also allowed initial respondents to identify relevant respondents during the SNA survey who we then screened for relevance and invited to participate where appropriate. Participants included executive officers, senior managers, and on-ground staff, and they represented the target population of NRM organizations both in terms of the range of organizations and the roles they play within the organizations. Participants were first invited to complete a SNA survey and respondents were then asked to complete a subsequent perception matrix survey (see details of both methods below).

Social Network Analysis Survey

We used a structured survey with open- and close-ended questions, including questions about the characteristics of organizations and the services they provide (Appendix S1). Respondents were asked to indicate whether they collaborated with each listed organization or to nominate additional organizations for each type of collaboration (i.e., service exchanged), including the exchange directionality (i.e., provider and/or receiver for each of the five services). We piloted the SNA survey with focus group participants (two pilot phases in which the survey was refined and tested with the same participants to ensure that questions were cognitively accessible) and the final survey was then piloted with colleagues. The pilot also included testing of web-based and in-person survey methods by having a subset of pilot participants complete the survey twice, once online unassisted and once in person. We found that responses were consistent across both collection methods; thus, participants were given the option of completing the survey online or in person. We obtained responses from 30 organizations (83% response rate at the organization level) with two incomplete responses, resulting in 28 organizations with full responses (39 respondents, out of the 53 invited participants); surveys took an average of one hour to complete.

Perception Matrices

We chose to use perception matrices to investigate perceptions of organizational characteristics and how this might explain the nature and existence of collaborations between organizations (Moon et al. 2017). Perception matrices are an adaptation of repertory grid technique (Moon et al. 2017), which is based on personal construct theory. The basic premise of personal construct theory is that people have a flexible psychological structure, or network, of processes that influences how they interpret the world, anticipate events and behave (Kelly 1991; Daniels, de Chernatony, and Johnson 1995). Perception matrices can thus be used to identify how an individual construes or interprets their world (Bjorklund 2008). Matrices, like repertory grids, are comprised of elements (objects), constructs (bipolar qualities or descriptors of objects), and a linking mechanism whereby each element is assessed against each construct (Easterby-Smith 1980; Daniels, de Chernatony, and Johnson 1995). For example, an organization (element) can be construed as innovative or not (construct), and can be measured using a rating scale (e.g., 1–5, where 1 = not innovative and 5 = highly innovative) (linking mechanism). We chose to supply elements and constructs (Moon et al. 2017) as this allowed us to make statistical comparisons of perceptions between respondents (Easterby-Smith 1980; Fransella, Bell, and Bannister 2004) and how the perceived similarities and differences of organizations could influence the presence of collaborative ties within each of the five networks (Tan and Hunter 2002; Moon et al. 2017).

We followed four stages to develop the constructs supplied to participants (Jankowicz 2004). First, three authors met to explore the terms used by participants during the SNA surveys to describe different organizations, increasing the likelihood that the constructs represented the possible range that participants would have provided spontaneously and whose meaning they understood (Easterby-Smith 1980). Participants offered descriptors of organizations when discussing why they did or did not collaborate with an organization. Descriptors included in the survey that were provided by participants are as follows: *represents users/constituents, collaborative, responsive*, and *influential*. Second, we refined some of the constructs to reflect terms found in the organizational literature to provide us with an opportunity to explain our results within the context of previous organizational research. Third, we engaged a further two authors in a peer-review process to assess the final set of constructs to ensure they were bipolar (i.e., opposites of one another) and could be clearly understood; a number of changes were made to increase the clarity of each construct, including the development of a set of definitions (see Appendix S2 for the perception matrix survey including full list of constructs, definitions and references, as well organization acronyms and full names). Finally, we piloted the revised perception matrix with colleagues.

We determined that the total possible number of organizations (36) was too large for designing a cognitively accessible perception matrix. Therefore, we reduced the number of organizations to only those organizations with a central mandate to undertake NRM projects ($n = 17$). Within the 17 organizations, all participants who completed the SNA survey were invited to complete a separate perception matrix survey over the telephone; each survey took on average 20 min. Nineteen of the 39 participants who completed a network survey also completed a matrix (five participants were no longer employed by their organization resulting in an effective response rate of 56%).

Data Analysis

Assessing the Strength of Evidence for Service Types Being Associated with Agency (Aim 1)

We first wished to develop and apply a set of criteria to identify whether organizations were voluntarily approaching one another for services (i.e., agency exists within those networks) or not. We assessed two criteria that could influence agency: (1) the existence of compulsory or regulatory requirements (termed "requirements") that could limit agency associated with each service type (e.g., are organizations legally required to collaborate with some organizations for certain services, such as legal advice/permitting); and (2) the availability of the service, measured as the percentage of organizations that reported providing each service as a core service. The first factor was developed from focus group discussions. The second factor was developed from the SNA survey responses. We assume here that individuals within organizations are more able to exert agency when a particular service is provided by several organizations (i.e., prevalence of organizations providing the service) and/or when that service is unconstrained (i.e., not compulsory or regulatory). We rated the evidential strength that agency exists as "low" (requirements exist and low prevalence), "moderate" (requirements exist and moderate prevalence), or "high" (no identified requirements and high prevalence).

Mapping the Social Networks to Identify Central Organizations (Aim 2)

For each service type, we recorded the presence of collaborative ties between organizations based on individual survey responses aggregated at the organization level. We used

UCINET software (Borgatti, Everett, and Freeman 2002) to map and describe the five service networks in terms of the total number of collaborative ties and the out-degree centrality of organizations (i.e., the number of organizations to which a given organization provides a service) (Borgatti, Everett, and Freeman 2002) within each network. Out-degree centrality is a relevant measure for investigating agency because it essentially captures the number of organizations coming to an organization to receive a given service. We ranked organizations within each of the five networks based on out-degree centrality to assess their relative importance in providing a given service.

Investigating Perceptions of Organizational Characteristics Using Perception Matrices (Aim 3)

To explore participants' perceptions of organizational characteristics that could foster collaborative ties, we sorted organizations and constructs according to their level of average similarity by generating a focus matrix with hierarchical clusters (all analyses were performed using Rep 5 V1.04, Centre for Person-Computer Studies, Cobble Hill, Canada) (Gaines and Shaw 2010). The focus matrix essentially brings closely matching constructs (i.e., characteristics) and elements (i.e., organizations) together. We used the standard city block metric in the Minkowski metric to compute matching scores for the focus matrix (Shaw 1980; Borgefors 1996). Constructs and elements in the clusters were first matched against interior items within an existing cluster (by checking the "interior" box), and then placed at the edge of the cluster that has the highest match to the item. Using the focus matrix, we were able to identify those organizations that were perceived to have similar or different characteristics to one another (Bjorklund 2008).

Identifying Organizational Characteristics That Relate to Collaborative Ties and Their Potential Relationship to Agency (Aim 4)

Finally, we tested whether we could identify organizational characteristics related to the presence of collaborative ties to explore the hypothesis that where agency is present, central organizations will be construed as having beneficial characteristics. If, however, the organizations with a high number of collaborative ties are construed negatively, then ties are less likely to be the result of agency.

To this end, we first explored how the social network and perception matrix analyses related to one another by identifying those organizations that were construed similarly, and then for these organizations we compared the out-degree centrality as well as their relative importance within each service network. We then conducted regression analysis for each service type to identify whether actors' different perceptions regarding organizational characteristics influenced the likelihood of these actors having a collaborative tie. Thus, the dependent variable was the directed "collaborative tie" (i.e., whether an organization goes to a given organization for a particular service) derived from the social network survey responses (for the 17 organizations included in the perception matrix). For each respondent who completed a perception matrix, we treated his/her assertions of other organizations characteristics as the independent variables. This approach resulted in a model in which the presence or absence of a collaborative tie with a particular organization was associated with how that same organization was construed (two individuals did not provide complete SNA survey resulting in responses from 17 respondents for 17 organizations, excluding self-ties $n = 280$).

We used a logistic regression analysis with collaboration presence/absence with an organization (binary variable) as the dependent variable and the 11 constructs for that organization reported by the respondent as the explanatory variables. Network data are problematic to analyze using standard regression models since the basic assumption of data independence is difficult to justify (i.e., if there is a network "effect," network data are essentially by definition not independent). This challenge implies that standard p-values can be misleading (e.g., model residuals might not be randomly distributed). To control for such possibilities, we used simulation techniques where some basic characteristics of the networks were held constant while generating a large set of random networks; each random network was then used in separate regression models (Multiple Regression Quadratic Assignment Procedure; e.g., Dekker, Krackhardt, and Snijders 2007) with the netlogic function in the R-routine sna (Butts 2014). By comparing the distribution of the regression coefficients from these generated "semirandom" networks with the coefficients drawn from the regression using the empirical network data, more reliable *p*-values were derived. We provide *p*-values here to indicate which factors are most influential, and in which direction, in terms of driving voluntarily collaborative ties.

Results and Discussion

Our research design draws on several methodological approaches to describe the nature of organizational collaborations through triangulation. This methodological integration implies that the presentation of the results is inherently linked to an interpretation of the stepwise methods undertaken. Therefore, we jointly present and discuss our results for each aim.

Assessing the Strength of Evidence for Service Types Being Associated with Agency (Aim 1)

Based on our assessment of the strength of evidence of agency, technical advice/knowledge was the only service type associated with agency (Table 1). In other words, in the technical advice/knowledge, network actors were likely to have voluntarily established the observed collaborative ties. Information/data management and on-ground support were assessed as having moderate evidence and legal advice/permitting and funding/material resources were assessed as having low evidence for agency. Based on these results, we hypothesized that, within the high agency (technical advice/knowledge) network, central organizations would be construed similarly with beneficial characteristics (as identified through perception matrix).

Mapping the Social Networks for the Five Service Types to Identify Central Organizations (Aim 2)

The technical advice/knowledge and information/data networks had the largest number of stated available providers (Table 1) and were also the networks with the largest number of total connections (Figure 2, Appendix S3). The technical advice/knowledge network had a set of central organizations with a large number of outward connections (17 organizations had out-degree centrality values greater than the average of 15, Appendix S3) (e.g., Northern Territory Department of Water Resources (Water Resources), Environment Centre NT (ECNT), Australian Fishers Association NT, The Nature Conservancy, and Territory

NRM (TNRM), Figure 2) (for full list of organizations and acronyms see Appendix S2). The centrality for each organization varied across the service type networks. Organizations had the largest number of outward connections (out-degree centrality) for either the technical advice/knowledge or information/data management networks (with the exception of the Commonwealth Department of Environment (DoE), whose main role was providing funding/material resources), reflecting a high level of collaboration among organizations for these two service types. When considering organizations' relative out-degree centrality compared to other organizations within the network, however, their rankings changed across networks (Appendix S3). For example, the Northern Territory Government Parks and Wildlife Commission and Northern Land Council (NLC) were highly ranked (4 and 5, respectively) for the legal advice and permitting network which reflects their important permitting roles; meanwhile, they had lower out-degree centrality compared to other organizations for other service types (e.g., for on-ground support where they were ranked 8 and 18, respectively, Appendix S3). This result is consistent with the expectation that different service providers exist in each network and thus depending on an organizations' service roles, some may be more or less central (i.e., have a higher out-degree centrality) in a network.

Investigating Perceptions of Organizational Characteristics with Perception Matrices (Aim 3)

The perception matrix results complement the network analysis by highlighting perceptions of organizational characteristics and showing similarities and differences between elements (i.e., organizations) and constructs (i.e., characteristics) (Focus average matrix, Figure 3). For example, the respondents rated Charles Darwin University (CDU), Daly River Management Advisory Committee (DRMAC), TNRM, and Northern Territory Government Department of Primary Industry and Fisheries (DPIF) similarly, and indicated that these organizations were different to other organizations. These results are visible in the dendrogram for the organizations (red), which shows two broad clusters (Figure 3), one organization ECNT located in between, and one organization NLC construed very differently to the rest. The first cluster contained four organizations CDU, DRMAC, TNRM, and Northern Territory Government DPIF.

The focus matrix and associated dendrograms illustrated which constructs were used similarly (Figure 3). The dendrogram for the constructs (blue) showed two main clusters: one cluster contained a single construct (bottom-up/top-down) and the second contained all other constructs (Figure 3). Within the second cluster, innovative, and leader constructs were rated similarly, as were collaborative and quality-focused constructs. The position of the constructs in the dendrogram can be explained by how they were used to rate each of the organizations, as demonstrated by the shading. For example, organizations that were considered most collaborative CDU, DRMAC, TNRM, and Northern Territory Government DPIF were also considered to be the most transparent, responsive, quality-focused, and ethical (Figure 3). We also observed some differences in the constructs associated with different groups of organizations (Figure 3). For example, the shading in the matrix showed that a small group of organizations DoE, Environmental Protection Agency, and Northern Territory Government Department of Water Resources (Water Resources)) were mainly perceived to be top-down organizations, while the rest were perceived to be less so.
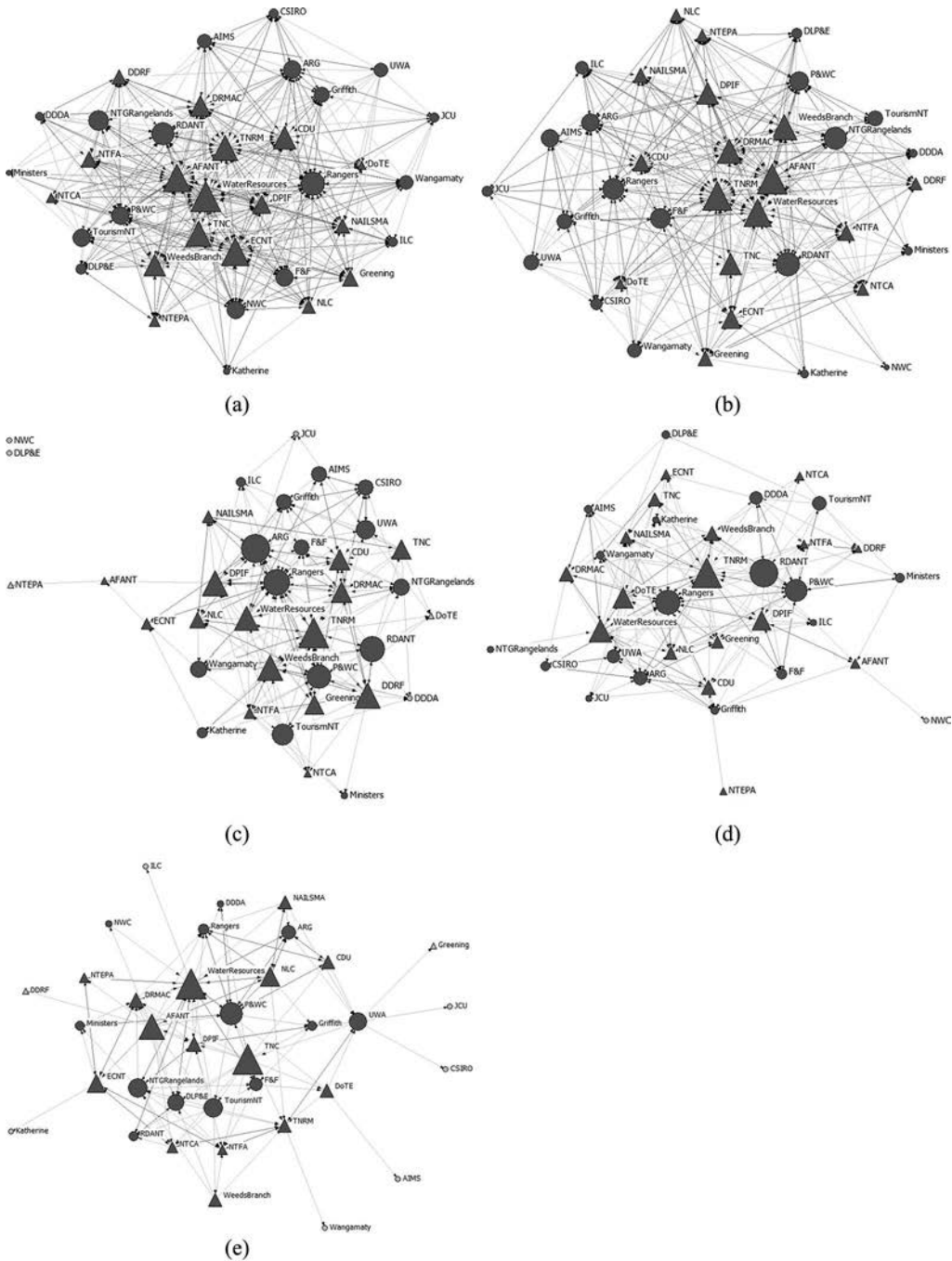
Figure 2. Social networks for a) technical advice and knowledge, b) information and data management, c) On-ground support, d) Funding/material resources, and e) Legal advice/permitting. Those organizations included in the perception matrix analysis are depicted with triangles and others are depicted with circles. Nodes are sized based on out-degree centrality (i.e., organizations with more connections out are larger).
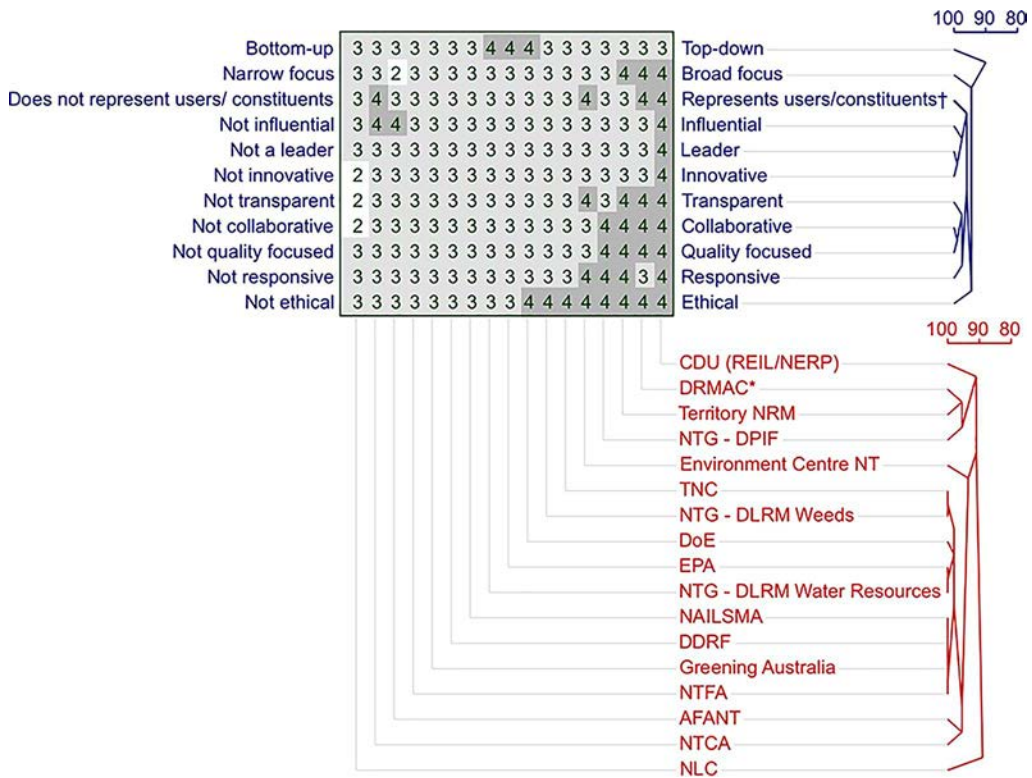
Figure 3. Focus matrix for all respondents. Blue text in rows represents constructs; the blue dendrogram represents the level of similarity between constructs. Red text in columns represents organizations; the red dendrogram represents the level of similarity between organizations. Shading indicates similarities between average ratings for each organization, on each construct: darker shades show a higher average score and the lighter/no shades show a lower average score.

Identifying Organizational Characteristics That Relate to Collaborative Ties and Their Potential Relationship to Agency (Aim 4)

Several results emerge from comparing the SNA results (i.e., centrality of organizations) to the perception matrix results (i.e., perceptions of the characteristics of organizations). First, those organizations that were considered to be most *collaborative* CDU, DRMAC, TNRM, and Northern Territory Government DPIF had higher out-degree centrality for the technical advice/knowledge and information/data management networks, indicating that organizations are more likely to seek advice and information from organizations they perceive to be collaborative (Figure 2 and Appendix S3). Second, organizations in the "*collaborative* cluster" were also highly central in other service type networks; for example, TNRM and Northern Territory Government DPIF had high out-degree centrality in the on-ground support and funding/material resources networks. This finding suggests that organizations that are perceived to have beneficial characteristics, such as being *collaborative*, are preferred collaborators across different networks, even when other organizations are available (Appendix S3). Third, our results revealed a set of characteristics across multiple methods that were associated with the presence of ties between organizations. The regression models predicting the presence of collaborative ties, while not explaining the majority of variance,

Table 2. Regression analysis for the five service types. The full model coefficients, AIC, and pseudo R^2 are provided for a) Technical advice/knowledge, b) Information/data management, c) Funding/material resources, d) Legal advice/permitting, and e) On-ground support. Significant p-values are indicated for $p < 0.01, 0.05, 0.1$ by ***, **, *, ·.

	a) Technical advice/knowledge		b) Information/data management		c) On-ground support		d) Funding/material resources		e) Legal advice/permitting	
	Coefficient	p	Coefficient	p	Coefficient	p	Coefficient	p	Coefficient	p
Constant	-3.9688	***	-3.5405	***	-3.1745	***	-1.3011		-2.5427	*
Collaborative	0.4059	*	0.4128	*	0.4735	**	-0.0332		0.1412	
Ethical	-0.2678		-0.0441		0.1882		0.1096		-0.3322	
Influential	0.1016		0.1096		0.4534	*	0.6579	**	0.0712	
Innovative	-0.0387		-0.1519		-0.1959		-0.2069		0.4157	
Leader	-0.0944		0.1486		-0.3522		-0.3976		0.0962	
Quality Focused	0.1961		0.0477		0.1899		0.1561		-0.0331	
Responsive	0.353		0.4149		0.3046		0.2615		0.2766	
Broad focus	-0.1284		0.2477		-0.01		0.0618		-0.3728	
Top Down	0.5484	**	0.2871		-0.1254		-0.6054	**	0.1326	
Transparent	0.4408	*	0.3382		0.372		0.5933	**	0.2168	
Represents constituents	0.0414		-0.4926	**	-0.6906	***	-0.6386	**	-0.2571	
AIC	252.62		273.31		251.58		232.2		216.74	
Pseudo R^2	0.2412		0.1812		0.2448		0.2925		0.3268	

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had pseudo R^2 values of 0.1812–0.3268 and included similar characteristics such as *collaborative, transparent*, and *influential* (Table 2).

Based on our results, we can make several inferences about the variance. First, beneficial organizational characteristics were positively related to the presence of collaborative ties in networks with moderate and high evidence for agency (i.e., technical advice/knowledge, information/data management, and on-ground support). The characteristic *collaborative* was a significant predictor of social ties across these three service type networks. Other beneficial characteristics that were significant predictors of the presence of collaborative ties included *transparent* and *influential*. Our regression also reveals characteristics of highly central organizations that may be perceived as beneficial depending on the context. For example, in the technical advice/knowledge network, Northern Territory Government Department of Water Resources (Water Resources) was highly central, but was also characterized as *top-down*, an attribute that may be positive for some service types, such as policy or law and order where strong coordination and direction are needed from the highest rank, but potentially negative for others, such as on-ground action that might rely on wide support from a range of stakeholders engaged through a more inclusive bottom-up approach. Second, different characteristics are associated with different service types, suggesting that organizations seek out different organizational characteristics for different services. For example, *influential* was a predictor for on-ground support and funding/material resources' collaborative ties, whereas *collaborative* was a predictor for technical advice/knowledge, information/data management, and on-ground support. Third, legal advice/permitting, which had the lowest evidence for agency, had no significant predictors. This finding suggests that collaborative ties for obligatory relationships do not relate to the characteristics of the organizations (at least not those tested here). Thus, collaborative ties might be driven by a required relationship rather than one made out of choice in response to characteristics associated with the organization. Finally, the attribute "*represents constituents*" was included in several of the models with a negative coefficient. This result could potentially reflect a perception around the type of organization that represents constituents (typically industry-based bodies in our case study), rather than a perception that representing constituents in itself is a negative quality.

Conclusion

While SNA presents an important opportunity for understanding the social structures around collaboration, additional complementary methods are necessary to gain a more comprehensive understanding of the nature of relationships. We present a novel multiple method approach that can be used to help to understand the nature of observed collaborative ties across various organizational networks. This suite of method includes approaches for assessing the evidence of agency, eliciting implicit perceptions of organizational characteristics with perception matrices and combining this information to identify organizational characteristics that are related to the formation of collaborative ties and their potential relationship to agency.

Our approach provides a deeper understanding of the nature of relationships and allows for clearer conclusions to be drawn about whether organizations are choosing to collaborate because of perceived beneficial characteristics of organizations or out of obligation. The assumption that agency underlies collaborative ties does not hold true across all five of our

networks. Besides being of academic interest (i.e., a network is not necessarily a reflection of actors seeking out others to collaborate with the sole purpose to solve common problems most effectively), this finding can have strong implication for various initiatives aiming to establish new collaborative ties (termed "network weaving") between actors for NRM initiatives. In such cases, it is common that the initiator (e.g., NGO, government agency) aims to establish ties among a large set of different stakeholders (Schneider et al. 2003; Bodin, Sandström, and Crona 2017); if, however, participants experience limited agency, it is unlikely that the initiator's investment will result in the desired increase in ties given actors do not have the required level of choice in establishing new relationships.

Likewise, facilitators should be careful in assuming that engaging with highly central actors will enable effective engagement with a larger set of actors (Prell, Hubacek, and Reed 2009; Crona & Bodin 2010). Our findings emphasize the importance of understanding the context in which social ties are established, for instance, if an actor is central due to a high number of prescribed social ties, its centrality does not necessarily reflect the actor to be "highly esteemed" by the other/s. The use of perception matrices can reveal how these central actors are perceived and complement the use of SNA in identifying actors for enabling diffusion of information or engagement with a larger set of actors. For example, perception matrices could reveal that a highly central actor in a low agency network is perceived negatively, therefore may not be an effective actor to work with to diffuse information because the observed relationships were not established by choice or due to perceived benefits. Conversely, perception matrices can identify actors that are construed as having beneficial characteristics and would otherwise be neglected in engagement activities due to low centrality metrics.

Our findings provide further evidence that more research, based on well-established and commonly agreed-upon approaches, to investigate the nature of relationships in SNA is necessary. The methods used here can be applied in any context to support conventional social network approaches to gain insight into the nature of relationships.

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