Complexity, Governance & Networks-Vol 02, Issue 01 (2015) 65–82
DOI: 10.7564/15-CGN25

The Shape of Watershed Governance: Locating the Boundaries of Multiplex Networks

Steve Scheinert*, Christopher Koliba, Stephanie Hurley,
Sarah Coleman, and Asim Zia

University of Vermont
E-mail: Steve.Scheinert@uvm.edu;
E-mail: ckoliba@uvm.edu;
E-mail: shurley1@uvm.edu;
E-mail: scoleman@uvm.edu;
E-mail: azia@uvm.edu

Governance networks are both nested and interconnected systems. Identifying internal boundaries within governance networks, such as those governance structures that influence and are influenced by large and diverse watersheds such as the Lake Champlain Basin, is necessary for differentiating between multiple functional subnetworks. Internal network boundaries exist between functional subnetworks when the networks have divergent structures (Weible & Sabatier, 2005). A qualitative case study of Lake Champlain Basin watershed governance networks identified several key overlapping subnetworks in which organizations interact in a variety of ways (Koliba, Reynolds, Zia, & Scheinert, 2015). An online survey of institutional actors was used to identify which actors were connected in five different functional subnetworks. Structural comparisons are made by analyzing the correlation between the subnetworks based on the quadratic assignment procedure (QAP) and network macrostructure. Results show that the information sharing, technical assistance, and project collaboration subnetworks formed one grouping, while the reporting and financial resource sharing subnetworks formed another grouping. The results demonstrated that this triangulated comparison was necessary to reach valid conclusions on the structural variation between the subnetworks on a multiplex network when subnetworks were structurally similar.

Keywords: multiplex networks, network boundaries, governance networks

Boundaries define the space of operations for actors in a complex system and influence the shifting coalitions that can exist within the system. Koliba, Meek, and Zia (2010) explain the importance of boundaries within governance networks, finding that, “Internal boundaries will likely be influenced by the nature of the multiplex ties formed between actors in the network” (p. 169). Multiplex ties are network ties that encode multiple types of interaction within a single network tie. Coding multiple meanings in a single multiplex tie renders reliable interpretation of analysis based on multiplex ties problematic (Butts, 2008, 2009). Disaggregating multiplex ties into their separate meanings generates

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* Corresponding author.

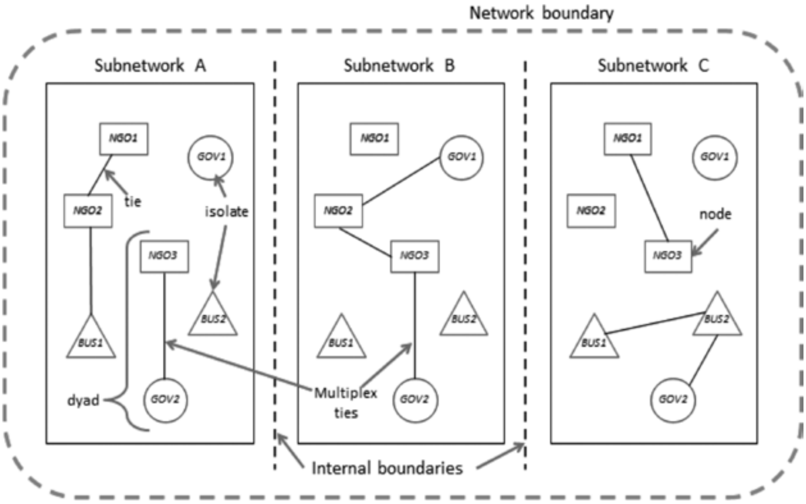

Figure 1. Network concept definitions in context

functional subnetworks, where all of the ties in each subnetwork encode only one type of interaction. Internal boundaries may exist between functional subnetworks when those subnetworks have different structures (Weible & Sabatier, 2005). The location of internal boundaries determines which functional subnetworks should be analyzed as a single network or analyzed individually. The presence and location of boundaries also influences how managers can ensure that services are delivered and policies are implemented (Provan & Lemaire, 2012). Structural analysis of the functional subnetworks of a governance network will reveal where boundaries exist between those functional subnetworks.

Identifying a network's internal boundaries is not the same as identifying its external boundaries. Approaches for defining external network boundaries can identify the outer boundary, the "network boundary," as seen in Figure 1 (Butts, 2008, 2009; Lauman, Marsden, & Prensky, 1989). The external boundaries of the multiplex network also define the external boundaries of the subnetworks; every node that is included in any subnetwork is included in the multiplex network and all of the other subnetworks. Since external bounding approaches can only set this external boundary, a different approach is needed to identify internal boundaries.

Weible and Sabatier (2005) offer a method for documenting the existence of boundaries within specific systems. They use a method of structural comparison, based in the argument that the subnetworks with the most similar structures are the most closely related ones. Figure 1 depicts three structurally different subnetworks, and shows where boundaries exist between them. Any structurally similar networks depicted would lack a boundary between them.

1. Boundaries within Networked Systems

A thorough structural analysis of a multiplex governance network can reveal the internal boundaries between the functional subnetworks of a governance network. However, research findings indicate that, in a multiplex network, the existence of a tie between two nodes in one subnetwork increases the likelihood that a tie will exist between those same two nodes in the other subnetworks (Provan, Fish, & Sydow, 2007; Weible & Sabatier, 2005), indicating that the subnetworks' dyadic structures will be highly correlated. For the purpose of placing internal boundaries, this expected correlation prevents from even quadratic assignment procedure (QAP), which Weible and Sabatier (2005) apply as their sole analysis for structural comparison, from demonstrating sufficiently strong conclusions about structural variation. Instead, for identifying internal boundaries, a more extensive structural analysis is needed to identify smaller, consistent structural variations. We examine this hypothesis through a case study of the empirical watershed governance networks that are present in portions of the Lake Champlain Basin.

1.1. Networks in Watershed Governance and Climate Change Policy

A major theme in the studies on governance networks is about how these networks can and should be managed (Klijn, Steijn, & Edelenbos, 2010; McGuire, 2002). These studies often focus on two issues: the role of trust between the actors in a network and how that trust can be built (Hajer & Versteeg, 2005; Klijn, Edelenbos, & Steijn, 2010; Klijn & Skelcher, 2007; Sorenson & Torfing, 2005, 2009) and the impact of network structure and design on network outputs (Agranoff, 2004; Provan & Kenis, 2008; Provan & Lemaire, 2012; Provan & Milward, 2001). In this literature, the governance network is treated largely as a proverbial "black box." Instead of linking differing structures to differing management strategies, universal approaches are promoted. Managers are instructed to use certain behaviors (Milward & Provan, 2006) or to build the networks with a certain network structure or pattern of relationships (Provan & Milward, 2001), to seek a minimum network density (Hirschi, 2010), or to manage through a certain type of organization, such as a governmental program or non-governmental organization (NGO) (Provan & Kenis, 2008). Further studies are needed regarding the structures that existing governance networks and their subnetworks take, and what implications those structures have for policy making and service delivery.

Where the general governance network literature tends to examine conceptual or theoretical networks, the literature on watershed governance networks is able to examine specific governance networks (Imperial, 2005; Schneider, Scholz, Lubell, Mindruta, & Edwardsen, 2003; Weible & Sabatier, 2005). The research on watershed networks includes a wide body of literature on the benefits and requirements of cooperation and coordination in networks (Hirschi, 2010; Imperial, 2005; Jost & Jacob, 2004; Lubell & Fulton, 2008; Schneider et al., 2003; Scholz, Berardo, & Kile, 2008; Weible & Sabatier, 2005), planning

(Dutcher & Blythe, 2012; Koontz & Johnson, 2004; Lienert, Schnetzer, & Ingold, 2013), knowledge diffusion and learning (Betsill & Bulkeley, 2004; Cash et al., 2003; Newig, Guenther, & Pahl-Wostl, 2010; Vignola, McDaniels, & Scholz, 2013), and system scaling (Cohen & Davidson, 2011; Norman & Bakker, 2009; Vignola et al., 2013), all of which are harnessed to build theories that apply to all governance networks. What the watershed governance literature continues to miss is a focus on implementation networks and the network reactions to policy decisions (Rykkja, Neby, & Hope, 2014).

1.2. The Role of Functional Ties in Forming Internal Boundaries

Butts (2009) determines that rigorous network analysis can only rest on networks that use a clear and consistent definition of what the included ties represent. These tie types each define a separate functional subnetwork within the multiplex network. In a rigorous analysis, separate subnetworks must be analyzed independently. The subnetworks in Figure 1, for example, arise as separate networks for analysis, each with its own unique type of interaction and pattern of network ties. Examples of different types of ties in an institutional network include sharing information, providing reports, and collaborating on projects.

The effectiveness of any network relies on its actors properly matching their strategies and structures to the network's environment, and dyadic and governance arrangements (Baltazar & Brooks, 2007; Koliba et al., 2010; Ostrom, 2012; Provan & Lemaire, 2012; Provan & Milward, 2001) and of forming an accurate situational awareness through coordination and collaboration (Hutchins, 1995; Luokkala & Virranttaus, 2014; Van de Walle & Turoff, 2008). Each instance of a network environment, structure, and governance arrangement generates a new and different operational environment. Baltazar and Brooks (2007) interpret this variation across operational environments as the formation of boundaries between systems, with organizations requiring different strategies for different environments. Since each subnetwork with a different structure is potentially a different operational environment, a method is needed to determine which subnetworks do represent different environments.

1.3. Methods for Defining External Network Boundaries

Finding the proper approach to define the external boundaries of a network is one of the most persistent challenges to any empirical network study (Butts, 2008, 2009). A wealth of literature examines the procedures researchers can apply to pre-determine external network boundaries. Two methods dominate this literature. The first is a "deductive approach," where the researcher defines a class of nodes that will be included in the study's network and then identifies the actors that fit this definition. Examples include the individuals of a social network (Lienert et al., 2013), the words of a semantic network (Diesner & Carley, 2011), or the organizations of an institutional network (Comfort, Oh, Ertan, & Scheinert, 2010; Koliba et al., 2010). While there are many ways to define a target group of nodes for inclusion, the key aspect of the deductive approach is that the researcher determines the complete list of included nodes in the network prior to collecting data on network ties (Betsill & Bulkeley, 2004; Jost & Jacob, 2004; Lubell & Fulton, 2008; Vignola et al., 2013). The second approach is "inductive," where a set of documents or a small group of informants is selected and the actors mentioned in the documents or by the informants are included in the network (Comfort et al., 2010; Johnson, 1990; Pustejovsky & Spillane, 2009; Scheinert & Comfort, 2014). The deductive method is generally used when boundaries are easily defined and membership in either the node class or network is easily determined. The inductive method is used when boundaries cannot be defined or are unknown in advance.

1.4. Structural Analysis for Locating Internal Network Boundaries

The most relevant literature on the definition and role of internal network boundaries focuses on the identification of communities in networks (Duch & Arenas, 2005; Fortunato, 2010). Subgroup detection, including clique analysis (Burt, 1978), Newman's grouping algorithms (Newman, 2006), structural equivalence (Burt, 1987; Sailer, 1978), and fuzzy overlapping groups (Davis & Carley, 2008; Gregory, 2011), among many other methods, identifies nodes that fit in certain groups. The difference between these methods is that subgroup detection uses a network's structure to carve that network into subgroups while the external boundaries approaches define the size of the network.

Weible and Sabatier (2005) offer the strongest example of how to build a structural comparison of institutional networks. They compare the structures of groupings of organizations within the subnetworks of a multiplex network for setting policy regarding marine protected areas. They define network links as Allies, Coordination, Advice/Information, and shared beliefs regarding a specific policy, the California Marine Life Protection Act, networks. They compare the position of existent dyads with a correlational analysis using quadratic assignment procedure (QAP). QAP correlation analysis provides a general indicator of when a tie between two given nodes in one network is likely to indicate a tie between those same two nodes in another network. This is a powerful process for comparing subnetworks, but it is not the only one that can and should be considered. Subtle differences in tie locations can lead to meaningful differences in network structure; changing just a few ties can be the difference between a lattice network and a small world network (Telesford, Joyce, Hayasaka, Burdette, & Laurienti, 2011; Watts & Strogatz, 1998), which is a small enough difference that it might not reflect in QAP correlation results. Additional, supporting results are needed to augment the QAP correlation results.

The network analyst must seek results through the triangulation of descriptive analytic techniques whose combined results yield an overall conclusion. To address this need for consistency across a range of results, in this study we applied several analyses of the subnetworks' structures to identify consistent and inconsistent structure: subnetwork dyadic correlations and subnetwork macrostructures. Internal boundaries will exist between subnetworks with different structures and not exist between subnetworks with similar structures. Since networks may take many different forms, it is more important to identify consistencies across a set of subnetworks. The results will support the placement of internal boundaries when measurements are differ across subnetworks.

Subnetwork dyadic correlation. In this study we applied QAP correlation analysis, as used by Weible and Sabatier (2005). When a high correlation exists between two networks, coded as matrices, there is a greater likelihood that the presence of a tie in one network accurately predicts the presence or absence of a tie between the same two nodes in the other network. High positive correlations indicate similar patterns of observed and unobserved ties while negative correlations indicate an opposite pattern of structural holes and ties. Similar networks will share high, positive correlation coefficients.

Subnetwork macrostructures Network macrostructural analyses include small world networks (Watts & Strogatz, 1998), scale free networks (Barabasi & Albert, 1999), and core-periphery networks (Wasserman & Faust, 1994). The public administration literature does not yet regularly apply network macrostructural concepts for describing and analyzing governance networks. Each macrostructural analysis defines a theoretical structure that networks can take, including identifying a test for determining if a given network fits that definition. This study identifies small world networks using the coefficient proposed by Telesford et al. (2011):

$$\omega = \frac{L_{rand}}{L} - \frac{C}{C_{latt}} \tag{1}$$

where L is the observed average path length, C is the observed clustering coefficient, L_{rand} is the average path length of a random network, and C_{latt} is the clustering coefficient of a lattice network. Small world networks produce a coefficient at or near zero. In a scale free network, the distribution of degree centrality scores, which count the number of ties that each nodes has (Wasserman & Faust, 1994), takes the form of a power-law distribution when plotted in a histogram. Core-periphery networks can be determined in UCINet (Borgatti, Everett, & Freeman, 2002), which provides an algorithm that identifies core membership and indicates how closely the network matches a core-periphery structure (Borgatti, Everett, & Johnson, 2013). UCINet's categorical core-periphery algorithm operates similarly to block modeling approaches, identifying and sorting nodes into two blocks (Borgatti, Everett, & Freeman, 2002). The variation patterns found in macro-structural analyses augment dyadic correlation results. Similar small world coefficient values, histogram shapes, and core-periphery correlations and core membership are used to determine the location of internal boundaries. If these results can corroborate the results of the QAP analysis, then both sets of results will indicate the location of an internal boundary.

2. Method

2.1. Case Study Focus

The Lake Champlain Basin (LCB) was chosen as a case study for its large and established watershed governance network (Osherenko, 2014). Lake Champlain is a large, freshwater lake that sits astride the borders between Vermont and New York in the United States and Quebec, Canada. The basin is the site of farming communities, particularly in Vermont and Quebec, and has struggled to meet its water quality requirements under the Clean Water Act. The arrangements made to govern the LCB and its sub-basins (Dutcher & Blythe, 2012; Osherenko, 2014) require interaction and collaboration across state and national borders in order to expand governance structures throughout the watershed. Vermont, with limited state budgets and producing the largest share of pollution, particularly from non-point sources (Lake Champlain Basin Program [LCBP], 2012; Osherenko, 2014), has relied on public-private partnerships for pursuing its water quality goals. This reliance has generated a large and engaged network of stakeholders. The extensive history of multi-stakeholder interactions related to water quality in the Vermont section of the LCB makes it an effective case study for examining the structures of a mature governance network and for demonstrating a method of identifying the boundaries between the functional subnetworks of a multiplex governance network.

2.2. Data

Our research used network surveys to acquire data regarding watershed-scale governance in the Lake Champlain Basin. As part of their work, Koliba, Reynolds, et al. (2015) used an inductive approach to define network boundaries (Comfort et al., 2010; Scheinert & Comfort, 2014), where water resource management documents are used to identify a wide swath of organizations that play a role pertaining to water quality outcomes in the Lake Champlain Basin. The current study approaches a targeted set of representatives from these organizations with an online survey that recorded interactions between organizations with a focus on two LCB sub-basins: the Winooski River watershed and the Missisquoi River watershed. These watersheds represent Vermont's primary region of development and one of Vermont's two primary agricultural environments, respectively. Land uses in these watersheds contribute to the two leading sources of non-point source pollution in Vermont into the LCB, urban stormwater runoff and agricultural runoff (LCBP, 2012).

We designed this study's survey as a whole population survey, rather than a sample-based survey. We established an initial alter roster, based on the organizational list that Koliba, Reynolds, et al. (2015) found. We augmented this list through a range of stakeholder interactions between July, 2012 and May, 2014, including eighteen stakeholder interviews, four focus groups, and two large-scale mediated modeling workshops. The focus groups included approximately two dozen different individual stakeholders representing nearly the same number of organizations while more than 100 stakeholders attended each mediated modeling workshop. This process produced a list of 187 organizations, including NGOs, governmental programs at both the state and federal level, regional and municipal governing entities, and private businesses, along with five collective groups which contain organizations that could not be reached for response.[1] We then reviewed this list in consultation with stakeholders to ensure consistency, accuracy, and completeness. During stakeholder consultations, we identified five key types of interaction between organizations: Information Sharing, Technical Assistance Provision, Reporting,[2] Financial Resource Sharing, and Project Coordination and Collaboration. Researchers identified and approached specified representatives from each organization through email, phone, and in-person contact to recruit participants. Each survey participant was presented with a list of all the other organizations in the network and asked to indicate whether they interact with that organization "frequently," "infrequently," or not at all for all five different types of interactions.

To account for the limits in identifying the initial list of organizations in a network survey, which Marsden (2005) discussed, we asked respondents to identify organizations that were not included in the original sample. Requests for additional organizations increased the total number to 198 organizations that could be contacted and to a total set of 204 potential alter organizations, including those groups of organizations that could not be reached for a response. As respondents suggested additions, these new additions were added to the survey's alter rosters and contacted to participate. This method combines the benefits of a pre-determined alter list with the benefits of snowball sampling for establishing an externally bounded governance network (Marsden, 2005; Scott, 1991). To aid respondents in addressing this extensive list of potential alters the list was divided into four groupings based on organizational type and geographic field of operation. These groupings were Governmental Programs, Regional Actors and NGOs, Organizations with interests in the Winooski Watershed, and Organizations with interests in the Missisquoi Watershed. We initially asked respondents if their organization interacted with any members of a grouping. If a respondent indicated that their organization did not, then the respondent was not asked about interactions with the members of that group. Table 1 contains the survey response rates by grouping. Responses provided the data to generate five separate subnetworks, each representing one type of interaction and a sixth network that is the mathematical union of the five subnetworks and representing the full multiplex watershed governance network in both the Winooski and Missisquoi watersheds of the Lake Champlain Basin.

Network data are sensitive to missing data (Wasserman & Faust, 1994). To minimize the error introduced by these missing data, we binarized and symmetrized the network matrices.[3] Once binarized and symmetrized, the representative of only one organization in the dyad must indicate that the link exists for the link to be included in the network, providing two possible observations of each link. Following binarization and symmetrization, the only part of the network that remains unobserved are the dyads that include any two

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[1] Collective groups were used to record interactions with large, medium, and small farms in each the survey's targeted watersheds and a catch-all organization for interactions with Vermont's Agency of Agricultural, Farms, and Markets (VTAAFM) that were not covered by the named VTAAFM programs included in the survey.

[2] For determining reporting structure, the network was designated as the respondent's "Report to" network and framed as a respondent's "direct reports."

[3] Binarization and symmetrization were performed such such that: $A_{ij} = A_{ji} = \text{Max}(A_{ij}, A_{ji})$, where A is the adjacency matrix and A_{ij} and A_{ji} are the related cells of the adjacency matrix. $A_{ij} = A_{ji} = \text{Max}(A_{ij}, A_{ji})$

Table 1
Network survey response rates by organizational grouping

Organizational Group	Number of Contacts	Completed Responses	Response Rate (%)	Observation Rate (%)
Governmental Programs	56	26	46.4	71.75
Regional Actors and NGOs	50	26	52.0	73.47
Winooski Watershed	52	11	21.2	38.16
Missisquoi Watershed	40	12	30.0	51.54
Total	**198**	**75**	**37.9**	**60.26**

nodes both of which did not respond. The observed percentage of the network is reported in Table 1's Observation Rate column.[4] Low observation rates for certain groups would undermine confidence if the analysis only used data from the members of those groups. Since the analysis always uses the full organization list the high observation rate for the complete network gives confidence in accuracy of the analytic results.

3. Network Analysis Results[5]

The following results indicate where boundaries fall between the functional subnetworks within the multiplex governance network for the Lake Champlain Basin. The results show two sets of substantially similar subnetworks. The variation in results is subtle, but present. These results suggest that internal boundaries separate two groups of subnetworks. One group contains the reporting and financial resource sharing subnetworks while the other group contains the information sharing, technical assistance provision, and project coordination and collaboration subnetworks.

3.1. *Subnetwork Dyadic Correlation*

The results from the QAP correlation analysis (Table 2) confirm the necessity of running additional analyses. The subnetworks are all highly correlated, preventing firm conclusions about structural differences. Nevertheless, there is a pattern in the results that

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[4] Observation Rate is obtained using the number of organizations that completed responses in each organizational group in the network such that:

$$Density = 1 - \frac{\#\ Unobserved\ Dyads}{Total\ Dyads} \tag{2}$$

$$Density = 1 - \frac{(NRN)(NRN-1)}{(N)(N-1)} \tag{3}$$

where NRN stands for the number of non-responding nodes and N stands for the total number of nodes. In the second, more specific version of this formula, both the numerator and denominator should be divided by 2, to account for the non-directionality introduced by symmetrization. Since both terms are divided by 2, this step becomes a multiplicative identity and so is omitted.

[5] This study uses two different network analysis programs: *ORA (Carley, 2001–2011) and UCINet (Borgatti, Everett, and Freeman, 2002). A note with each result will indicate which program was used to obtain that result.

Table 2
QAP correlation matrix

	Reporting	Project Coordination	Financial Resources	Information Sharing	Technical Assistance	Multiplex Network
Reporting	1					
Sig.	–					
Project Coordination	0.618	1				
Sig.	(0.000)	–				
Financial Resources	0.700	0.719	1			
Sig.	(0.000)	(0.000)	–			
Information Sharing	0.542	0.735	0.595	1		
Sig.	(0.000)	(0.000)	(0.000)	–		
Technical Assistance	0.602	0.788	0.670	0.765	1	
Sig.	(0.000)	(0.000)	(0.000)	(0.000)	–	
Union	0.526	0.760	0.586	0.940	0.809	1
Sig.	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	–

provides some guidance on where internal boundaries may lie. The weakest correlation coefficients are in the relationships where either the reporting or financial resource sharing subnetworks are compared with either the information sharing, technical assistance, or coordination subnetworks. The reporting and financial resource sharing subnetworks are relatively highly correlated, as are any pairings of the information sharing, project coordination, and technical assistance subnetworks. This pattern suggests that this system has two separate sets of related functional subnetworks. One set includes the information sharing, coordination and collaboration, and technical assistance subnetworks. The second set includes the reporting and financial resource sharing subnetworks. The correlation coefficients are all high, and high correlations prevents firm conclusions about the placement of boundaries and supports the conclusion that observing a tie in one network increases the likelihood of observing that same tie in the other subnetworks (Provan Fish, & Sydow, 2007; Weible & Sabatier, 2005).

3.2. Subnetwork Macrostructures

Figure 2 contains the histograms that can be used to determine if each functional subnetwork is a scale free network. All five subnetworks and the union network fit the definition of a scale free network, displaying a power law distribution for their centrality scores. The reporting subnetwork fits a consistent and unambiguous power law; each successive step in the graph is lower than the preceding step until the graph tails off with single nodes marking the highest levels. The graphs for information sharing, coordination, technical assistance, and for the union network contain a consistent complicating characteristic. In each, a secondary hump emerges at around 40% of the total possible ties.

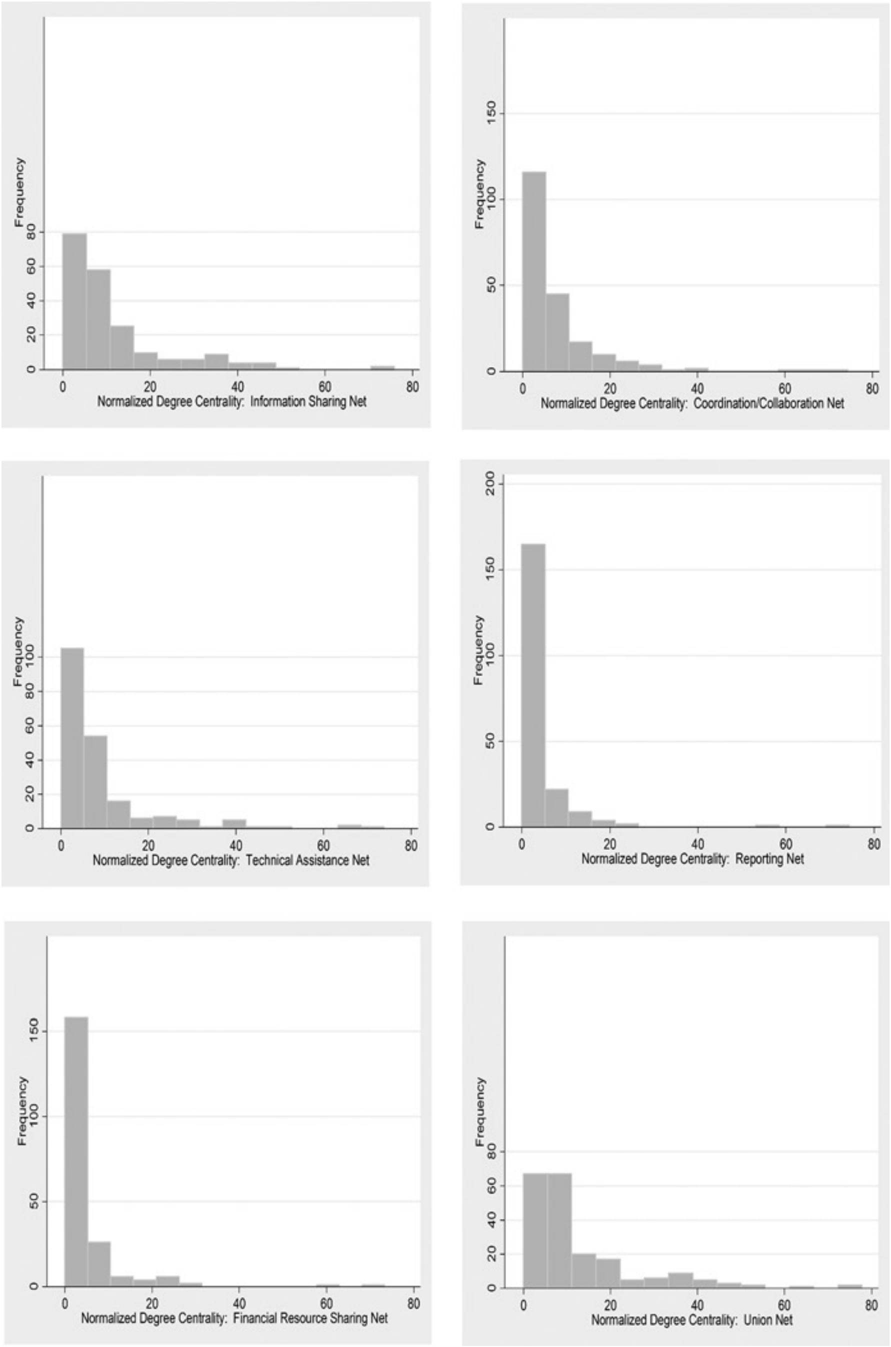

Figure 2. Scale free network analysis: Histograms of normalized degree centrality in all subnetworks

Table 3
Small world coefficient calculation (UCINet)

	Reporting	Project Coordination	Information Sharing	Financial Resource Sharing	Technical Assistance	Multiplex Network
Node Count	204	204	204	204	204	204
Density	0.041	0.080	0.117	0.050	0.090	0.130
Average Degree	8.10	16.19	23.74	9.94	18.19	26.47
Clustering Coefficient[6]	0.606	0.581	0.611	0.603	0.566	0.614
Average Distance	2.196	2.112	1.985	2.133	2.068	1.954
Clustering Coefficient (Lattice)	0.643	0.700	0.717	0.667	0.706	0.720
Ave. Distance (Erdos-Renyi)	2.738	2.171	1.936	2.538	2.088	1.899
Clustering Ratio (Lattice)	0.94	0.83	0.85	0.90	0.80	0.85
Distance Ratio	1.25	1.03	0.98	1.19	1.01	0.97
Telesford Small World Coefficient	**0.30**	**0.20**	**0.12**	**0.29**	**0.21**	**0.12**

This pattern is clearest in the information sharing network and least clear in the coordination network but remains present. The financial resource sharing subnetwork has a similar small hump, though it is at a lower centrality score, about 20%. This pattern of differences supports linking the information sharing, technical assistance, and coordination subnetworks, while not supporting the links between the reporting and financial resource sharing subnetworks that emerged in the QAP analysis. The results for the small world network analysis (Table 3) show the clearest divides of any analysis yet, suggesting three groupings. In this case, the information sharing and union networks stand out from both the grouping of the technical assistance and coordination subnetworks and the group of the reporting and financial resource sharing subnetworks. All subnetworks can likely be considered as small world networks. While Telesford et al. (2011) suggest a range of $-0.5 < \omega < 0.5$ on a scale between -1 and 1, while allowing for variation in the range in different network contexts. This suggested range would likely make a value of 0.3, as observed for the reporting and financial resource sharing subnetworks, a borderline result. With positive coefficients of less than 0.2, the information sharing, technical assistance, and coordination subnetworks are small world networks.

The results of the core-periphery analysis (Table 4) suggest similar internal boundary locations and begin to offer some basis for why the reporting and financial resource sharing subnetworks differ from the other subnetworks. Though all of the subnetworks are core-periphery networks, the reporting and financial resource sharing subnetworks do not correlate as highly with a theoretical core-periphery network as do the other three

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[6] Though the definition of the clustering coefficient is consistent across UCINet and *ORA, the two programs consistently produce different values for this measure. All comparisons of the value are made using a consistent program to avoid potentially erroneous conclusions being made as a result of comparing differently scaled results. Small world coefficients were calculated using clustering coefficients calculated in UCINet.

Table 4
Core-Periphery analysis results

Network	Core-Periphery Correlation	# Core Members	Gov in Core	%Gov in Core
Reporting	0.568	30	20	66.7%
Project Coordination	0.610	47	27	57.4%
Information Sharing	0.699	49	23	46.9%
Financial Resource Sharing	0.535	39	23	59.0%
Technical Assistance	0.659	47	25	53.2%
Union	0.700	52	25	48.1%

subnetworks. The reporting and financial resource sharing subnetworks also have the largest number of government agencies in their cores, calculated as a percentage of the nodes in their core, showing that the cores for the reporting and financial resource sharing subnetworks differ, in a similar, substantive, way, from the cores of the other three subnetworks.

4. Empirically-Identified Network Boundaries

As was expected due to the influence that presence of ties in one subnetwork has across other subnetworks (Provan, Fish, & Sydow, 2007; Weible & Sabatier, 2005), these subnetworks are substantially similar, showing high correlation coefficients between all five subnetworks. We can confirm that ties of different types are highly correlated. We can also conclude that our additional structural analyses are necessary to find internal boundaries within governance networks.

The results of this thorough structural analysis indicate that internal boundaries do exist between the functional subnetworks of the water quality governance network in the Lake Champlain Basin. Similar to how a factor analysis in statistics allows for viewing different variables as contributing to the same underlying conceptual factors, our analysis allows for viewing certain functional network ties as part of the same underlying subnetworks. In this governance network, the reporting and financial resource sharing subnetworks show quantitative differences from the information sharing, technical assistance, and project coordination and collaboration subnetworks. The QAP correlation coefficients between the members of these two groupings of subnetworks are higher than those between subnetworks in different groupings. The subnetworks of one group are a better fit to the scale free network model and poorer fits to the small world and core-periphery network models. The cores of these same subnetworks also contain a higher percentage of governmental programs than the information sharing, technical assistance, and coordination and collaboration subnetworks. The same sets of subnetworks show similar patterns for the degree to which they fit macrostructural concepts and show similar deviations from the definitions when the subnetworks do not fit the definitions exactly, such as in the scale free analysis. Each of these results could be interpreted separately and offer different conclusions about the network. The consistency in the patterns of variation, even while that pattern is nuanced, is what allows these results to be interpreted as identifying the boundaries between the functional subnetworks of a governance network.

Regardless of the amount of latitude organizations have in choosing their own ties across all the subnetworks, they will have the least latitude in the reporting subnetwork. This is the subnetwork that will be the most affected by mandated relationships, as much of the reporting regime exists between legally-defined and established governmental programs within the nested hierarchies of state and federal government (Osherenko, 2014). Further, the core of the financial resource sharing subnetwork is dominated by these same government programs, which routinely require evidence of how funds are used by those who receive those funds. This requirement links the reporting and financial resource sharing to each other, while also separating them from the sections of the network where organizations are freer to act.

The financial resources and reporting subnetworks are the subnetworks through which money flows and performance is monitored. Organizations active in this subnetwork can be expected to be the most effective in implementing policy and completing projects as they will have the most resources (Scheinert & Comfort, 2014). The reporting and financial resource sharing subnetworks also have the least correlation with information sharing, which is the most important subnetwork for supporting the operation of all other subnetworks (Kenis & Knoke, 2002). A greater correlation between the financial resource sharing and information sharing subnetworks would indicate that organizations are finding resources from a greater variety of sources, and so more aggressively matching the funds in the network to those who can best use the funds. Improving this connection would effectively increase funding in the system by improving the efficiency by which funds are used.

5. Conclusion

Currently, in the Lake Champlain Basin, internal boundaries within the watershed governance network separate the financial resource sharing and reporting subnetworks from the information sharing, technical assistance, and collaboration subnetworks. The results of this study show that there is some separation of information sharing from the governance network's other subnetworks, a division which could expand or contract over time. However, the current data are cross-sectional data, so they cannot provide any guidance on this change. The two sets of subnetworks supported by these data show an internal consistency. As discussed above, the combination of the financial resource sharing and reporting network takes the form of a semi-official network where formal accountability is important. Activities like information sharing and project collaboration, though not without forms of accountability, are typically less hierarchical activities. Nevertheless, access points for financial resources are limited and focused on government agencies, which demand accountability for the use of their funds. The need for resources to support technical assistance and collaboration forces actors to work in different parts of the watershed governance network.

Other governance networks may not have this distinction as strongly as the watershed governance network in the LCB does. Each governance network must be examined individually for its own internal boundaries to be recognized. This research suggests a new approach for how this analysis can be done. This research shows that structural analysis of the subnetworks of a multiplex network can reveal small but important differences in the structures of these networks. These small differences represent important variations that but are too small to be reliably recognized by any one network analytic technique, variations that change the relationships between functional tie types that researchers apply and the operational pictures that managers face. Instead, triangulation of techniques is required to give managers and researchers the information they both need to build situational awareness.

The scale free network analyses do show a different pattern for the financial resource sharing subnetwork and the reporting subnetwork. Additionally, where the information sharing, technical assistance, and coordination subnetworks have nearly identically-sized cores, the reporting and financial resource sharing subnetworks differ in core size by nearly ten organizations. In both cases, the financial resource sharing subnetwork is closer in structure to the subnetworks in the other grouping than it is the reporting subnetwork, though the financial resource sharing is still more similar to the reporting subnetwork than to the subnetworks of the other grouping. While the patterns so far discussed are still observed and so the boundaries are still supported, this break from consistency limits the certainty of these results and suggests that the boundaries may be porous or shifting. Further research using this governance network as a case study should either use the two groups that we argue for or use three groups, one which includes information sharing, technical assistance, and coordination, and then two others that treat reporting and financial resource sharing individually.

Governance networks encode multiple types of interactions and so generate functional subnetworks. Few studies to date have made thorough use of multiplex ties, preferring to select and analyze only one type of network or another. There is good reason for adhering to this limit (Butts, 2008, 2009). Even in exploring the relationship between functional subnetworks, this study must still adhere to this limit in defining its initial set of subnetworks. Adhering to this limit does prevent researchers from examining questions that cross the boundaries between types of network interactions. Without a way to explore the boundaries between functional subnetworks, no language can be developed for describing these boundaries, testing for their existence, or interpreting their meanings and impacts within a given multiplex networks. Being able to address questions about the relationships between the functional subnetworks of a governance network will allow researchers to improve our understanding of governance networks generally and it will allow managers in governance networks to improve their situational awareness and so manage more effectively.

6. Acknowledgement

This document was developed by support provided by Vermont EPSCoR with funds from the National Science Foundation Grant EPS-1101317.

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