water

MDPI

Article

The Agricultural Community as a Social Network in a Collaborative, Multi-Stakeholder Problem-Solving Process

Hugh C. Simpson [1,2,*] and Rob C. de Loë [1]

[1] Water Policy and Governance Group; School of Environment, Resources and Sustainability, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1, Canada; rdeloe@uwaterloo.ca

[2] School of Environmental Design and Rural Development, University of Guelph, Guelph, ON N1G 2W1, Canada

* Correspondence: hugh@uoguelph.ca; Tel.: +1-519-500-2735

Received: 28 April 2017; Accepted: 27 September 2017; Published: 30 September 2017

Abstract: Collaborative approaches are being promoted as inclusive forums for bringing state and non-state interests together to solve complex environmental problems. Networks have been recognized through previous research as important ways to involve stakeholders in such forums with members participating in knowledge creation and sharing as part of deliberative processes. Less well understood is the effectiveness of network creation and promotion by external actors, especially in relation to knowledge creation and sharing. A case study approach was used to evaluate the efforts of a farm organization to organize a provincially-cohesive network of locally-elected agricultural representatives in Ontario, Canada. Network structure and function were evaluated using a combination of participant observation and Social Network Analysis as part of a mixed methods research approach. The results indicate that stakeholder network development can be actively supported, and that knowledge creation and sharing in these networks occurs within a complex structure of local and provincial-scale relationships.

Keywords: agriculture; collaborative problem-solving; mixed methods research; participant observation; social network analysis; stakeholder networks; vernacular knowledge

---

1. Introduction

Collaboration has emerged as an important strategy in numerous settings where multiple actors share responsibility for, or an interest in, resolving common problems. Hence, researchers from a host of fields are studying real-world collaborative processes. Examples of fields where collaboration is receiving attention include public administration [1,2], planning [3], environmental management and governance [4,5], and water management [6], to name a few. Given these differing perspectives, definitions of collaboration vary considerably. In this paper, we define collaboration as an approach to environmental problem-solving characterized by voluntary participation, collective decision making based on consensus, long-term relationships among parties, sharing and pooling of resources, and a commitment to deliberation. These characteristics have both normative and empirical dimensions: normative because many in the collaboration literature view qualities such as deliberation as positive and beneficial (e.g., [3]); and empirical because evaluations of successful collaborations reveal these qualities as indicators of successful collaboration (e.g., [7]).

A commitment to deliberation is important because collaborative forums are often formed in situations where the concerns of the broader community must be considered. These approaches are important in situations where no single actor has all the knowledge required for resolving complex problems, such as those that involve the environment and risk [4,8,9]. Collaboration is a highly relational process. As a result, concerns such as the co-production of knowledge, building of trust [10–12], and the negotiation of vernacular knowledge [8,13,14] are prominent in collaboration scholarship. Social networks support all of these aims [15,16] and are thus highly complementary to collaborative processes.

Social networks, composed of inter-dependent members representing state and non-state interests [17], promote communication and encourage cooperation between members concerning issues that span vertical and horizontal scales and cross administrative, physiographic, and political boundaries [18,19]. The deliberation and negotiation of complex problems within social networks can result in the sharing of multiple knowledges [17,20], which supports collective learning and the development of knowledge and expertise [21].

The ability of non-state actors to participate effectively in the creation and sharing of knowledge is a particularly important concern in collaborative processes [3,22]. Benefits of collaborative processes, their proponents suggest, include providing forums that lead to more inclusive and robust problem-solving [10,12]. Such an inclusive approach supports the interaction of non-state actors, scientists, and state actors to co-produce knowledge [8,10,11]. The outcome of this process can be 'vernacular' knowledge or science that integrates expert science and local knowledge with community beliefs and values [23,24] through the discussion of problems and the negotiation of solutions [8,13,14].

Diverse stakeholders increasingly are being asked to participate in collaborative processes formed to address environmental concerns because the involvement of these people is critical for problem-solving processes and to establish legitimacy [3,22]. A common example is the involvement of non-state actors in watershed partnerships in Australia, Europe, and North America at different scales in order to help negotiate and implement solutions for managing natural resources through collaborative efforts [9,25,26]. In some of these processes, participants are embedded in larger social networks [27]. While empirical evidence exists supporting the claim that social networks assist with the creation and sharing of knowledge, less well understood is the extent to which collaborative processes can be strengthened through the direct contribution of knowledge by network members who have been deliberately embedded in those processes.

Using social network analysis (SNA), the social ties between network members can be mapped, as can the knowledge that is embedded in, and flows through, the social ties that connect them [20,28,29]. SNA is being used increasingly to help understand the structure and function of these networks and to measure how they influence the creation and sharing of knowledge [15,29]. Traditional quantitative approaches to SNA are currently being augmented with qualitative data that are used in a complementary fashion [30,31]. These approaches are being used to better understand how knowledge sharing within a network can help build shared values, promote social learning, build social capital, and lead to innovation [32,33].

In this paper, the Province of Ontario, Canada provides an empirical setting for evaluating the structure and function of a deliberately created network of locally elected farmers whose development was supported by a key provincial farm organization involved in collaborative processes for protecting drinking water sources. In Ontario, the farm community functions as a provincial-scale network [34,35]. Using a mixed methods research approach involving participant observation and SNA, the ability of a provincial farm organization to organize a group of locally elected farmer representatives into a cohesive network, and the ability of that group to co-produce vernacular knowledge, were evaluated. The paper begins with an overview of the literature related to the role of stakeholder networks in collaborative problem-solving. The case study background and methods are then described. Study results are then presented, along with the discussion of the research findings in the context of the literature. Finally, conclusions for research and practice are shared.

Collaborative Approaches to Environmental Problem-Solving

Collaborative approaches are built around formal and informal forums that typically are designed to ensure that the concerns of affected actors are considered. These approaches are important because the knowledge possessed by different interests often is required for developing solutions to complex problems [4,8,9]. The literature indicates that collaborative approaches have several benefits. First, collaboration can encourage the co-production of knowledge involving scientists, along with state and non-state actors, through the sharing and integration of scientific and local knowledge, and the discussion of beliefs and value-based issues [10,11,36,37]. Second, collaboration can nurture the development of relationships, trust, accountability, legitimacy, reciprocity, common rules, shared values, and a sense of inclusion and empowerment [10,11,38]. Collaborative processes, proponents suggest, also improve problem-solving capacity when they incorporate local perspectives that promote robust outcomes through the co-production of knowledge [10,12]. Finally, the integration of expert science, local knowledge, and beliefs and values within collaborative processes can produce vernacular knowledge. Vernacular knowledge is the outcome of a process where environmental problems are deliberated and solutions are negotiated by stakeholders [8,13,14]. The co-production of vernacular knowledge is important because it encourages greater participation by engaging the community in the negotiation and implementation of solutions to complex problems [8,38,39]. Ideally, this involves the community in developing a broadly accepted and locally relevant knowledge that will form the foundation for tackling complex problems [8,36,39]. This has the potential to help mitigate power differentials among actors by encouraging reasoned debate and negotiation of value-based issues [3,40,41]. Importantly, however, it would be naïve to believe that knowledge co-production through collaboration can eliminate the fundamental power imbalances that frequently exist in collaborative processes [42].

There is growing recognition that networks can support collaborative approaches to problem-solving [15,22,27]. This support can help network members to overcome challenges and to innovate more quickly—within and between networks—than those who are not connected to a network [32,33]. It typically takes three forms. First, networks can support the development of relatively close relationships grounded in shared beliefs and values by helping network members to form well integrated and cohesive networks, and by encouraging bridging between members of diverse groups [22,43]. Second, knowledge sharing within and between networks can help to challenge or reinforce existing positions [44] and may facilitate the sharing of expert science, local knowledge, and community values and beliefs [22]. Finally, networks can encourage the creation of vernacular knowledge by providing a setting for the deliberation of problems and the negotiation of solutions during the problem-solving process [8,13,14].

Three aspects of networks are less well understood. First, what circumstances and factors—internal and external—influence the formation and function of stakeholder networks [45,46]? Second, do networks adopt the characteristics of successful collaborative approaches outlined above when problem-solving? For instance, does the problem-solving process within a network promote the integration of new and existing ideas and information with the beliefs and values of members [46,47]? Third, how does the structure and function of a network contribute to the creation and sharing of vernacular knowledge in a collaborative manner [32,33]?

2. Materials and Methods

A mixed methods research (MMR) approach was used to combine data collected using different research methods within a single case study. MMR is an inclusive and pragmatic approach that encourages a systematic use of different research methods that share the same research question, collecting data that are complementary, and conducting data analysis in a coordinated manner [48]. This approach is inclusive and pragmatic because data collected using different research methods can be used in an integrated fashion, which is difficult to do with studies that are strictly qualitative or quantitative. Although the different types of data were collected at different times, all data were given equal priority and were evaluated and analyzed concurrently. This concurrent triangulation approach to MMR emphasizes confirming, cross-validating, and corroborating findings collected using the different methods as part of a single study [49]. Triangulation supports the interpretation of data and development of conclusions using quantitative and qualitative data collected by different methods in a manner that promotes comprehensiveness, increased credibility, and encouraged reliability, and demonstrates validity of the research process and its findings [50,51].

2.1. Case Study Setting

Source water protection became part of the water governance landscape in Ontario following the Walkerton Tragedy in May 2000. Seven people died and several thousand became ill when an extreme storm event flushed contaminants into an improperly maintained and operated municipal water supply [52]. Justice Dennis O'Connor investigated the causes of the tragedy, and made recommendations to ensure the safety of water supply systems in Ontario. These were structured around a five-part multi-barrier approach [53]. The first barrier includes the development of source protection plans (SPPs) at a watershed (catchment) scale. The Province of Ontario responded in 2006 by implementing the Clean Water Act, 2006, which created a system of nineteen watershed-based Source Protection Committees (SPCs) that were charged with preparing local SPPs (OMOE 2008). Each SPC has a mandated structure and timeline, overseen by a local Source Protection Authority (SPA), with one-third of the members representing, respectively, municipal, business, and public interests within the watershed [54]. These committees function in a manner consistent with the attributes of collaboration outlined above.

Farmers are key actors in source protection planning in Ontario. They comprise two percent of the overall population, but own or rent approximately 33 percent of the land in southern Ontario [55]. Agriculture in southern Ontario occurs alongside urban areas, and exists in the watersheds that serve the urban populations that will be protected by source protection planning. As a result, between one and three member(s) of the SPC were mandated by the provincial government to be representatives of agriculture in each catchment where agriculture was deemed to be a significant local land use activity. Farm organizations expressed support for the concept of source water protection from the outset; they initiated a process to participate in the SPP process, and to promote consistency among forthcoming SPPs and existing programs that promote economically and environmentally sustainable farming [56]. To coordinate farm sector efforts, the Ontario Farm Environmental Coalition (OFEC), which represents 37 farm and commodity organizations concerned with agri-environmental matters, established a working group. The working group includes staff from four major farm organizations, and two program staff from the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) with technical expertise involving extension education and source water protection. OMAFRA staff members, including the first author, participated in the working group at the invitation of OFEC and with the support of their Deputy Minister.

The working group recognized the importance of preparing the agricultural representatives to take an active role in the SPP multi-stakeholder problem-solving process. Its members agreed that an important role of agricultural representatives was to educate the largely urban membership of SPCs by sharing agricultural science and local farmer knowledge during the SPP problem-solving processes. This, they believed, would help SPC members to recognize that protecting municipal drinking water sources and promoting economically and environmentally sustainable agriculture can be complementary objectives. To increase the legitimacy of agricultural representatives, OFEC and the County Federations of Agriculture organized elections. Under the Clean Water Act, SPAs were authorized to select their members. However, in recognition of the democratic process used, 34 of the 37 agricultural representatives elected by the local farm community were appointed to 15 of the 16 SPCs with agricultural members.

The working group supported the agricultural representatives in three ways. First, agricultural representatives were brought together by OFEC at a series of workshops where they could engage in social learning and integrate agricultural and environmental science, their local knowledge, and their beliefs and values. The goal was to consolidate vernacular knowledge that could be shared with SPC colleagues. Second, agricultural representatives were encouraged to develop a network within which they could share ideas and provide emotional and technical support to each other outside of the formal workshop setting through discussions in person, by telephone, and using the internet. Third, ongoing technical assistance was provided to the agricultural representatives through telephone and email discussions, and by delivering presentations at individual SPC meetings where requested.

The six OFEC workshops involved a combination of formal and informal learning opportunities, and included presentations by a farm organization and OMAFRA staff, as well as external academic, consultant, municipal, and provincial government technical experts. Each meeting also included a facilitated discussion involving the agricultural representatives and Ontario Ministry of the Environment (OMOE) senior management representatives. The workshops were supplemented with frequent teleconferences and online discussion sessions. Collectively, these activities augmented the existing agricultural network that existed in Ontario.

2.2. Social Network Analysis

Human communities comprise a series of overlapping social networks, within which members are connected by relational ties. Knowledge flows, and is shared, through these ties [20,31]. The movement of knowledge within and between networks is related to the "strength of ties" between different actors in a network [29,31,57]. Strong ties indicate bonds between network members that support the sharing of information and advice, help build and maintain trust between members, allow members to influence other members' beliefs and values, and encourage two-way communication between members [29,58]. Weak ties are formed by network members who bridge with disconnected or dissimilar groups either within or outside their network. These members act as brokers by helping to build trust and mutual understanding by sharing knowledge [59,60].

Strong and weak ties form a structure that can be mapped and analyzed to determine patterns, both of the relationships between the actors and the knowledge they share, using methods that are collectively known as social network analysis (SNA) [28]. SNA has been used to study the effectiveness of processes such as knowledge sharing by evaluating network structures [15,61]. For instance, SNA can be used to analyze the number of strong and weak ties in a network in order to better understand how knowledge is created and shared within and between members. These concepts are useful for explaining what is actually transpiring within a social network structure [31,62]. This kind of analysis can identify network members who are influential in creating and sharing knowledge.

Centrality measures are an indicator of how central an actor is within a social network [63]. Specific centrality measures presented in Table 1 were used to evaluate the structure of a network composed of agricultural representatives in order to identify influential members and to better understand the potential for the creation and sharing of knowledge [28,60,64]. 'Degree' centrality considers the immediate ties that a member has within a network and identifies central members who act as brokers because other members seek their knowledge [28,60,64]. In directed networks, where the direction of ties has been observed, degree centrality indicates a member's role in knowledge-sharing. Members with many 'in-degree' ties (high in-degree centrality) can be prestigious, or have high prominence, because many other members seek and trust their knowledge [31]. A member with many 'out-degree' ties (high out-degree centrality) can be influential because he or she shares knowledge with many other network members, along with perspectives on different issues [60,64].

Table 1. Selected social network concepts and their importance in knowledge creation and sharing.

Concept	Importance
Density	Members of highly dense networks are well connected with other members. High density structures may form cohesive networks that encourage knowledge sharing and help build trust, common norms and expectations.
Out-Degree Centrality	Members with high out-degree centrality are highly influential because they are well connected and influence problem-solving by sharing knowledge and views—quickly, where ties are strong. These members tend to make contact and make connections with other members.
In-Degree Centrality	Members with high in-degree centrality are highly prestigious or prominent, are important for brokering knowledge, and can connect diverse segments of a network, especially where ties are strong. These members tend to attract and make connections with other members.
Betweenness Centrality	Members with high betweenness centrality are intermediaries that help link the network. These actors share knowledge quickly and build redundancy.

Sources: [28,63,64].

'Betweenness' centrality reflects the number of times a member falls on the geodesic, or shortest path, between two other members within a network [60,63,64]. A member with high betweenness centrality can act independently across the network and has an ability to act as an intermediary and help share knowledge efficiently to different parts of the network [28,63,64]. Members with high betweenness centrality also have a high capacity to broker relationships, serving as the "movers-and shakers" in the network [60]. Members with high betweenness centrality can also create bridges between disconnected members or parts of the network, resulting in much of the knowledge in the network to pass through them.

Data concerning the direction and strength of ties were collected using a standardized survey questionnaire consisting of a single closed-ended question for determining the presence and strength of relationships. Through this question, each agricultural representative was asked to indicate how often he or she shared information with each of the other agricultural representatives. The questionnaire was constructed using a five-point Likert-type scale format (Very Often or Always, Often, Neither Often nor Seldom, Seldom, and Very Seldom). The questionnaire was distributed at an OFEC workshop in May 2012, or by email to those who could not attend, and was followed up with email and telephone reminders. All 37 agricultural representatives responded to the questionnaire. Agricultural representatives who were never named in the responses were distinguished from those who were. Response data were coded and then analyzed using SNA software UCINET Version 6 [65]. Specifically, the ties were differentiated by strength and graphed separately as follows: weak (tie strength = 1 or 2 out of 5); moderate (tie strength = 3 out of 5); and strong (tie strength = 4 or 5 out of 5). This approach has been documented in the literature as a useful way of identifying patterns within a network, such as finding cohesive sub-groups [63].

2.3. Participant Observation

Participant observation was conducted from 2007 to 2013 by the first author at six workshops involving agricultural representatives. Additional contextual information was also collected by the first author during meetings, and telephone and email discussions, during this time. Participant observation added richness to the results, and allowed for collection of complementary evidence to corroborate data collected through the survey questionnaire [66]. Participant observation enabled the first author to listen actively to interchanges between members, and allowed for collecting information that helped to explain or illustrate concepts that were identified during data collection. General concerns that had been raised by the agricultural representatives were identified, and then classified according to different themes that were presented and discussed concerning the creation and sharing of knowledge. Crossley [31] observes that participant observation has several advantages: (1) the observer is able to identify changes in the attitude of participants as the discussion on different topics progresses, and how the group did or did not manage to collaborate to find a mutually acceptable solution to any disagreements that arose—something that could not be known by researchers who were not present; and (2) the observer is able to identify and assess the importance of what Crossley [31] describes as the "mechanisms of relationship formation" (page 20), such as the "identities, expectations, rituals, shared feelings and meanings" that create a collective identity.

3. Results

The results in this section are used to evaluate the efforts of a provincial farm organization to organize locally-selected members into a cohesive network, and to determine if the structure of the resulting network was successful in promoting the co-production of vernacular knowledge. The effectiveness of the network to share vernacular knowledge as part of the broader SPP process is evaluated elsewhere [36]. It is important to remember that the structure and function of networks evolve over time [31,45], and thus the results presented here represent the structure of the network when the data were collected (2007 through 2013).

Figure 1a summarizes the pattern of all ties of different strengths between agricultural representatives within the network. A visual inspection of the graph suggests that there are many ties among network members. The network was analyzed using the SNA measure of density (Table 1), which provided a measure of how well-connected the members were, as well as an indication of how cohesive the network was during data collection [28,60,64]. A density score of 0.60 was calculated for valued and directional data, indicating that 60% of the possible ties in the network were present. This score suggests that, overall, the network was moderately cohesive, which allowed for the sharing of beliefs and values [59], but possibly not so closed that new ideas could not be introduced and discussed within the network as has been speculated in the literature [67].

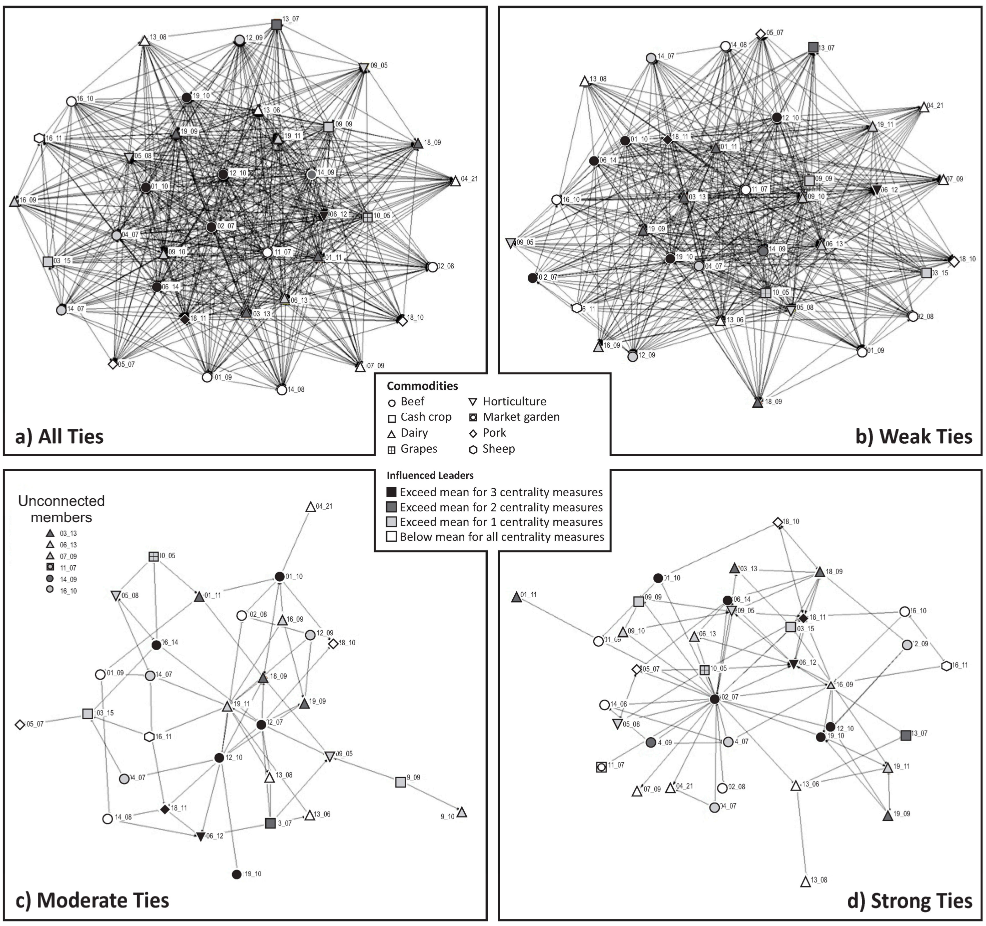

Figure 1. Strength of connections in agricultural representative network.

Participant observation during the workshops indicated that the agricultural representatives were able to achieve agreement concerning the majority of issues in a constructive manner. Specifically, a high level of engagement and agreement among the agricultural representatives was observed at the workshops, and they appeared to hold similar views and beliefs on many key issues. This suggested that the network was more cohesive than was indicated by the moderate density score. For instance, when new issues were raised at the workshops, the agricultural representatives often reached consensus quite quickly.

However, several more complex issues arose during the source protection planning process that required several meetings for the different perspectives to be deliberated and for consensus to be negotiated. Observations revealed that discussions were sometimes vigorous, with intense questioning and debate of scientific and local knowledge shared by technical experts, agricultural representatives, or OFEC working group members. However the process took place in a manner that was respectful, and often with a sense of humour. Participant observation results suggested little evidence of frustration with the process and outcomes of the OFEC. In contrast, a common concern raised by the agricultural representatives was that the workshops were not long enough to discuss all their concerns. This limitation contributed to more contentious issues being discussed and negotiated during more than one workshop. The contradiction between the calculated density measure and the highly cohesive behaviour that was observed suggested that the structure and function of the network was complex. In order to better understand how the pattern of ties was affecting the structure and function of the network, the ties were evaluated by different strength, having been differentiated and graphed separately as follows: weak (tie strength = 1 or 2 out of 5) in Figure 1b; moderate (tie strength = 3 out of 5) in Figure 1c; and, strong (tie strength = 4 or 5 out of 5) in Figure 1d.

Participant observation indicated that agricultural representatives often congregated with their SPC colleagues—they travelled together, and often sat together, during formal and informal parts of the workshops. Informal parts of the workshops—coffee and meal breaks—appeared to be particularly valuable times for negotiating vernacular knowledge, as well as for comparing and contrasting scientific knowledge gained during formal presentations with local knowledge, values, and beliefs. An inspection of Figure 1d supported the results of participant observation. The analysis of survey responses for the presence of strong ties between the members of the same SPC provided striking results: four of the five (80%) of the SPCs with two members reported strong ties for all relationships, and, for the eight SPCs with three members, five (63%) had reported strong ties and three (37%) reported moderate-strength ties. The single two farmer member SPC that reported a weak tie had recently experienced the replacement of an agricultural member. This suggested that the majority of network members had bonded tightly and formed cohesive sub-groups [43,63]. This also suggested that collaborative processes may be facilitated where conditions that support the formation of strong ties are present, promoting conditions that would support processes and outcomes such as the sharing of knowledge and building trust between network members. This is consistent with the literature that states that individual actors develop relationships and form sub-groups through close and frequent interaction over time as part of their participation in the same event or organization [63], which, in this case, involved being members of the same SPC. This bonding would facilitate agricultural representatives working together at frequent SPC meetings and contribute to the creation and sharing of knowledge during problem-solving efforts within their SPCs.

The analysis for the presence of strong ties helped explain the level of cohesion within sub-groups formed by network members who belonged to the same SPC, but it did not explain the level of cohesion that was observed within the broader network that showed weak ties (Figure 1b) and moderate ties (Figure 1c). To better understand the underlying pattern of ties within the broader network, the three centrality measures presented in Table 1 were evaluated. Centrality is an indicator of the relative importance of a network member for influencing the function of the network and is related to the number and direction of ties that they have with other members of the network [28,60,64]. The results of this analysis are summarized in Table 2, which contains the centrality measure scores for each of the agricultural representatives. Individual scores that exceed the mean for each centrality measure are highlighted.

Table 2. Agricultural representative centrality measures.

Actor Code	Centrality Measure [1]		
	Out-Degree (Mean = 38.4)	**In-Degree (Mean = 38.4)**	**Betweenness (Mean = 12.3)**
01_09	24	35	2.52
01_10	79	43	19.8
01_11	40	33	16.4
02_07	131	43	30.0
02_08	10	32	0.74
03_13	40	41	43.6
03_15	12	52	4.60
04_07	44	29	8.46
04_21	0	31	0
05_07	11	39	0.67
05_08	48	35	7.84
06_12	63	61	52.1
06_13	42	27	0.09
06_14	49	44	25.7
07_09	0	27	0
09_05	27	43	2.12
09_09	40	34	6.96
09_10	43	28	0.21
10_05	81	29	0.21
11_07	36	26	0.21
12_09	11	47	3.25
12_10	82	47	36.5
13_07	53	32	15.4
13_08	12	35	0.4
13-06	0	35	0
14_07	6	49	2.67
14_08	13	34	1.37
14-09	42	26	26.2
16_09	46	39	2.17
16_10	26	37	3.83
16_11	25	37	0.42
18_09	41	50	5.56
18_10	19	37	1.33
18_11	46	63	57.3
19_09	49	35	16.1
19_10	65	43	16.1
19_11	63	41	8.03

Note: [1] Highlighted centrality measure values exceed the mean value.

Table 3 indicates that 7 (19%) of the members exceeded the mean for all three of the centrality measure scores, 4 (11%) exceeded the mean for two of the centrality measure scores, and 13 (35%) exceeded the mean for one of the centrality measure scores. Overall, this indicates that 24 (65%) of the agricultural representatives had the potential to act as "opinion leaders" [59]—members who had the potential to influence the function of the network. The out-degree centrality scores are consistent with participant observation during the workshops, the teleconference, and the online sessions. Specifically, actors with a high out-degree centrality scores often initiated or participated actively and consistently in discussions. The in-degree and betweenness centrality scores also reflect their propensity to be involved in discussions, asked for their insight, or have their opinions referenced implicitly and explicitly by other agricultural representatives during discussions. As a consequence, centrality appeared to be an important measure of the level of activity within the network, such as the movement of knowledge.

Table 3. Centrality Measure Scores Exceeding Mean Values.

Centrality Measurement	Scores Exceeding Mean Values	
	Number	Percentage
For 3 Centrality Measures	7	19
For 2 Centrality Measures	4	11
For 1 Centrality Measure	13	35

The influence of the opinion leaders is evident by examining and comparing Figure 1b–d. As would be expected, the majority of influence leaders were well-connected within the network, having weak, moderate, and strong ties with many other members. However, the comparison also revealed that the opinion leaders were part of several different sub-groups formed by weak, moderate, and strong ties. The first sub-group, formed by 742 weak ties, included all members. Figure 1b indicated that the opinion leaders occupy a central position in this sub-group, with many in-degree and out-degree ties. Further, the members who are not influence leaders also have many in-degree and out-degree ties, indicating that they are well integrated into this sub-group of weak ties. The second group, connected by 80 moderate ties, again indicates that the majority of opinion leaders occupy a central role within this sub-group. Figure 1c indicates that five members, including three opinion leaders, were not connected to the sub-group through moderate ties. Also, moderate ties created a structure for multiple paths for the movement of knowledge within the sub-group. The third sub-group, formed by 119 strong ties, included all members, and demonstrated that the opinion leaders occupy a central position within the sub-group. Figure 1d indicates that the paths for the movement of knowledge were much more limited and radiated out from several centrally located members (e.g., 02-07, 18-11), who were also connected through numerous weak and moderate ties.

4. Discussion

Participant observation and SNA results confirmed that the cohesive sub-groups were connected in two ways within the network. First, weak ties formed bridges for connecting members and for sharing knowledge within the network. This is consistent with current theory and practice, which holds that weak ties can bridge and provide a means for accessing and sharing resources between disconnected or diverse parts of the community [57,68]. Second, moderate and strong ties between opinion leaders connected the cohesive sub-groups, albeit through a small number of members (Figure 1d), forming an overarching structure that was connected to at least one member of all the sub-groups within the network. This is consistent with the theoretical literature that indicates that networks promote bonding between members who have close relationships where there are shared values within smaller well-integrated and cohesive groups and bridging between diverse groups [43,59]. This was consistent with participant observation during informal parts of the workshop that revealed that agricultural representatives from different SPCs often became involved in lengthy discussions, revisiting issues that had arisen during formal parts of the workshop. These discussions appeared to provide an additional opportunity for members to participate in the negotiation of vernacular knowledge.

Participant observation indicated that no single sub-group dominated discussions within the workshops. This suggested that different perspectives within the network were relatively well represented and balanced during problem-solving discussions. Centrality measures, summarized in Table 2, supported these qualitative results: 15 of the 16 SPCs (81%) had at least one influential Agricultural Representative; the SPC that did not have an influence leader (07) had only one Agricultural Representative and was geographically isolated from the other sub-groups. Participant observation also indicated that the agricultural representatives were highly cohesive concerning some issues, but less cohesive on others. For instance, the agricultural representatives were able to reach consensus on a set of guiding Source Water Protection (SWP) principles within a single afternoon of a workshop. Draft SWP principles were presented by members of the OFEC working group, were discussed in detail, and were then modified and accepted with minimal negotiation. In contrast, extended discussion was required to resolve more contentious issues.

One example of an extended discussion concerned the relative advantages and disadvantages of using a regulatory versus a voluntary approach for mitigating risks associated with the handling and storage of animal manure. This discussion was contentious because it concerned the development of vernacular knowledge concerning the management of animal manures. The development of the position played out over several workshops, and involved two groups of agricultural representatives with differing perspectives. One group advocated for the use of a regulatory approach that would involve the mandatory phase-in of affected farms that were not currently subject to provincial nutrient management legislation. A key member of this group was agricultural representative 14-07, who was very prominent in the broader agricultural community. A second group promoted a voluntary approach, which they described as more flexible and site-specific, and would avoid the disadvantages of a regulatory approach. A key member of the second group was Agricultural Representative 02-07, who had been heavily involved in agricultural organizations at the local and provincial scales.

The centrality measures summarized in Table 2, and the patterns formed by the different strength ties shown in Figure 1b–d, provided insight into the problem-solving process within the network. Despite the high level of prominence indicated by his high in-degree centrality score (49), Agricultural Representative 14-07, a proponent of the regulatory approach, had limited influence on the sharing of knowledge and beliefs within the network, as reflected in low out-degree (6) and betweenness (2.67) centrality scores. In contrast, Agricultural Representative 02-07, a proponent of the voluntary approach, had high out-degree (131), high in-degree (43), and high betweenness (30) scores. As a consequence, this person was well connected and better positioned to share knowledge and influence beliefs within the network. Further, Agricultural Representative 14-07 was positioned on the margin of the sub-groups in Figure 1b–d and was the recipient of many in-degree ties but did not have the out-degree ties needed for sharing knowledge or acting as the intermediary for knowledge sharing. In contrast, Agricultural Representative 02-07 occupied a strategic position within all three sub-groups, benefiting from many in-degree and out-degree ties and by acting as an intermediary for the sharing of knowledge.

Neither group was successful in getting their position fully adopted and endorsed by the network, reflecting a balanced collaborative approach to problem-solving. Deliberation of the two opposing approaches appeared to help both groups to better understand each other's concerns, which provided an opportunity for negotiating and accepting concessions, and developing a mutually acceptable outcome that included components of the regulatory and voluntary approaches. This suggests the ability of influential members to link sub-groups and to promote the sharing of knowledge that helped support a collaborative problem-solving approach. This was demonstrated by the ability of members to negotiate mutually acceptable outcomes through the problem-solving process. The outcome was the integration of each group's values and beliefs, which were both grounded in a mutual acceptance of agricultural science, to create a vernacular knowledge.

5. Conclusions

Stakeholder participation in the creation and sharing of knowledge is necessary for collaborative forms of problem-solving [3,22]. Social networks have been recognized as an important way to involve stakeholders in these forums [27]. In this paper, we explored the extent to which, and the mechanisms through which, a locally-organized agricultural network was able to develop and participate in a province-wide collaborative approach to drinking water source protection. The goal of this network was ensuring that agricultural interests were represented consistently and effectively in the source protection planning process.

The results of SNA indicated that the efforts of a farm organization, OFEC, were successful in organizing locally-elected agricultural representatives into a cohesive provincial-scale network whose members served on local-scale source protection committees. Participant observation indicated that the network members were able to negotiate and reach consensus on contentious issues even though the density measure calculated for ties between members indicated that the network was moderately connected. Furthermore, although the calculation of centrality measures indicated the presence of opinion leaders who had the potential to influence the problem-solving process, complementary data from participant observation suggested that no individual or group of members dominated discussions. This balanced approach was attributed to the connections between cohesive sub-groups that were formed through weak, moderate, and strong ties, combined with the previous experience of the agricultural representatives with multi-stakeholder problem-solving processes. Importantly, the research revealed that the agricultural network consisted of a series of cohesive sub-groups that were linked by different strength ties. This finding is consistent with research indicating that networks can have structures composed of highly cohesive sub-groups that are connected by a combination of bridging weak and moderate ties and bonding strong ties [43].

The results of this research provide broader insight for theory and practice. First, regional-scale stakeholder networks can be intentionally organized to participate in creating and sharing of vernacular knowledge in individual local-scale collaborative forums. In this instance, the formation of the stakeholder network was facilitated by a working group composed of a farm organization and state agricultural agency representatives. This insight complements existing research that has focused on identifying stakeholder networks that can participate in environmental problem-solving [9,29]. Given that social networks can make an important contribution to problem-solving [22], it stands to reason that helping stakeholder groups to create or bolster their networks would result in more robust problem-solving processes.

Second, the fact that the network contained opinion leaders who influenced the creation and sharing of knowledge indicates that there may be preferential pathways for the transfer of information into, and within, a network. This may be useful for sharing knowledge concerning alternative agri-environmental management practices with members of farm networks, and may have implications for networks in different sectors [60]. There may also be interest among researchers to explore less resource-intensive methods for identifying opinion leaders within networks. This insight is important for practitioners who are interested in sharing knowledge or influencing problem-solving within a stakeholder network. Strategically identifying and forming ties with opinion leaders in order to optimize the uptake of knowledge within a stakeholder network may be an effective strategy.

Third, the research provided insight concerning how collaborative processes can be strengthened through the contributions of knowledge from network members who have been deliberately embedded in those processes. In the example considered here, the network allowed members to engage in the creation and sharing of knowledge in preparation for participating in broader multi-sector collaborative forums by deliberating and negotiating solutions to complex problems. This also provided members who had experience with collaborative approaches, and who had the expectation that these approaches would be employed when addressing complex environmental problems. Finally, it provided members with experience in negotiating and accepting concessions, which is often a necessary part of the process of reaching mutually acceptable outcomes.

Fourth, the research builds on the growing interest in combining qualitative and quantitative approaches for studying networks [30,31]. In this example, a combination of participant observation and SNA provided insight concerning the structure and functioning of a network. Findings in this research are based on a single network. This limitation should be addressed in the future by comparing the structure and function of multiple networks from different settings using combinations of qualitative and quantitative methods.

Acknowledgments: This research was supported by research grants from the Social Sciences and Humanities Research Council (Standard Research Grant 410-2011-2294, R. de Loë Principal Investigator); the Canadian Water Network (NCE-4000-2010, R. de Loë Principal Investigator); and a Social Sciences and Humanities Research Council Doctoral Fellowship (H.C. Simpson). The first author gratefully acknowledges the Ontario Ministry of Agriculture, Food and Rural Affairs, which provided release time during his studies.

Author Contributions: The first author designed the study, conducted the research, analyzed the data, and led the writing process. The second author served as the supervisor, contributed to project conceptualization and design, and supported the writing of the manuscript.

Conflicts of Interest: The first author was an employee of the Ontario Ministry of Agriculture, Food, and Rural Affairs during the time the research was conducted. The research reported in this paper was independent from his employment, and the Ministry played no role in the work beyond providing release time. The second author declares no conflicts.

References

1. Emerson, K.; Nabatchi, T.; Balogh, S. An integrative framework for collaborative governance. *J. Public Adm. Res. Theory* **2012**, *22*, 1–29. [CrossRef]
2. Ansell, C.; Gash, A. Collaborative governance in theory and practice. *J. Public Adm. Res. Theory* **2007**, *18*, 543–571. [CrossRef]
3. Innes, J.E.; Booher, D.E. *Planning with Complexity: An Introduction to Collaborative Rationality for Public Policy*; Routledge: New York, NY, USA, 2010.
4. Holley, C.; Gunningham, N.; Shearing, C. *The New Environmental Governance*; Earthscan: New York, NY, USA, 2012.
5. Margerum, R.D. A typology of collaboration efforts in environmental management. *Environ. Manag.* **2008**, *41*, 487–500. [CrossRef] [PubMed]
6. Sabatier, P.; Focht, W.; Lubell, M.; Trachtenberg, Z.; Vedlitz, A.; Matlock, M. *Swimming Upstream: Collaborative Approaches to Watershed Management*; The MIT Press: Cambridge, MA, USA, 2005.
7. Memon, A.; Weber, E.P. Overcoming obstacles to collaborative water governance: Moving toward sustainability in new zealand. *J. Nat. Resour. Policy Res.* **2010**, *2*, 102–116. [CrossRef]
8. Lach, D.; Rayner, S.; Ingram, H. Taming the waters: Strategies to domesticate the wicked problems of water resource management. *Int. J. Water* **2005**, *3*. [CrossRef]
9. Blackstock, K.L.; Richards, C. Evaluating stakeholder involvement in river basin planning: A scottish case study. *Water Policy* **2007**, *9*, 493–512. [CrossRef]
10. Carr, A.J.L. Why do we all need community science? *Soc. Nat. Resour.* **2004**, *17*, 841–849. [CrossRef]
11. Turner, S. Quasi-science and the state: "Governing science" in comparative perspective. In *The Governance of Knowledge*; Stehr, N., Ed.; Transaction Publishers: New Brunswick, NJ, USA, 2004; pp. 241–268.
12. Van Wyk, E.; Breen, C.M.; Sherwill, T.; Magedlela, D. Challenges for the relationship between science and society: Develping capacity for ecosystem governance in an emerging democracy. *Water Policy* **2007**, *9*, 177–189.
13. Orr, D.W. What is education for? Six myths about the foundations of modern education and six new principles to replace them. *Learn. Revolut.* **1991**, *27*, 52–57.
14. Bartel, R. Vernacular knowledge and environmental law: Cause and cure for regulatory failure. *Local Environ.* **2014**, *19*, 891–914. [CrossRef]
15. Lauber, T.B.; Decker, D.J.; Knuth, B.A. Social networks and community-based resource management. *Environ. Manag.* **2008**, *42*, 677–687. [CrossRef] [PubMed]
16. Reed, M.S.; Evely, A.C.; Cundill, G.; Fazey, I.; Glass, J.; Laing, A.; Newig, J.; Parrish, B.; Prell, C.; Raymond, C.; et al. What is social learning? *Ecol. Soc.* **2010**, *15*, r1. [CrossRef]
17. Fish, R.D.; Ioris, A.A.R.; Watson, N.M. Integrating water and agricultural management: Collaborative governance for a complex policy problem. *Sci. Total Environ.* **2010**, *408*, 5623–5630. [CrossRef] [PubMed]
18. Peters, B.G.; Pierce, J.C. Multi-level governance and democracy: A faustian bargain? In *Multi-Level Governance*; Bache, I., Flinders, M., Eds.; Oxford University Press: Oxford, UK, 2004; pp. 80–100.
19. Reed, M.G.; Bruyneel, S. Rescaling environmental governance, rethinking the state: A three-dimensional review. *Prog. Hum. Geogr.* **2010**, *34*, 646–653. [CrossRef]

20. Brummel, R.F.; Nelson, K.C.; Jakes, P.J. Burning through organizational boundaries? Examining inter-organizational communication networks in policy-mandated collaborative bushfire planning groups. *Glob. Environ. Chang.* **2012**, *22*, 516–528. [CrossRef]
21. Cundill, G.; Rodela, R. A review of assertions about the processes and outcomes of social learning in natural resource management. *J. Environ. Manag.* **2012**, *113*, 7–14. [CrossRef] [PubMed]
22. Yaffee, S.L.; Wondolleck, J. Making collaboration work. *Conservation* **2000**, *1*, 17–24.
23. O'Riordan, T.; Rayner, S. Risk management for global environmental change. *Glob. Environ. Chang.* **1991**, *1*, 91–108. [CrossRef]
24. Fischer, F. *Citizens, Experts, and the Environment*; Duke University Press: Durham, NC, USA, 2000.
25. Leach, W.D. Collaborative public management and democracy: Evidence from western watershed partnerships. *Public Adm. Rev.* **2006**, *66*, 100–110. [CrossRef]
26. Taylor, B.; de Loë, R.C.; Bjornlund, H. Evaluating knowledge production in collaborative water governance. *Water Altern.* **2012**, *6*, 42–66.
27. Innes, J.E. Networks and planning thought. In *The Network Society: A New Context for Planning?* Albrechts, L., Mandelbaum, S.J., Eds.; Routledge: New York, NY, USA, 2005; pp. 57–62.
28. Scott, J. *Social Network Analysis: A Handbook*, 2nd ed.; SAGE: London, UK, 2000.
29. Prell, C.; Hubacek, K.; Reed, M.S. Stakeholder analysis and social network analysis in natural resource management. *Soc. Nat. Resour.* **2009**, *22*, 501–518. [CrossRef]
30. Edwards, G.; Crossley, N. Measures and meanings: Exploring the ego-net of helen kirkpatrick watts, militant suffragette. *Methodol. Innov. Online* **2009**, *4*, 37–61. [CrossRef]
31. Crossley, N. The social world of the network. Combining qualitative and quantitative elements in social network analysis. *Sociologica* **2010**, *4*. [CrossRef]
32. Wenger, E. Communities of practice and social learning systems: The career of a concept. In *Social Learning Systems and Communities of Practice*; Blackmore, C., Ed.; The Open University: London, UK, 2010; pp. 179–198.
33. Liebowitz, J. *Social Networking: The Essence of Innovation*; Scarecrow Press: Lanham, MD, USA, 2007.
34. Skogstad, G. The farm policy community and public policy in ontario and quebec. In *Policy Communities and Public Policy in Canada: A Structural Approach*; Coleman, W.G., Skogstad, G., Eds.; Copp Clark Pitman: Mississauga, ON, Canada, 1990; pp. 59–90.
35. Montpetit, E. *Misplaced Distrust: Policy Networks and the Environment in France, the United States, and Canada*; UBC Press: Vancouver, BC, Canada, 2003.
36. Simpson, H.; de Loë, R.; Andrey, J. Vernacular knowledge and water management—Towards the integration of expert science and local knowledge in Ontario, Canada. *Water Altern.* **2015**, *8*, 77–97.
37. Cash, D.W.; Borck, J.C.; Patt, A.G. Countering the loading-dock approach to linking science and decision making: Comparative analysis of el niño/souther oscillation (ENSO) forecasting systems. *Sci. Technol. Hum. Values* **2006**, *31*, 465–494. [CrossRef]
38. Simpson, H.C.; de Loë, R.C. A collaborative approach to groundwater protection: The rural water quality program for waterloo region. *Can. Water Resour. J.* **2014**, *39*, 228–239. [CrossRef]
39. Wagner, W. Vernacular science knowledge: Its role in everyday life communication. *Public Underst. Sci.* **2007**, *16*, 7–22. [CrossRef]
40. Schusler, T.M.; Decker, D.J.; Pfeffer, M.J. Social learning for collaborative natural resource management. *Soc. Nat. Resour.* **2003**, *15*, 309–326. [CrossRef]
41. Reed, M.G.; McIlveen, K. Toward a pluralistic civil science? Assessing community forestry. *Soc. Nat. Resour.* **2006**, *19*, 591–607. [CrossRef]
42. Brisbois, M.C.; de Loë, R. State roles and motivations in collaborative approaches to water governance: A power theory-based analysis. *Geoforum* **2016**, *74*, 202–212. [CrossRef]
43. Blanco, I.; Lowndes, V.; Pratchett, L. Policy networks and governance networks: Towards greater conceptual clarity. *Political Stud. Rev.* **2011**, *9*, 297–308. [CrossRef]
44. Prell, C.; Hubacek, K.; Quinn, C.; Reed, M. 'Who's in the network?' when stakeholders influence data analysis. *Syst. Pract. Action Res.* **2008**, *21*, 443–458. [CrossRef]
45. Hay, C. The tangled webs we weave: The discourse, strategy and practice of networking. In *Comparing Policy Networks*, 1st ed.; Marsh, D., Ed.; Open University Press: Maidenhead, UK, 1998; pp. 32–51.
46. Torfing, J. Introduction: Democratic network governance. In *Democratic Network Governance in Europe*; Marcussen, M., Torfing, J., Eds.; Palgrave MacMillan: New York, NY, USA, 2007; pp. 1–22.

47. Bevir, M.; Richards, D. Decentring policy networks: A theoretical agenda. *Public Adm.* **2009**, *87*, 3–14. [CrossRef]
48. Johnson, R.B.; Onwuegbuzie, A.J. Mixed methods research: A research paradigm whose time has come. *Educ. Res.* **2004**, *33*, 14–26. [CrossRef]
49. Cresswell, J.W. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*; SAGE: Thousand Oaks, CA, USA, 2003.
50. Morse, J.M. Principles of mixed methods and multimethod research design. In *Handbook of Mixed Methods in Social Behavior Research*; Tashakkori, A., Teddlie, C., Eds.; Sage Publications, Inc.: Thousand Oaks, CA, USA, 2003; pp. 189–208.
51. Teddlie, C.; Tashakkori, A. *Foundations of Mixed Methods Research: Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2009.
52. O'Connor, D.R. *Report of the Walkerton Inquiry: Part One, the Events of May 2000 and Related Issues*; Queen's Printer for Ontario: Toronto, ON, Canada, 2002.
53. O'Connor, D.R. *Report of the Walkerton Inquiry: Part Two, a Strategy for Safe Drinking Water*; Ontario Ministry of the Attorney General, Queen's Printer for Ontario: Toronto, ON, Canada, 2002.
54. Ontario Ministry of the Environment. *Stakeholder Engagement Reference Manual for Drinking Water Source Protection*; OMOE: Toronto, ON, Canada, 2007.
55. Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). *2011 Census of Agriculture*; Queen's Printer of Ontario: Guelph, ON, Canada, 2012.
56. Legislative Assembly of Ontario. *Clean Water Act*; Legislative Assembly of Ontario: Toronto, ON, Canada, 2006.
57. Granovetter, M.S. The strength of weak ties. *Am. J. Sociol.* **1973**, *78*, 1360–1380. [CrossRef]
58. Crona, B.; Bodin, O. What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. *Ecol. Soc.* **2006**, *11*, 7. [CrossRef]
59. Burt, R.S. *Brokerage and Closure: An Introduction to Social Capital*; Oxford University Press: Oxford, UK, 2005.
60. Currie, G.; White, L. Inter-professional barriers and knowledge brokering in an organizational context: The case of healthcare. *Organ. Stud.* **2012**, *33*, 1333–1361. [CrossRef]
61. Diani, M. Networks and social movements: A research programme. In *Social Movements and Networks: Relational Appoaches to Collective Action*; Diani, M., McAdam, D., Eds.; Oxford University Press: New York, NY, USA, 2003; pp. 299–319.
62. Hollstein, B. Qualitative approaches. In *The Sage Handbook of Social Network Analysis*; Scott, J., Carrington, P.J., Eds.; SAGE Publications Ltd.: Cornwall, UK, 2011; pp. 404–416.
63. Prell, C. *Social Network Analysis: History, Theory and Methodology*; SAGE: Thousand Oaks, CA, USA, 2012.
64. Hanneman, R.A.; Riddle, M. A brief introduction to analyzing social network data. In *The Sage Handbook of Social Network Analysis*; Scott, J., Carrington, P.J., Eds.; SAGE: Thousand Oaks, CA, USA, 2011; pp. 40–54.
65. Borgatti, S.P.; Everett, M.G.; Freeman, L.C. *Ucinet Software Version 6*; Analytic Technologies: Harvard, MA, USA, 2002.
66. Kearns, R. Being there: Research through observing and participating. In *Qualitative Research Methods in Human Geography*; Hay, I., Ed.; Oxford University Press: Oxford, UK, 2000; pp. 103–121.
67. Sørensen, E.; Torfing, J. Theoretical approaches to governance network dynamics. In *Theories of Democratic Network Governance*; Sørensen, E., Torfing, J., Eds.; Palgrave MacMillan: Houndmills, Basingstoke, UK, 2007; pp. 25–43.
68. Borgatti, S.P.; Lopez-Kidwell, V. Network theory. In *The Sage Handbook of Social Network Analysis*; Scott, J., Carrington, P.J., Eds.; SAGE: Thousand Oaks, CA, USA, 2011; pp. 40–54.