LETTER

Mapping stewardship networks in urban ecosystems

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Abstract

Collaboration is often promoted as an effective strategy for conservation and natural resource management. Collaboration and communication can be particularly important—but challenging—in cities where there are many diverse stakeholders. However, there is little information about the factors that increase social interactions in urban stewardship networks. We used social network analysis to examine the extent of collaboration and patterns in the flow of information, ideas, and funding among stakeholders in an industrial urban ecosystem. Organizations associated with a regional conservation alliance (Chicago Wilderness) had more connections than other organizations. Geographic proximity, of both office locations and shared field sites, also increased interactions. All interaction types were correlated with each other, suggesting that one form of interaction may lead to additional connections. Despite spanning a large geographic area and incorporating many diverse organizations, the network we evaluated appeared to be remarkably well connected and shows great promise for successful conservation outcomes. Our approach can be used to identify strengths and weaknesses in other collaborative stewardship efforts and uncover key actions that may improve conservation in urban areas.

Introduction

Conservation and natural resource management often involve a complex network of diverse stakeholders, especially in urban ecosystems (Svendsen & Campbell 2008). In cities, a range of land uses and interests frequently coexist in close proximity. Ultimately, the social interactions among stakeholders, such as collaborating, planning, and taking action, affect environmental outcomes in these systems. Despite the importance of these interactions, few studies have focused on the people who work at the interface of urban ecological and social systems (Ernstson *et al.* 2010).

The patterns of social interactions in a community affect the flow of information, ideas, and resources, as has been noted in many different fields (e.g., scientific collaboration (Newman 2001); biotechnology research and development (Powell *et al.* 1996)). Interactions between community members build knowledge-sharing capacity and social capital, develop trust, and facilitate cooperation (Borgatti & Foster 2003; Pretty 2003). Collaborative social interactions have been widely promoted as an important component of effective natural resource management (U.S. EPA 1997; Wondelleck & Yaffee 2000; Keough & Blahna 2006). For example, collaboration between diverse stakeholders facilitates exchange of information and creative problem-solving across different sectors and levels of government (Carlsson & Berkes 2005; Newig *et al.* 2010). Collaborative efforts can also promote shared ownership of challenging problems, even among stakeholders with very different values (Schneider *et al.* 2003; Bryan 2004). Multiple factors are important for collaborative efforts to be successful, including interactions between different groups to expand the knowledge base (Armitage *et al.* 2009; Poteete *et al.* 2010) and linkages between actors working at different scales (Ernstson *et al.* 2010).

One internationally recognized example of a collaborative conservation network is the Chicago Wilderness (CW) consortium (Miller 2005). CW, a regional alliance of over 250 public and private environmental organizations in the Chicago metropolitan region, identifies specific recovery goals and research agendas (Moskovits *et al.* 2004) and offers a potential model for improving collaboration. CW organizations have collaborated on many projects that contribute to conservation and restoration in the Chicago area, including the restoration of a wetland deemed an "urban treasure" (Hegewisch Marsh) and construction of the Ford Calumet Environmental Center. While the CW model intuitively should enhance collaboration and advance conservation goals (e.g., by linking organizations that would otherwise be unconnected and by incorporating organizations working at various scales), the effect of membership in such an organization has not been studied.

Ultimately, as Yaffee & Wondolleck (2001) suggest, "successful collaborative efforts are built on human relationships." However, many questions remain about the factors influencing interactions, especially among urban stewardship organizations, and how collaboration can be improved (Svendsen & Campbell 2008). Social network analysis, a tool to map social interactions (Wasserman & Faust 1994), has recently been applied to collaborative efforts in ecological systems (e.g., Crona & Bodin 2006; Ernstson *et al.* 2008; Lauber *et al.* 2008; Muñoz-Erickson *et al.* 2010). In these systems, patterns of social interactions affect the people involved and the way they work together, which has implications for the ecosystems in which they work (Bodin & Crona 2009).

Here we applied social network analysis to examine the flow of information and resources among organizations working to preserve and restore a highly industrialized and unique urban ecosystem. Our objectives were to (1) examine patterns of interactions among organizations working in the region, (2) assess the importance of geography and organization type to network connections, and (3) evaluate the role of the regional alliance—CW—in fostering connections among environmental organizations. Regional-scale social network analyses like this one can potentially improve communication and strengthen stewardship efforts in other urban ecosystems.

Methods

Study area and focus group

We studied the Calumet region (Figure 1), an area just south of Chicago, IL (USA) with a long history of industrial development and recognized ecological significance (Cowles 1899; Greenberg 2002). Despite declining steel production in recent years, more steel is produced and processed in Calumet than anywhere else in the U.S.A. (*Berg et al.* 2002). Across Calumet, industrial land is interspersed with ecologically significant wetlands that provide habitat for over 250 bird species (Sparks 2000) and several endangered and threatened species (Greenberg 2002). Many organizations, government agencies, universities, and private businesses (e.g., consulting companies) have become actively involved in conservation, remediation, and restoration in the region, and the Calumet Summit was held in spring 2010 to encourage connections and collaboration. The summit provided an opportunity to survey these organizations about their interactions, and the focus group for this study comprised the list of summit registrants.

Survey methods

Prior to the summit, an email with a link to an online survey was sent to all registrants ($n = 257$) (survey included in supporting information). If multiple members of an organization registered for the summit, all were invited to take the survey. We assumed that the number of respondents from an organization would reflect their actual involvement in Calumet, and therefore including all survey responses would provide the most complete picture of the social network.

The first section of the survey contained a roster of all 151 organizations registered for the summit. Participants were asked to identify all organizations having members with whom they interact, with free choice to select an unlimited number of organizations (Wasserman & Faust 1994, 46–47). Blanks were included for additional organizations to be added. "Interaction" was defined as including (1) exchanging ideas or advice, (2) collaborating on projects, (3) serving on a steering or advisory committee, (4) having personal friends, or (5) receiving funding.

In the next section of the survey, participants identified up to five organizations with whom they interacted most. This section constrained respondents' choices to their "top five" interactions in order to decrease survey time and increase the response rate. Participants then specified the types of interaction they had with those organizations, selecting from the five interaction types above with a sixth option for "other."

The final section of the survey asked participants to list specific locations within Calumet where they or their organization have worked (e.g., preserving land, restoring ecosystems, or conducting ecological research) along with more details about their organization.

Analysis

Our survey design allowed several different networks to be generated. In the first portion of the survey,

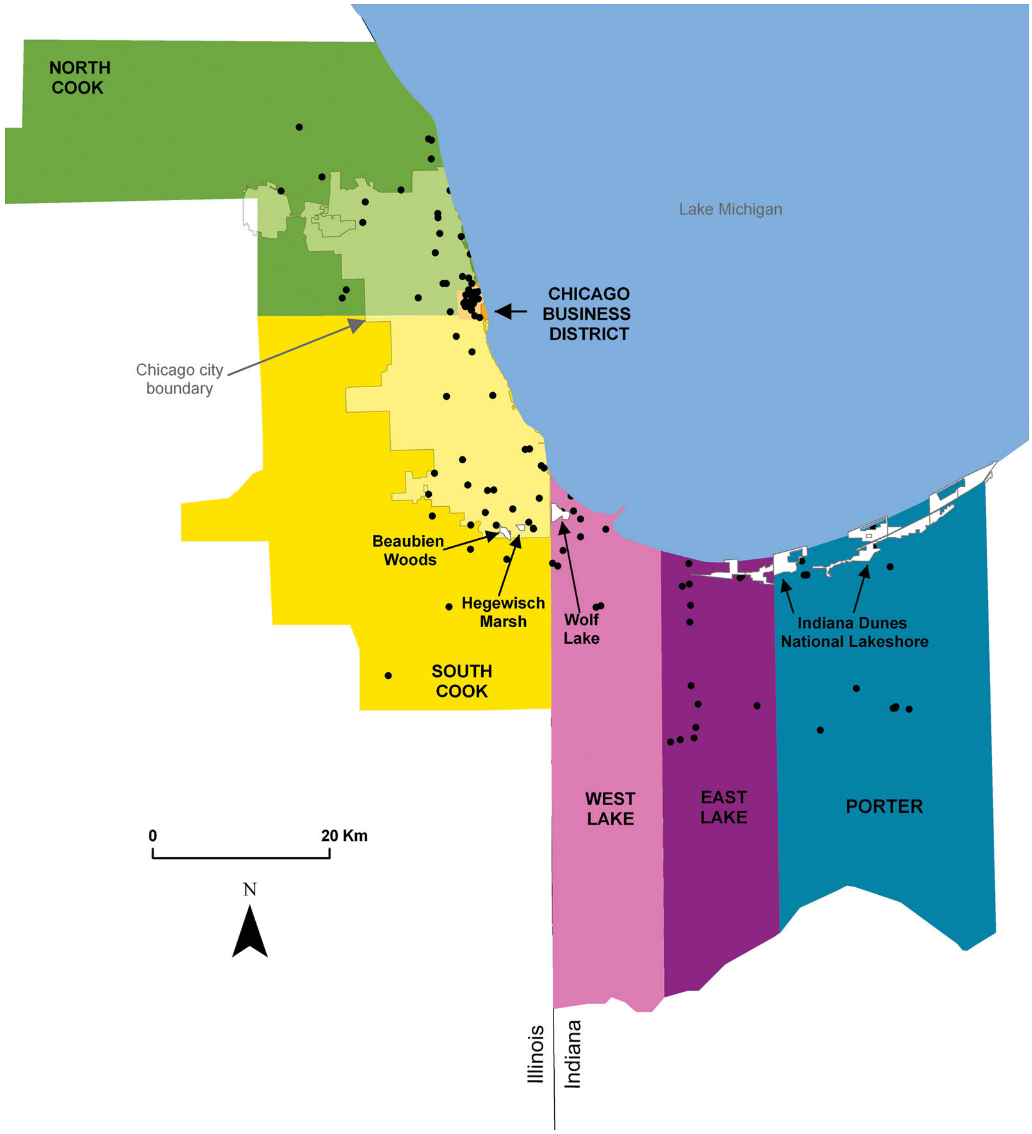

Figure 1 The Calumet region is an urban ecosystem on the south shore of Lake Michigan. Local office locations of stakeholder organizations (shown as points) were divided into six clusters based on geographic features: north Cook County, south Cook County, Chicago Central Business District (CBD) in Illinois; west Lake County, east Lake County, and Porter County in Indiana. The four labeled polygons were listed in the site-specific portion of the survey by at least 10 organizations.

respondents could identify an unlimited number of connections but did not distinguish specific types of interactions, allowing us to depict the entire network and evaluate patterns in organization type and spatial location (described below). In the second portion of the survey, we asked for more details about the "top five" connections for each organization, allowing us to examine patterns in interaction types.

Many metrics are available to quantify network characteristics, but we focused on measures highlighted in the literature as relevant for organizations working on natural resource problems (Table 1) (Newman & Dale 2005; Bodin *et al.* 2006, Bodin & Crona 2009). For each measure, "link" is an interaction between two organizations identified by either member of the pair. Network measures were calculated with Pajek software (Batagelj & Mrvar 2003).

We calculated link density for the whole network by dividing the number of reported links by the number of possible links. We accounted for missing data

Table 1 Definitions of quantitative network measures and relevance to social networks

Term	Definition	Relevance to social networks in natural resource management
Number of links	Number of social connections reported for an organization (also called degree centrality)	Organizations with a large number of links could be considered "hubs" and may have more influence on flow of information and resources in the network (Bodin & Crona 2009).
Link density	A network-level (or subnetwork-level) metric describing the number of reported links divided by number of possible links. This is sometimes called *connectance* in food web theory. The number of possible links in this network is a function of the total number of organizations and the number that responded to the survey (see supplemental information for calculations). Link density ranges from 0 to 1.	High link density implies more potential for communication, collaboration, and exchange of ideas across the entire network (Bodin & Crona 2009).
Internal links	Links among similar organization types (e.g., connections between universities) or within the same geographic cluster (e.g., connections within Porter County, IN). We report number of internal links as a ratio of the number of observed internal links to the number of expected internal links in random networks, classifying links as "strong" if the ratio was ≥ 1.0	Strong internal links may promote "bonding" ties, which implies more potential for internal trust and exchange of knowledge among similar groups (Newman & Dale 2005; Bodin *et al.* 2006).
External links	Links among dissimilar groups (e.g., connections between universities and government agencies) or spanning across different parts of the region (e.g., connections between Porter County, IN and north Cook County, IL). We report number of external links as a ratio of the number of observed external links to the number of expected external links in random networks, classifying links as "strong" if the ratio was ≥ 1.0	Strong external links may promote "bridging" ties, which implies greater access to diverse resources (Newman & Dale 2005).

(i.e., less than 100% survey response rate) explicitly in these calculations, which are described in the supporting information. To understand the importance of organizational characteristics and the role of CW in forming network connections, we supplemented the survey data with Internet searches to determine whether the organization was a CW member and, when not indicated by the respondent, the type of organization (listed in Table 2). We then evaluated how often organizations interacted with similar organizations ("internal links") or dissimilar organizations ("external links"). We assumed that different organization types have different expertise and resources and often work at different spatial scales (e.g., advocacy groups likely have strong community knowledge (Corburn 2005) while federal government agencies likely to have greater access to funding). We used contingency table analysis in Ucinet 6 (Borgatti *et al.* 2002), based on random permutations of the data, to assess whether internal and external links were greater than random networks (Hanneman & Riddle 2005). We calculated the ratio of observed/expected connections and classified internal and external links as "strong" if the ratio was ≥ 1.0. We also used a general linear model to determine whether organization type or membership in CW affected the number of links an organization had in the network. For these analyses, we only included organizations that responded to the survey and were listed on the original roster. Museum/library groups and K-12 schools were removed from the general linear model because they did not have both CW and non-CW members.

To investigate spatial influences on network connections, we determined geographic location of each office location, calculated Euclidean distances between every pair of organizations, and used a Mantel's test to determine if spatial distance was associated with network distance (i.e., whether geographically close organizations interact more). A Mantel's test examines the correlation between two matrices (e.g., one matrix for geographic distance between pairs of organizations and a second matrix with network distance between pairs of organizations). We also divided local office locations into six clusters based on geographic features (Figure 1), which allowed us to ask how often organizations within a geographic cluster interact with each other ("internal links") and with more spatially distant organizations ("external links"). We expected that organizations located in the heart of Calumet would have strong connections with one another, while more distant organizations would have weaker connections; contingency table analysis

Table 2 Summary of organizational characteristics

Organization type	Total number of organizations in the network	Organizations that responded to the survey: Number of organizations	Number in Chicago Wilderness	Mean number of links
Advocacy groups	87	37	18	40.4
College/universities	27	13	5	40.2
Museum/libraries	4	3	3	58.3
K-12 schools[a]	3	2	0	36.0
Federal government	8	7	6	66.9
State government	8	6	2	57.8
Local government	27	11	7	53.1
Commercial businesses	32	17	4	28.9
Industry	8	0	0	NA
Total for network	204	96	45	43.3

[a]K-12 schools include primary and secondary schools (from kindergarten to 12th grade).

was again used to compare observed connections to expected connections in random networks (Hanneman & Riddle 2005). We also measured link density between organizations working at shared field sites.

Separate networks were created for each interaction type with data from the portion of the survey focused on the "top five" connections. This allowed us to ask which interaction types are most common and whether certain interaction types tend to be correlated (e.g., does the number of reported friendships correlate with the number of reported collaborations?).

Results

Structure of network

The survey generated responses from 187 participants representing 96 organizations (response rate of 73%). The total number of organizations in the network, 204, included those on the original roster list and organizations added by survey participants. There were no organizations in the network without any connections. For all organizations in the network (i.e., including those that did not participate in the survey), the average number of links per organization was 24.2 (range = 1–100, median = 16) and link density was 0.16. Among organizations that were listed on the original survey roster and participated in the survey, the average number of links was much higher (48.5). For statistical analysis, we only compared number of links for those organizations that participated in the survey and were listed on the original survey roster.

Organization characteristics

Advocacy groups were the most common respondents to our survey (Table 2). At the other extreme, no industry groups took the survey or attended the conference (as indicated by the final list of summit attendees), although eight industry groups were connected to the network by other survey respondents. Because no industry organizations took the survey, their ratio of observed/expected connections for internal and external links could not be calculated. However, they are included in the network because other survey-takers indicated connections to industry.

The network structure partitioned by organization type deviated from random ($\chi^2 = 560.65$, $P = 0.0003$). Internal links for federal government and K-12 schools were both much stronger than expected in random networks (observed/expected links = 3.1 and 4.0, respectively) (Figure 2). On the low end, advocacy organizations and commercial businesses had internal links that were weaker than expected in random networks (observed/expected links = 0.95 and 0.60, respectively). All external links for federal government and museum/library organizations were stronger than random networks except for their links to commercial businesses. Commercial organizations had the weakest external links with all other organization types (the mean ratio of observed/expected external links was 0.71), although the connection between commercial business and local government was 1.21 times stronger than expected in random networks.

Over one-third of the organizations at the summit were members of CW, the regional alliance of environmental groups (Table 2). While federal government groups had more links than all other groups (Table 2), results suggest that this difference was attributed to the large percentage of federal government groups that were members of CW. Our general linear model showed that membership in CW was the primary factor that affected number of links (Table 3), with CW members having significantly more links (mean = 61.2) than non-CW members (mean = 37.9). The model explained 38% of the variation in number of links among organizations.

Spatial influences

Organizations with nearby offices tended to be closer in the social network (Mantel's test between network distance and spatial distance, $r = 0.23$, $P < 0.05$). The contingency table analysis of internal and external links by geographic cluster further confirmed this result; the partitioned network structure deviated from random ($\chi^2 = 565.48$, $P = 0.0003$). Internal

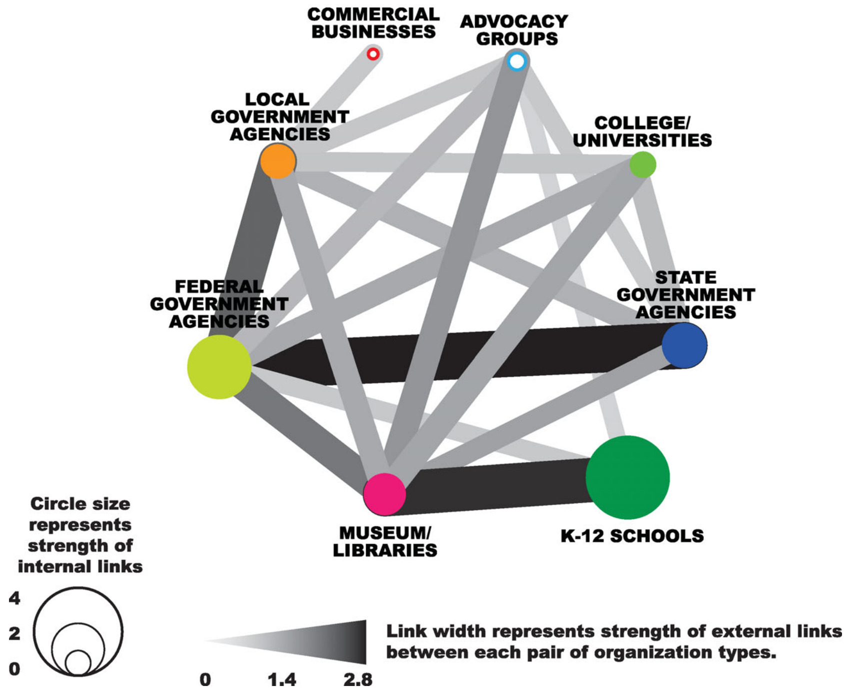

Figure 2 Social connections are shown by organization type. Circles represent groups of organizations (rather than nodes in a traditional network representation). Circle size represents the strength of internal links, which is based on the ratio of observed/expected links. Hollow circles indicate that internal connections are weaker than expected in random networks (ratio < 1) whereas solid circles indicate stronger than expected internal connections (ratio ≥ 1). Connections were reported between all organization types but lines were only drawn when external links were stronger than expected in random networks. No industry groups participated in the survey so we could not compare their connections to random networks.

links were strongest for west Lake County, Indiana (observed/expected = 2.7) (Figure 3). This cluster also had relatively high external links with all other geographic clusters (all connections were stronger than random networks except for those with north Cook County). External links were notably strong between the three Indiana clusters (e.g., the connections between east and west Lake County were 2.6 times stronger than expected in random networks).

Almost 40 individual locations were listed in the site-specific portion of the survey; of these, four sites were listed by at least 10 organizations (Figure 1). We found link densities of those site-specific networks to be much higher than the network at-large: Beaubien Woods (10 organizations, link density 0.66), Indiana Dunes National Lakeshore (12 organizations, link density 0.64), Wolf Lake (12 organizations, link density 0.60), and Hegewisch Marsh (17 organizations, link density 0.38).

Table 3 ANOVA for general linear model explaining the number of links for each organization that took our survey Museum/library and K-12 were removed from the analysis because they did not have both CW and non-CW members. Model $R^2 = 0.38$.

Source of variation	d.f.	Type III SS	*F*-ratio	*P*-value
CW membership	1	7282.713	16.375	0.000
Organization type	5	2791.708	1.255	0.293
CW*Organization	5	2701.650	1.215	0.311
Residual	71	31577.267		

Interaction types

The portion of the survey focused on interaction types revealed 492 pairs of frequently interacting organizations (i.e., "top five" selected by each organization, although some organizations selected less than five). Among pairs of "top five" organizations, collaboration was the most common type of interaction ($n = 438$, 89.0%), followed by exchange of ideas and advice ($n = 360$, 73.2%) and personal friendships ($n = 298$, 60.6%). Serving on a steering or advisory committee ($n = 147$, 29.9%) and receiving funding ($n = 120$, 24.2%) occurred less frequently.

Among organizations that took the survey, the number of links for each interaction type was correlated with the number of links for all other interaction types (e.g., organizations with many collaborations also had many friendships, Figure 4). This does not indicate that two interaction types (e.g., friendship and collaboration) both happen between the same pair of organizations; rather, the correlations show that an organization with more friendships also tends to have more collaborations. Spearman correlations were lower for all pairs of interaction types involving funding ($0.53 \leq r \leq 0.66$) than for all other pair-wise interactions ($0.79 \leq r \leq 0.90$). However,

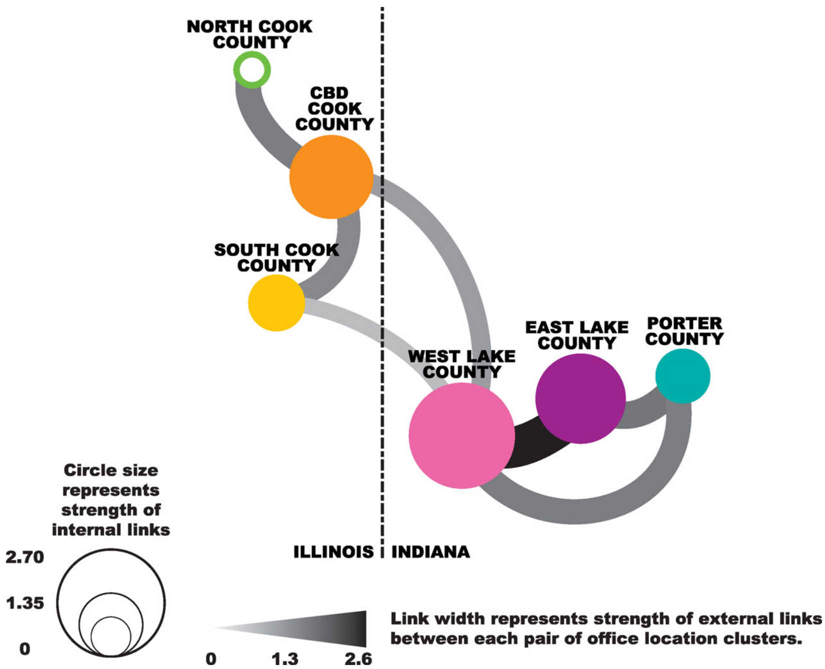

Figure 3 Social connections are shown by geographic location. Circles represent groups of organizations in each spatial cluster (rather than nodes in a traditional network representation); color of circles corresponds to map colors in Figure 1 (CBD = Chicago Central Business District). Circle size represents the strength of internal links, which is based on the ratio of observed/expected links. Hollow circles indicate that internal connections are weaker than expected in random networks (ratio < 1) whereas solid circles indicate stronger than expected (ratio ≥ 1). Connections were reported between all geographic clusters but lines are only drawn when external links were stronger than expected.

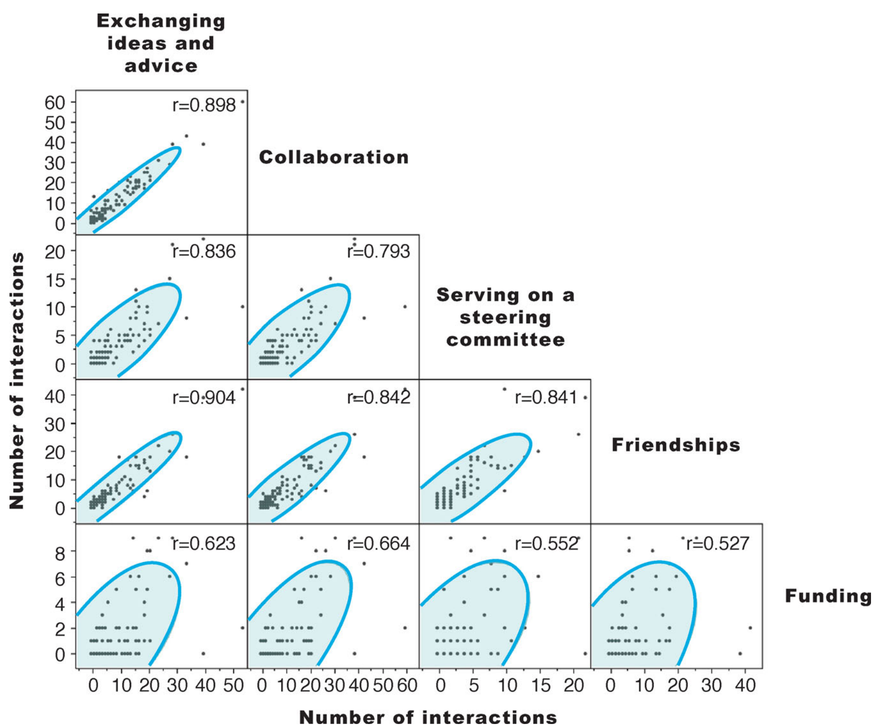

Figure 4 Correlations between the number of occurrences of each interaction type. Each point represents an organization that took the survey. Ellipses indicate where 95% of the organizations are expected to lie assuming a bivariate normal distribution.

when looking only at government agencies, funding did correlate more highly with other interaction types ($0.69 \leq r \leq 0.99$; data not shown).

Discussion

The social network working to conserve and restore Calumet ecosystems is remarkably well connected. Membership in CW was associated with significantly more connections in the network. Spatial distance also appeared to influence network connections, with organizations that are geographically close or sharing a field site having more interactions. Internal and external links varied by organization type, with commercial and industrial groups having especially few connections with other groups. Collaboration, exchanging ideas and advice, and friendships held together the Calumet network and were correlated with all other interaction types.

Implications for conservation

Collaboration is consistently highlighted as a key element in successful natural resource management (Wondelleck & Yaffee 2000) and has been embraced by federal agencies (e.g., U.S. EPA 1997) and grassroot organizations alike. Collaborative efforts can provide an effective alternative to top-down, centralized approaches, especially in the face of complex and unpredictable environmental systems (Koontz & Thomas 2006; Newig *et al.* 2010). Collaboration means that multiple stakeholders are pooling their knowledge and resources to "solve a set of problems which neither can solve individually" (Gray 1985). Bringing together multiple groups for collaborative stewardship is itself a major accomplishment, but evidence indicates that improved environmental and social outcomes can also follow (Wondelleck & Yaffee 2000). However, as stated in Newman & Dale (2005), "not all social networks are created equal," and more connections may not always be better (Bodin & Crona 2009). Instead, a more detailed examination of collaboration patterns may be necessary to truly understand their implications for conservation and natural resource management.

Here, we used social network analysis to understand the patterns of collaboration in a network of urban stewardship organizations. The network we evaluated appeared inclusive of diverse organizations, with links between organizations with different types of knowledge and resources and between organizations working at various operational scales. These types of links could be considered "bridging links" that facilitate trust-building and collective action among different types of stakeholders (Bodin & Crona 2009). Our results demonstrate these strengths in the Calumet network while simultaneously highlighting opportunities to increase interaction among less-connected groups. In particular, commercial and industry groups stand out as being poorly connected with most other types of organizations. Although we could not calculate the strength of industry's external links, we take their absence from both the survey and summit as an indicator of relatively weak connections in the network. The current patterns of interactions may reflect historic attitudes and conflicts between environmental interests and commercial development/industry. Despite being recognized early on for its unique ecology (Cowles 1899), the Calumet region also endured much environmental abuse as it grew to be an important industrial center (Greenberg 2002). Fostering interactions among diverse stakeholders in a region like Calumet may lead to a sense of shared ownership over complex, challenging problems (Bryan 2004), allow trust and common perspectives to develop over time (Pretty 2003; Schneider *et al.* 2003), and provide mechanisms for resolving conflicts (Carlsson & Berkes 2005).

Spatial relationships—shared field sites and distance between office locations—affected social connections in Calumet, as has been demonstrated in other social networks (Wellman 1996; Wong *et al.* 2006). While the boundaries we drew around clusters of office locations were arbitrarily based on geographic features (e.g., administrative boundaries), the results of our geographic internal and external link analysis, coupled with the boundary-free Mantel's test, confirm that location does matter. Organizations with office locations closer to one another have an easier time meeting face-to-face, both formally and informally. These types of ties could be seen as "bonding ties" that allow groups in a specific place to build and share local knowledge (e.g., Crona & Bodin 2006). Administrative boundaries (e.g., state or county lines) may also play a role in interactions. West Lake County, IN organizations had the strongest external links with all other clusters, perhaps due to their central location at the boundary of Illinois and Indiana and in the heart of Calumet. These cross-regional ties may facilitate "bridging links" between groups with complementary types of resources and knowledge (Crona & Bodin 2006), which can bolster creative problem-solving for complex environmental challenges in an industrialized ecosystem like Calumet (Newig *et al.* 2010). Organizations working at common sites were also well connected relative to the whole network, implying that the potential for collaboration and sharing knowledge, ideas, and resources in those places is high (Bodin & Crona 2009).

All interaction types were highly correlated with one another except for interactions involving funding (Figure 4). This highlights the importance of social networks, as one form of interaction may lead to additional types of interactions in the network. Funding relationships may be the exception to this trend because few organizations provide funding and not all organizations require funding.

Conservation applications

Social network analysis can identify strengths and weaknesses in collaborative stewardship efforts, and this study suggests several key actions that may improve connections among a regional network of stakeholders. In Calumet, more efforts could be made to connect with and involve commercial and industry groups. Well-connected "hubs" in the network, like CW members, could reach out to these organizations to connect them with the conservation network.

The CW alliance, which takes a collaborative approach to conservation, appears to provide an important social backbone in Calumet. Our results indicate that CW members have more connections in the network than non-CW members, although we cannot eliminate the possibility that CW members tend to have more connections prior to becoming members. Furthermore, it is unclear whether CW members have more connections to the Calumet network in general or simply tend to connect with other CW members. However, CW does make a concerted effort to bring together diverse organizations through working groups and outreach, and the role of CW as a liaison between groups working at various operational scales highlights its potential to foster "scale-crossing brokers" (Ernstson *et al.* 2010). Therefore, we believe that the alliance model should be encouraged, and possibly extended, as a potentially effective way to link otherwise unconnected organizations.

Our spatial analysis also indicates that shared field sites and office location play an important role in network connections and therefore potentially in conservation outcomes. Engaging various stakeholders at a shared field site could promote collaboration and build trust among organizations that are less well-connected. We suggest that centrally located organizations capitalize on their location to host formal and informal gatherings to help foster connections. The importance of geography in social connections also presents an argument for conservation organizations having a physical presence in their region of interest rather than working remotely.

We used social network analysis to highlight the strengths and limitations in a network of urban environmental stewards, pointing out communication gaps that, if bridged, would potentially lead to more effective conservation work in the region. Social connections can link together people with different types of knowledge, resources, and operational scales, and ultimately build problem-solving networks that are well equipped to address multifaceted environmental issues. The network analysis approach, which is especially helpful for understanding and strengthening collaboration among diverse urban stewardship groups, could easily be extended to other social networks to identify potential avenues for improving communication. A better understanding of collaboration, as illuminated by network analysis, may also help regional institutions advocate for more collaborative conservation efforts in the future. Further work could explore the environmental impacts of collaboration (Conley & Moote 2003; Koontz & Thomas 2006) and focus on untangling the links between social and ecological aspects of urban systems (Alberti 2008).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix 1. Calumet Summit 2010 survey
Appendix 2. Calculating link densities

Please note: Wiley-Blackwell is not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

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