

ARCHEOLOGY

Effects of population dispersal on regional signaling networks: An example from northern Iroquoia

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The dispersal of Iroquoian groups from St. Lawrence River valley during the 15th and 16th centuries A.D. has been a source of archaeological inquiry for decades. Social network analysis presented here indicates that sites from Jefferson County, New York at the head of the St. Lawrence River controlled interactions within regional social signaling networks during the 15th century A.D. Measures indicate that Jefferson County sites were in brokerage liaison positions between sites in New York and Ontario. In the network for the subsequent century, to which no Jefferson County sites are assigned, no single group took the place of Jefferson County in controlling network flow. The dispersal of Jefferson County populations effectively ended this brokerage function concomitant with the emergence of the nascent Huron-Wendat and Iroquois confederacies and may have contributed to the escalation of conflict between these entities. These results add to a growing literature on the use of network analyses with archaeological data and contribute new insights into processes of population relocation and geopolitical realignment, as well as the role of borderlands and frontiers in nonstate societies.

INTRODUCTION

Northern Iroquoia, consisting of portions of present-day New York, Ontario, and Quebec, is best known as the homeland of the Haudenosaunee (Iroquois) and Wendat (Huron) confederacies (Fig. 1). Detailed ethnohistoric texts provide tangible evidence for the social and political activities of these groups (1–3), and extensive archaeological records attest to the evolution of each confederacy and the lifestyles of people inhabiting their respective territories before European incursions (4–8). Iroquoian societies that occupied the St. Lawrence Valley are less well known (9–15). While encountered during early explorations of the St. Lawrence, the valley was largely abandoned before sustained European presence. Although there is an extensive archaeological record of Iroquoian groups in this area, little is known about how these groups functioned within pan-Iroquoian sociopolitical networks. Here, we use social network analysis (SNA) to address this issue, focusing on groups that occupied a physiographic border and cultural frontier between the historical Haudenosaunee and Wendat territories on the east shore of Lake Ontario and the headwaters of the St. Lawrence River.

SNA is increasingly used in archaeology to understand regional social interactions in nonstate contexts (16–22) and can be used to help build understandings of frontiers. Frontiers, often located at physiographic and cultural divides, are unique areas that have been explored extensively by archaeologists investigating geopolitical trends in colonial settings and regions between nation states (23–25). These investigations have helped elucidate the often complex, shifting nature of sociopolitical and cultural boundaries. Frontiers in noncolonial and nonstate settings have not been as widely explored (26). Hence, less is known about how groups in frontiers at nonstate cultural divides function within regional interaction networks (24).

Some recent network analyses have focused on regional population movements, particularly in the pre-Hispanic southwestern United States, where population reorganization led to massive social transformations (17, 21, 27). A smaller number of studies have examined what happens to a regional network when one or more of the constituent groups no

longer exist, including what impact these dispersals have on network topologies when the dispersed group held a position of control over network flow. For example, Knappett and colleagues have studied how the Thera eruption may have transformed maritime exchange in the Bronze Age Aegean by increasing exchange costs (28). In the southwestern United States, Peeples and Haas have examined how groups strive to mediate risks through collectivist strategies during periods of regional instability (17). The present study contributes to understandings of how population dispersal can transform regional network interactions and to broader-scale historical outcomes when brokers in a nonstate context disperse from a frontier. Northern Iroquoia is an excellent region to investigate this issue. Iroquoian groups in the western St. Lawrence River valley occupied a strategic position in the region—a frontier (24) at a physiographic boundary between two cultural groups. Many sites are clustered at the eastern end of Lake Ontario, typically referred to as the Jefferson County (JC) Iroquoians. The territory occupied by these groups constitutes one of two overland routes between groups in New York and southern Ontario. Other St. Lawrence Iroquoian (SLI) groups to the east occupied the valley itself, with the easternmost of these accessing the Gulf of St. Lawrence and the Atlantic Ocean. During the early 16th century, these were among the first indigenous groups encountered by French traders and explorers. Soon thereafter, SLI groups abandoned these territories. Their dispersals have been a source of archaeological interest for well over a century with a focus on determining why these groups “disappeared” (2, 9, 14, 29–33) and where their constituent populations relocated (33–35). Although these traditionally investigated issues are important, the roles of SLI groups in wider interaction networks have been addressed less often [but see previous studies (10, 32, 34, 36)].

Previous SNA of northern Iroquoia for the period A.D. 1350–1650 have focused on regional social signaling networks. These analyses are predicated on pottery decoration having served as active signals in both production and consumption contexts facilitating social interactions (16). These analyses addressed two issues: (i) whether historically documented ethnic territories and/or geographical distances constrained social signaling (16, 37) and (ii) how social signaling networks changed to reflect independently documented changes in regional sociopolitical systems (38). Results indicated that neither the historical ethnic territories nor the geographical distances constrained signaling or (therefore) interactions, and that network topologies changed

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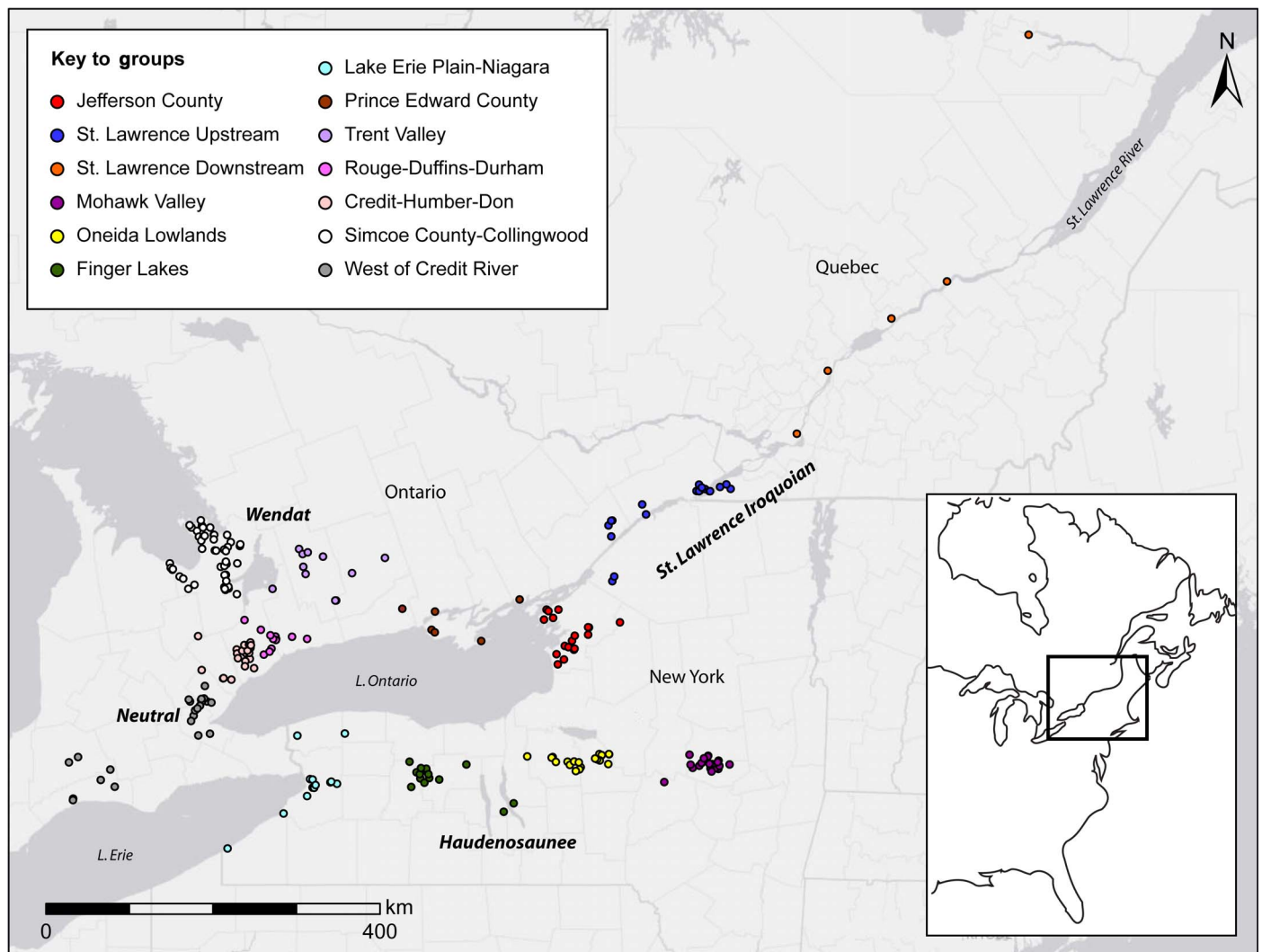


Fig. 1. Regional map. Geographic groups used in the SNA indicated.

to accommodate the dynamics of sociopolitical systems. Initial exploratory analyses of the role of SLI in these signaling networks suggested dynamics that differed from other groups in Ontario and New York, respectively (39).

JC Iroquoians have long been recognized as a distinct archaeological unit dating between approximately A.D. 1350 and 1500 (Fig. 1) (12, 29, 30, 33, 34, 40). On the basis of the distributions of distinct effigy smoking pipes, they have been identified as key players in an interaction sphere that connected SLI populations with Iroquoian groups in present-day east-central New York (36, 41). However, the role that these village populations played in pan-northern Iroquoian interaction networks remains unclear. Here, we use data from the period A.D. 1350–1600 to understand the role of the JC Iroquoian groups in pan-northern Iroquoian social signaling networks.

In our analyses, we address two questions: (i) What role did the JC groups play in pan-northern Iroquoian social signaling networks? (ii) How did the networks change after their dispersal? SNA results indicate that JC villagers occupy brokerage liaison positions (42) in the 15th-century network between New York and Ontario sites. After their dispersal just after A.D. 1500, no single group assumed a liaison position.

Rather, overall, the subsequent century's network flow appears to have been more dispersed, with greater segmentation between groups in Ontario and New York, which assumed divergent network topologies. These results establish a new baseline to understand regional dynamics in the 15th and 16th centuries in northern Iroquoia. In particular, our analyses provide an important objective means of assessing interaction patterns independent of traditional material culture studies that focus on, for example, distributions of select trade goods. The results reveal that JC groups played a far more important role in regional interaction networks than has previously been assumed. Their dispersal may have impeded network interactions between groups in New York and Ontario contributing, in part, to the polarization of the nascent Wendat and Haudenosaunee confederacies in the late 16th and 17th centuries A.D.

Pottery and signaling

Pottery production and use in Iroquoian groups were primarily female activities (43, 44). Northern Iroquoian pots are characterized by thickened bands of clay called collars that extend around the pot and up to several centimeters down from the lip. Collars served as platforms for decorations consisting of geometrical patterns created from numerous,

usually straight stamped and/or incised lines. These designs were sometimes embellished with annular punctations and/or effigy figures. Collars and their decorations were not needed for pots to function well as cooking vessels and required additional resources and time for pot construction. Collars were the most visible parts of pots in their primary context of use, the longhouse (45), which was the center of female domestic and political activities (46, 47). Hence, the decorations were active signals having both high contextual and absolute visibility (48) that conveyed readily understood information about the users and makers of the pots during social interactions between members of one community and individuals from other communities (16, 38); in other words, they functioned as symbolically generalized communication media, facilitating communication in large-scale networks (49).

Regional setting

Sites recognizable as Iroquoian appear in the archaeological record of southern Ontario, southern Quebec, and upper New York by approximately A.D. 1000. These are generally characterized as small, seasonally occupied base camps (50, 51). By A.D. 1300, Iroquoian populations were living in longhouse villages sustained by extensive maize-based agricultural systems (52, 53) and were experiencing population growth associated with the Neolithic Demographic Transition (8, 54). After A.D. 1450, sites become fewer, larger, increasingly situated in defensive locations, and surrounded by multirow palisades (4). Although the precise mechanisms for what has been interpreted as evidence for region-wide conflict are unclear, the outcomes appear to have included the development of complex organizational strategies within and between community groups. In the late 1500s and early 1600s, formative nations related to these defensive communities developed into the historically documented Haudenosaunee (Iroquois) confederacy in New York and the Wendat (Huron) and Neutral confederacies in Ontario, each of which was encountered by early European explorers and missionaries in the 17th century (55, 56).

St. Lawrence Iroquoians

When Jacques Cartier journeyed up the St. Lawrence River in 1534 and again in 1535, he encountered two groups of SLI people occupying multiple palisaded villages in the areas of present-day Quebec City and Montreal, situated within the “Downstream” and “Upstream” groups in this analysis, respectively. When Champlain returned to the region in 1603, the valley was devoid of permanent occupation (2, 56). Contrary to the eventual histories of the Haudenosaunee, Wendat, and Neutral confederacies, there is no evidence that SLI populations formed self-identified ethnic or political groups (9, 10, 31). Rather, archaeological and historical evidence suggests that these groups comprised series of community clusters inhabiting discrete subregional territories. However, it is not impossible that they formed a confederacy similar to the Iroquois, Wendat, or Neutral confederacy (31). Archaeologically, SLI groups shared a number of traits, including complex incised pottery design sequences, a paucity of chipped lithic tools, a well-developed bone tool industry, and a strong focus on the procurement of lacustrine and riverine resources (9, 11, 30, 57, 58).

The abandonment of the St. Lawrence Valley by the mid-to-late 16th century is thought to have occurred in two stages, the first preceding and the second following the arrival of Jacques Cartier and taking place along a west-to-east continuum (9, 31, 34). SLI-style pottery appears on sites on the northwest shore of Lake Ontario and in the Trent Valley, Ontario after ca. A.D. 1450 in quantities representing 3 to 15% of the assemblages (8, 14, 59–62). At select ancestral Wendat sites in southern

Ontario, bone tools and items of adornment from eastern sources also suggest the presence of SLI by A.D. 1500 (58, 63).

JC groups occupied a physiographic boundary, the area between the west shore of Lake Ontario and the headwaters of the St. Lawrence River. JC groups were also culturally distinct from contemporaneous groups in present-day New York and Ontario, respectively, as represented archaeologically in their material culture. Hence, JC groups occupied a frontier (24) between two distinct cultural territories where the Haudenosaunee and Wendat confederacies formed following the abandonment of JC.

Although the exact timing is unknown, JC was abandoned ca. A.D. 1500. It appears that certain JC groups established new communities on the north side of the St. Lawrence Valley (33). Others moved further north and west, joining existing groups in the Trent Valley (33, 61), or south, amalgamating with groups among the eastern Haudenosaunee (40, 64, 65). Many SLI sites in JC and all of those on the north shore of the St. Lawrence include defensive palisades and earthworks (33, 66–68). It has been hypothesized that the abandonment of this region resulted from conflict with the eastern Haudenosaunee, the Wendat, or both (2, 31, 34, 58).

Around A.D. 1550, the remaining SLI populations in the valley shifted east (9, 10). These populations were involved in exchange with Basque fishers and whalers until ca. 1580, after which time the valley was abandoned (9, 10, 32). Ethnohistoric evidence suggests that depopulation may have been accelerated by warfare, perhaps relating to how this key conduit was transformed by European contact (2, 56). Ultimately, the final Downstream SLI may have moved north and west, amalgamating with mobile Algonquian groups (34), and south, joining Abenaki groups in northern New England (31, 69, 70).

RESULTS

A total of 200 Iroquoian sites dating from A.D. 1350 to 1600, each assigned to a 50-year time span and 1 of 13 geographical groups, were used in the present analyses (Fig. 1). Iroquoian village sites were typically occupied for 20 to 30 years (71, 72), and temporal assignments were based on ceramic seriation, radiocarbon dates, and settlement patterns. Adjacency matrices for four undirected graphs were created to investigate the role of JC Iroquoians in regional signaling networks using the Brainerd-Robinson (BR) similarity index (73, 74). Following Hart *et al.* (38), each graph consisted of a 100-year time span overlapping 50 years with the chronological previous and subsequent graphs: A.D. 1350–1450, 1400–1500, 1450–1550, and 1500–1600 (data file S1). This was carried out to account for lags in network responses to subregional population movements and uncertainties in the temporal assignments of archaeological sites to the 50-year periods. We began our analyses with the A.D. 1400–1500 graph because the largest number of

Table 1. Network fragmentation by time period and BR cut points.

Time	BR ≥ 100	BR ≥ 110	BR ≥ 120	BR ≥ 130	BR ≥ 140	BR ≥ 150
1350–1400	0.068	0.134	0.197	0.278	0.558	0.525
1400–1500	0.021	0.062	0.234	0.340	0.594	0.785
1450–1550	0.000	0.077	0.391	0.470	0.611	0.866
1500–1600	0.000	0.206	0.391	0.741	0.795	0.822

Table 2. Regressions of geodesic distance on BR by network.

Time	n	Distance (km)	r	R ²	P
1350–1450	518	50	0.0812	0.0066	0.06487
	1183	100	0.0711	0.0050	0.01450
	1627	150	0.1606	0.0258	0.00000
	1975	200	0.2047	0.0419	0.00000
	2291	250	0.2854	0.0815	0.00000
	2757	300	0.3985	0.1588	0.00000
	3083	350	0.4413	0.2118	0.00000
	3343	400	0.4739	0.2245	0.00000
	3605	500	0.4734	0.2241	0.00000
	3741	763	0.4772	0.2277	0.00000
1400–1500	564	50	0.1933	0.0374	0.00000
	1134	100	0.3128	0.0978	0.00000
	1650	150	0.4108	0.1688	0.00000
	2162	200	0.3894	0.1516	0.00000
	2636	250	0.4503	0.2027	0.00000
	2966	275	0.5023	0.2523	0.00000
	3309	300	0.5575	0.3108	0.00000
	4560	966	0.5748	0.3304	0.00000
1450–1550	266	50	0.0430	0.0018	0.48473
	613	100	0.2655	0.0705	0.00000
	909	150	0.3937	0.1550	0.00000
	1294	200	0.4173	0.1741	0.00000
	1677	250	0.4974	0.2473	0.00000
	1869	275	0.5116	0.2618	0.00000
	2043	300	0.5489	0.3013	0.00000
	2926	965	0.5423	0.2940	0.00000
1500–1600	216	50	0.2152	0.0463	0.00146
	453	100	0.0200	0.0004	0.67086
	629	150	0.1023	0.0105	0.01025
	832	200	0.0269	0.0007	0.43828
	1127	250	0.3063	0.0938	0.00000
	1269	300	0.3936	0.1548	0.00000
	1546	350	0.5213	0.2717	0.00000
	1641	375	0.5456	0.2977	0.00000
	1731	400	0.5663	0.3206	0.00000
	2016	571	0.6047	0.3656	0.00000

JC sites is assigned to this time span. We use three network measures to assess the role of JC sites in the networks: fragmentation, flow betweenness centrality, and edge betweenness centrality. A BR threshold of ≥ 110 was chosen for network visualizations because it provides the most interpretable visualizations while minimizing network fragmentation compared to lower and higher thresholds, respectively (Table 1). Graphs were binarized as specified below when required for specific measures.

The network visualization at a BR threshold of ≥ 110 for the A.D. 1400–1500 graph indicates a well-connected network across northern Iroquoia. This is reflected in a regression of geodesic distances (in kilometers) (data file S2) on all BR values (Table 2). Consistent with previous results using smaller samples of sites (37, 38), distance has limited explanatory value for decoration similarity. Distances of less than 200 km have R^2 values indicating that less than 20% of the variation in BR values is explained by distance (Table 2). Only at 300 km does distance explain more than 30% of BR variation. The average distance between all site pairs is 225 km, and the median distance is 216 km (Table 3). Similar results were obtained for the other graphs (Tables 2 and 3).

JC sites occupy network positions between sites in southern Ontario and other sites in New York (Fig. 2A). Eastern New York sites are connected to the rest of the network only via a single JC site, whereas the strongest tie for the Finger Lakes sites is a St. Lawrence Upstream site, which, in turn, has its strongest connection to a JC site. Removal of the JC sites from the network disconnects the Mohawk River and Oneida Lowlands sites (Fig. 2B). On the other hand, the Finger Lakes sites now connect to a St. Lawrence Upstream site, and the St. Lawrence Upstream sites are more clustered together. Sites in southern Ontario groups appear to be largely unaffected by the removal of the JC sites.

Edge betweenness centrality was calculated with UCINET (data file S3) using a binarized graph, as required by the measure (75), at a BR ≥ 110 threshold. Edge betweenness is a measure of how many shortest paths in a graph pass through a given edge. The larger the value, the more edge controls flow through the network (75). Those edges with high values may act as bridges between two parts of a network. We posit that network flow represents human social linkages and interactions, as represented by the pottery collar signals (76, 77).

Several edges are greater than 3 SDs above the mean (Fig. 2B). The edge with the highest value occurs between a JC site and the Oneida Lowlands sites. Other values greater than 3 SDs above the mean occur between sites in the JC group, JC and Oneida Lowlands group sites, and sites within the Oneida and Mohawk River groups. Values greater than 1 SD above the mean occur within the JC group and between a JC site and at least one site from each of the Ontario groups and one St. Lawrence Upstream site. In other words, the flow between JC and Ontario is more diffuse than that between JC and New York. These results suggest that edges connecting JC sites are bridges between sites of the Ontario and St. Lawrence groups and New York sites.

Table 3. Node-pair geodesic distance central tendency values.

Network	n	Mean distance (km)	SD (km)	Median distance (km)
1350–1450	3741	206.5	145.1	184.5
1400–1500	4560	224.7	154.1	216.0
1450–1550	2926	235.4	149.1	225.7
1500–1600	2016	233.0	135.2	230.7

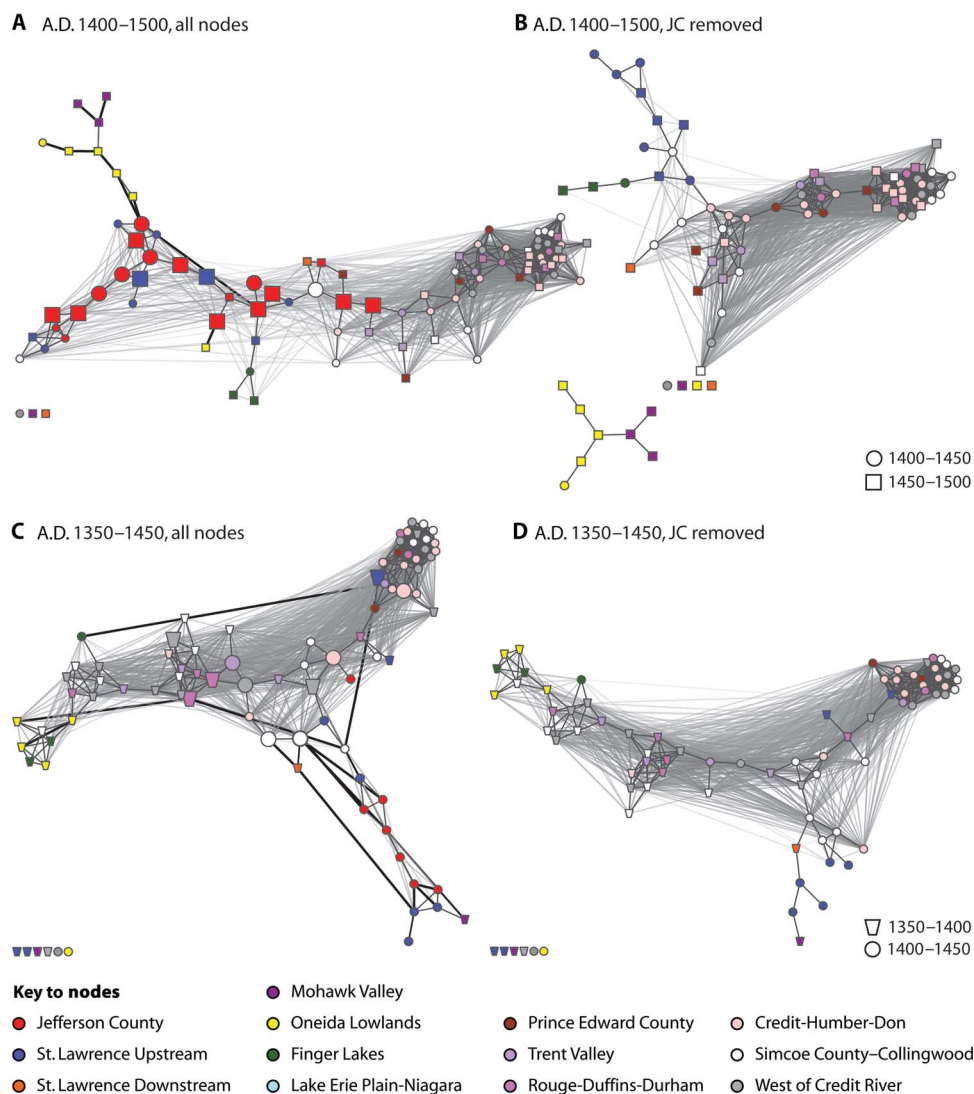


Fig. 2. Network visualizations, A.D. 1400–1500 and 1350–1450. (A) A.D. 1400–1500, all nodes; (B) A.D. 1400–1500, JC nodes removed; (C) A.D. 1350–1450, all nodes; (D) A.D. 1350–1450, JC nodes removed. Larger nodes are those with flow betweenness values of $>1\sigma$ above the mean for each graph. Heavy black edges (lines) indicate edge betweenness values of $>3\sigma$ above the mean of values greater than zero.

Fragmentation values were determined after removing each geographical group from the A.D. 1400–1500 binarized graph at each of three BR thresholds: 100, 110, and 120. Fragmentation is the inverse of network connectedness. It is the proportion of all node pairs in a network that cannot reach one another via any path (78). Removal of the JC sites from the graph results in the largest fragmentation value at each BR threshold (Table 4). Along with Fig. 2B, these results indicate that the JC sites are network cut points (79).

To further explore the role of the JC group in network flow, we calculated flow betweenness centrality in UCINET using the valued 1400–1500 graph (77). Flow betweenness is a measure of the total flow of a network that passes through a given node (77). Nodes with flow betweenness values greater than 1 SD above the mean are highlighted in Fig. 2A. All but two of these are JC sites. We used the nonparametric permutation *t* test in UCINET (80) to determine whether the mean of flow betweenness values for the JC group is greater than the means for combined groups in New York, Ontario, and the St. Lawrence River valley. Results indicate that the JC mean is significantly greater than

the means of each combined geographic group (Table 4). The Ontario and St. Lawrence means are both significantly greater than the New York mean.

The results of analyses using valued and binarized graphs are complementary (81). Together, the results indicate the importance of the JC group to network flow, and presumably, social interactions, between sites in Ontario and those in New York during the 1400–1500 time span. JC sites not only occupied a physiographic boundary (24) but also occupied brokerage positions in the social signaling network. In the Gould-Fernandez brokerage typology (42), JC sites occupied a liaison position between sites in New York and Ontario.

These results contrast with the preceding A.D. 1350–1450 network in which no group controls network flow. The $BR \geq 110$ threshold network visualization shows most JC sites forming an appendage to the larger network along with one Mohawk River site and several St. Lawrence Upstream sites (Fig. 2C). The strong ties for this appendage are to Simcoe County sites. The strongest ties of the Oneida Lowlands and Finger Lakes sites are to the sites in the West of Credit River

Table 4. Network group removal fragmentation values.

Network	1350–1450		
	BR ≥ 100	BR ≥ 110	BR ≥ 120
All groups	0.068	0.134	0.197
Mohawk River removed	0.000	0.115	0.159
Oneida Lowlands removed	0.024	0.119	0.187
Finger Lakes removed	0.024	0.139	0.204
JC removed	0.025	0.145	0.258
Upstream St. Lawrence removed	0.063	0.101	0.038
Downstream St. Lawrence removed	0.058	0.115	0.012
Prince Edward County removed	0.024	0.137	0.202
Trent River removed	0.024	0.142	0.209
Rouge-Duffins-Durham rivers removed	0.025	0.145	0.013
Credit-Humber-Don rivers removed	0.027	0.155	0.027
Simcoe County–Collingwood removed	0.029	0.165	0.478
West of Credit River removed	0.028	0.137	0.214
1400–1500			
All groups	0.021	0.062	0.234
Mohawk River removed	0.022	0.043	0.055
Oneida Lowlands removed	0.107	0.129	0.056
Finger Lakes removed	0.022	0.064	0.241
JC removed	0.229	0.276	0.306
Upstream St. Lawrence removed	0.023	0.068	0.257
Downstream St. Lawrence removed	0.000	0.022	0.203
Prince Edward County removed	0.022	0.065	0.246
Trent River removed	0.022	0.065	0.246
Rouge-Duffins-Durham rivers removed	0.022	0.065	0.246
Credit-Humber-Don rivers removed	0.026	0.076	0.284
Simcoe County–Collingwood removed	0.024	0.071	0.265
West of Credit River removed	0.023	0.067	0.254
1450–1550			
All groups	0.000	0.077	0.391
Mohawk River removed	0.000	0.058	0.244
Oneida Lowlands removed	0.000	0.262	0.292
Finger Lakes removed	0.000	0.081	0.410
JC removed	0.000	0.118	0.490
Upstream St. Lawrence removed	0.000	0.088	0.418
Downstream St. Lawrence removed	0.000	0.080	0.384

Network	1450–1550		
Prince Edward County removed	0.000	0.080	0.405
Trent River removed	0.000	0.082	0.415
Rouge-Duffins-Durham rivers removed	0.000	0.082	0.415
Credit-Humber-Don rivers removed	0.000	0.088	0.441
Simcoe County–Collingwood removed	0.000	0.083	0.420
West of Credit River removed	0.000	0.080	0.405
1500–1600			
All groups	0.000	0.206	0.391
Mohawk River removed	0.000	0.039	0.224
Oneida Lowlands removed	0.000	0.226	0.400
Finger Lakes removed	0.000	0.223	0.625
Lake Erie Plain–Niagara removed	0.000	0.269	0.546
Upstream St. Lawrence removed	0.068	0.227	0.584
Trent River removed	0.000	0.223	0.394
Rouge-Duffins-Durham rivers removed	0.000	0.213	0.402
Credit-Humber-Don rivers removed	0.000	0.216	0.408
Simcoe County–Collingwood removed	0.000	0.250	0.468
West of Credit River removed	0.000	0.213	0.402

and Rouge-Duffins-Durham rivers groups. Removal of the JC sites from the network have little effect, as would be expected from their positions. In the network visualization (Fig. 2D), St. Lawrence Upstream sites and the Mohawk River site previously connected to the network through the JC sites now connect via a St. Lawrence Downstream site.

The largest edge betweenness centrality value is the edge connecting a JC site and a West of Credit River site (Fig. 2C and data file S2). Another exceptionally large value is the tie between the same JC site and a Simcoe County site. The only tie with a value greater than 1 SD above the mean between a JC and New York site is that between the same JC site and a lone Mohawk River site. Other values greater than 1 SD above the mean include edges between JC sites and sites in the Simcoe, Credit-Humber-Don River drainages, and St. Lawrence Upstream groups. Network flow to the JC sites from Ontario involves fewer groups than in the 1400–1500 network but, like the 1400–1500 network, is more diffuse than from the JC to New York sites.

Fragmentation values for the network when the JC sites are removed are within the range of values for other group removals at each BR threshold (Table 4); the JC sites are not cut points in this network. Unlike in the 1400–1500 network, the JC group’s flow betweenness mean for the 1350–1450 network is only significantly larger than New York’s, the result of the position of its sites relative to the three St. Lawrence Upstream sites and the single Mohawk River site in the network appendage (Table 5). JC sites did not function as brokers between New York and Ontario in this network.

As with the 1400–1500 graph, JC sites in the following A.D. 1450–1550 network visualization occupy positions between Ontario and New York sites (Fig. 3A). As shown in the BR ≥ 110 threshold network visualization, there is a single Oneida Lowlands site that connects the Oneida

Table 5. Flow betweenness permutation *t* test *P* values.

Group	<i>n</i>	JC	New York	St. Lawrence	Ontario
1350–1450					
JC	7	—	0.993	0.925	0.590
New York	10	0.007	—	0.087	0.001
St. Lawrence	11	0.075	0.913	—	0.060
Ontario	59	0.410	0.999	0.940	—
1400–1500					
JC	18	—	1.000	0.998	1.000
New York	13	0.000	—	0.006	0.010
St. Lawrence	12	0.002	0.994	—	0.932
Ontario	53	0.000	0.990	0.068	—
1450–1550					
JC	11	—	0.998	0.958	1.000
New York	20	0.002	—	0.163	0.999
St. Lawrence	13	0.042	0.837	—	1.000
Ontario	32	0.000	0.001	0.000	—
		Lake Erie Plain	New York	St. Lawrence	Ontario
1500–1600					
Lake Erie Plain	9	—	0.013	0.009	0.737
New York	24	0.987	—	0.499	1.000
St. Lawrence	7	0.991	0.501	—	0.999
Ontario	24	0.263	0.000	0.001	—

Lowlands and Mohawk River sites to the network via a strong tie to a JC site. Removal of the JC sites from the network visualization results in these sites connecting to the Ontario sites via the same Oneida Lowlands site and a Trent River site (Fig. 3B). The Finger Lakes sites connect to the network via the St. Lawrence Upstream sites. The St. Lawrence sites now connect to the network primarily through the same Oneida Lowlands site as the JC sites in the complete network visualization.

The two ties with the largest edge betweenness values are between two Oneida Lowlands sites (data file S2). Ties between JC sites and sites in the Oneida Lowlands and St. Lawrence Upstream also have large values. Notably, no edge between a JC site and a site in one of the Ontario groups is as large as 1 SD above the mean. This implies that the focus of JC signaling changed during this time span to focus primarily on sites to the south and, particularly, to the Oneida Lowlands.

The fragmentation values for the $BR \geq 110$ threshold indicate the removal of the Oneida Lowlands sites results in the greatest fragmentation value and removal of the JC sites in the second greatest value (Table 4). Removal of the JC sites from the network at the $BR \geq 120$ threshold produces the largest fragmentation, but it is not substantially higher than values for most other geographical groups. These results and Fig. 3B indicate that the JC sites are not cut points in this network.

Permutation *t* tests indicate that the mean of the JC sites' flow betweenness centrality values is significantly greater than the means of the combined

New York, Ontario, and St. Lawrence groups (Table 4). The means of the New York and St. Lawrence groups are significantly larger than Ontario's.

The JC sites remain important to network flow in the 1450–1550 period. However, the dispersal of the JC group during this span of time is reflected in the increased importance of the Oneida Lowlands group in the network, consistent with previous analyses focused on Oneida Lowlands sites using a smaller data set (82). This may reflect changes in southern Ontario signaling networks that tracked sociopolitical developments as groups moved north toward the Simcoe highlands–Collingwood region and the formation of the Wendat confederacy (38).

The A.D. 1500–1600 network visualization at the $BR \geq 110$ threshold shows the St. Lawrence Upstream sites in an intermediate position between the Ontario and New York sites (Fig. 3C). Removal of these sites results in a direct connection between the New York and Ontario sites with the strongest tie between an Oneida Lowlands and Simcoe County site (Fig. 3D).

The edge with the maximum betweenness centrality value connects two St. Lawrence Upstream sites (Fig. 3C and data file S2). The edge with the second greatest value connects a Finger Lakes site and an Oneida Lowlands site. Other high edge betweenness values connect this Finger Lakes site and other Oneida Lowlands sites. Compared to the previous networks, there are many more edges with values greater than 1SD above the mean. These edges primarily connect sites in different eastern New York groups, sites in eastern New York groups with sites in the Lake Erie Plain–Niagara group, and New York sites with a Simcoe County site. Notably, however, of the 31 edges with values greater than 1 SD above the mean, only 3 fall between New York sites and sites in Ontario and one between a St. Lawrence Upstream site and an Ontario site.

The greatest fragmentation value in the $BR \geq 110$ threshold graph occurs when the Lake Erie Plain–Niagara group sites are removed (Table 3). However, it is not substantially higher than the values for the other groups, except for the Mohawk Valley. The greatest fragmentation value for the $BR \geq 120$ threshold graph occurs with the removal of the Finger Lakes sites. None of the geographical groups are cut points during this time span. Most nodes with flow betweenness values greater than 1 SD above the mean are New York sites (Fig. 3C). Permutation *t* tests indicate that the means of the combined New York and the combined St. Lawrence groups are significantly greater than the means for the Lake Erie Plain–Niagara group and the combined Ontario group (Table 4). Together, these results indicate that no group replaced the JC group in a liaison brokerage network position.

DISCUSSION

In small-scale societies, signaling has been shown to be an essential component in securing the benefits of collective action (83, 84). SNA of A.D. 1350–1600 pan-northern Iroquoian signaling networks identifies JC sites as liaisons between New York and Ontario sites in the 1400–1500 network. This result expands on Wonderley's (36, 41) analysis of effigy pipes from JC and eastern Iroquois sites, which suggested a prominent role for JC in an interaction sphere with the Oneida Lowlands and Mohawk River valley. The dispersal of the JC group during the 1450–1550 time span is reflected in the increased importance of the Oneida Lowlands group to network flow and fewer strong connections between JC sites and sites in Ontario.

The analyses presented here situate the JC dispersal within larger regional trends, including the gradual movement of Ontario groups northward to the Simcoe highlands–Collingwood region with concomitant changes in the Ontario signaling network (38). Consistent with our

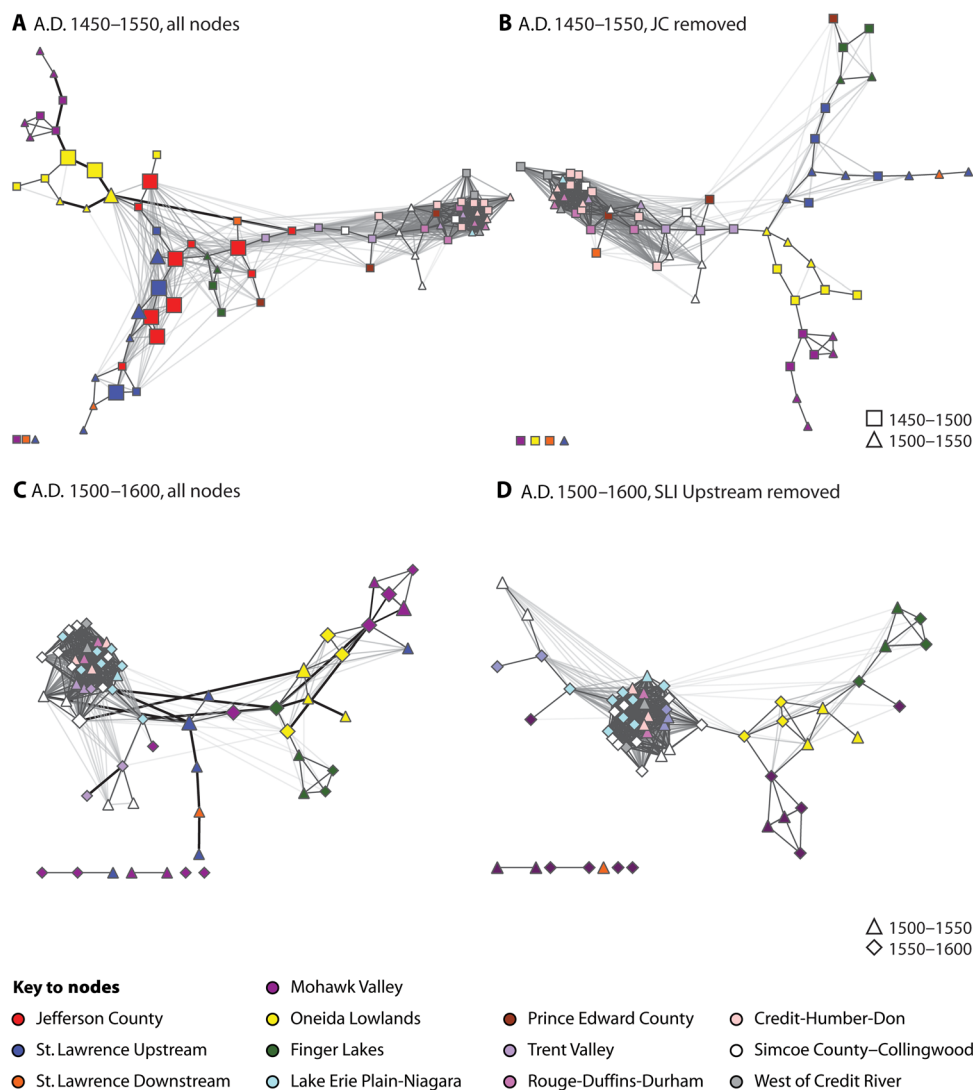


Fig. 3. Network visualizations, A.D. 1450–1550 and 1500–1600. (A) A.D. 1450–1550, all nodes; (B) A.D. 1450–1550, JC removed; (C) A.D. 1500–1600, all nodes; (D) A.D. 1500–1600, SLI Upstream removed. Larger nodes are those with flow betweenness values of $>1\sigma$ above the mean for each graph. Heavy black edges (lines) indicate edge betweenness values of $>3\sigma$ above the mean of values greater than zero.

findings here, analyses in the southwestern United States demonstrated that network brokers in nonstate and noncolonial contexts were often located at physiographic and cultural divides (17). In addition, notably, the influence of these sites in both northern Iroquoia and the southwestern United States was short-lived (17). In the case of northern Iroquoia, the influence of JC sites was limited to at most a 100-year time span, recognizing that the chronological uncertainties limit our ability to precisely estimate the period of influence. Our results suggest that the JC sites formed a short-lived frontier or borderland fostering interaction between emergent nations and confederacies and provided contexts for the negotiation of power and identity (24, 85). Although the literature on sociopolitical borderlands focuses primarily on colonial and state-building contexts, this study suggests that these phenomena also played out among nonstate societies.

Peoples and Haas (17) attribute the peripheral and impermanent nature of sites or nodes acting as brokers to the fragility of these positions in societies where strategies aimed at promoting collective well-being are valued over those promoting individual achievements (86, 87). Their

model suggests that brokerage is more likely to promote strengthened relations between the groups being brokered as opposed to among the brokers themselves. Rather than accruing advantages as a result of their position in the network, JC groups may have been viewed with suspicion by groups on either side. Hence, the historical outcome of this set of relations may have fostered stronger collectivity for the nascent Wendat and Haudneosaunee confederacies, but not for JC groups, who found themselves unable to form strong external alliances in an increasingly factional political environment (34, 58).

The subsequent 1500–1600 period after the JC dispersal witnessed significant political transformations in the region, including the formation of politically cohesive and territorially circumscribed confederacies in both New York and Ontario. Our results demonstrate that no group fostered communication between Ontario and New York in the 1500–1600 period, suggesting that changes in network flow between the regions were occurring concomitantly with changes in the geopolitical landscape and the dispersal of JC groups. This builds on earlier results from which changes in social signaling networks in southern Ontario

were shown to adapt to changing sociopolitical landscapes (38). Whereas that study identified changes within emerging nations and confederacies, the present study has demonstrated that these processes developed in a multilinear fashion, depending on the situation of groups within evolving social networks and landscapes.

Because JC groups dispersed by the time of European contact and thus have scant representation in ethnohistoric texts, their relative geopolitical importance has likely been underestimated. On the other hand, sites from other SLI groups, for which a robust historic record exists, are mostly peripheral to the flow of signaling networks, although the upstream sites play a secondary role in the 1450–1550 and 1500–1600 networks. However, our results are limited by the small samples of sites in the Upstream and Downstream St. Lawrence groups.

Future analyses may productively consider the implications of JC dispersal on later 17th-century political formations and patterns of conflict. The Haudenosaunee and Wendat confederacies are often perceived as equivalent political formations. However, the coalitional network structure of the New York groups contrasts with the cohesiveness or completeness of the network structure for groups in Ontario and the Lake Erie plain after A.D. 1550 (88, 89). After A.D. 1650, the Haudenosaunee confederacy successfully displaced or absorbed all other northern Iroquoian populations. What effect did regional network dynamics and the differential absorption of JC migrants have on those processes?

This study has generated new understandings of social interactions within the northern Iroquoia region over a 200- to 300-year period. These analyses highlight the value of network science in exploring and evaluating archaeological data, particularly because it relates to groups that have otherwise been underrepresented in archaeological and historical narratives.

MATERIALS AND METHODS

Sample and coding

Engelbrecht's (90, 91) coding scheme was used to code pottery collar decorations. Sites were included in the database that had a minimum of 25 decorated rims representing distinct vessels. Each rim was assigned to 1 of 29 decorative motif categories. These included the 28 originally described by Engelbrecht plus the distinctive corn-ear motif, generally associated with sites in the St. Lawrence River valley (9). A total of 235 sites are represented in the current database. Each of the sites in the database was assigned to one of six 50-year time periods that began at A.D. 1350 and ended at 1650. Chronological assignments were based on radiocarbon dates, when available, and relative dating based on ceramic seriation, coefficients of similarity, chronological patterning in other suites of material culture, and the built environment. We acknowledge that in some cases, site occupations may bridge the 50-year periods used and that future chronological refinement may result in changes in chronological assignments. Two hundred of the sites were assigned to 50-year periods between A.D. 1350 and 1600 and were used in the present analyses. Each site was also assigned to 1 of 13 geographical groups based on proximity and distinct geographic subdivisions. Locations of the groups are identified in Fig. 1. Each geographic group comprised one or more site clusters that mapped onto archaeologically and historically defined social units.

BR similarity index

Decorative motif category counts were used to calculate a BR coefficient matrix (73, 74), a city-block index originally designed for use with archaeological artifact categories (92). BR values range from 0 to 200, with

200 indicating perfect similarity (data file S1). The matrix was calculated with the similarity and distance module of Tools for Quantitative Archaeology 5.0 (93) using the module's Monte Carlo pairwise routine with a random seed generated by the clock and 1000 trials to adjust for sample size variation.

Graphs

Following Hart *et al.* (38), adjacency matrices for undirected graphs were constructed using the BR matrix for 100-year time spans using sequential 50-year periods for this analysis: A.D. 1350–1450, 1400–1500, 1450–1550, and 1500–1600. This was carried out to account for lagged responses in networks to shifts in subregional settlement systems and to account for uncertain temporal assignments of sites to 50-year periods.

Network visualizations

Network visualizations were carried out using Visone 2.16 (94) with valued graphs at a BR threshold value of ≥ 110 . That is, all edges with values of ≥ 110 were used in the visualizations. The backbone algorithm was used for network layout. This algorithm resulted in an untangled visualization that positioned nodes in natural groupings. The program's default settings were used for layouts maintaining weak ties; strong ties were identified with darker edges.

Statistical analysis

Freeman edge betweenness centrality (data file S3), flow betweenness centrality, and fragmentation measures were calculated using the graphs with UCINET 6.627 (78, 80). Graphs were binarized for the fragmentation and edge betweenness as required for measures (75, 78). Valued graphs were used for the flow betweenness measure (77). Permutation *t* tests were carried out in UCINET with 10,000 permutations, random number seed between 1 and 32,000, and a significance level of 0.05.

Geographic distance matrix

A geographic information system (GIS) database was developed using ArcINFO version 10.2. Individual site locations were digitized in their native coordinate system, and all were then reprojected into North America Lambert Conformal Conic (North American Datum 1983). A geodesic distance (in kilometers) matrix between all sites was produced using the ArcInfo Point Distance Tool (data file S2).

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at <http://advances.sciencemag.org/cgi/content/full/3/8/e1700497/DC1>

data file S1. BR similarity matrices (Excel file).

data file S2. Geodesic distance matrices (Excel file).

data file S3. Edge betweenness matrices (Excel file).

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