12

Evaluating Adaptive Network Strategies with Geochemical Sourcing Data: A Case Study from the Kuril Islands

Erik Gjesfjeld and S. Colby Phillips

12.1 INTRODUCTION

In all parts of the world and throughout time, humans have developed strategies for dealing with the unpredictable nature of their environment, and for adapting to the conditions in their environment that change at varying scales. Optimization models derived from human behavioural ecology (HBE) propose that the behavioural decisions of low-density foragers regarding resource procurement and consumption activities are made with the ultimate goal of maintaining or increasing their fitness in an efficient manner. Establishing and maintaining inter- as well as intra-group social ties is one way that hunter-gatherer groups have adapted to living in the face of environmental unpredictability where assistance or outside resources may be required (Alexander 2000; Binford 2006; Grattan 2006; Hofman et al. 2007; Kirch 1988; Reycraft and Bawden 2000; Sheets and Grayson 1979; Torrence 1999, 2002; Whallon 1989, 2006; Wiessner 1982). The exchange of material and non-material resources provides a vehicle or mechanism for developing and maintaining these networks of social relationships.

Social network analysis (SNA) provides a body of theory and a set of techniques for visualizing and measuring sets of human relationships (such as exchange), and for evaluating the implications of those relationships (Wasserman and Faust 1994). By focusing on the relationships between social entities rather than just comparisons of entity attributes, patterns that are not immediately obvious in the data may become visible. In addition, SNA is a way to superimpose a measure of non-Cartesian social geography represented by human relationships on top of cartographic space to make comparisons between geographic and social space (Mackie 2001; Thomas 2001).
However, it is difficult to quantify and qualify social network relationships that existed in the past based on a fragmented and incomplete record of human activity, which is what the archaeological record provides. This is particularly true for small, mobile groups of people who did not leave a large impact on the landscape. In addition, the archaeological record is constantly changing; as new sites are discovered and excavated, new artefact assemblages are added to those already available for use in generating the empirical basis for reconstructing past social networks. The observed network structures that can be created with archaeological data and evaluated with node- and graph-level SNA techniques represent only a basic level of analysis of the cause, nature, and impact of relationships between humans, whether as individuals or as corporate groups.

Alternatively, new techniques for modelling social networks go beyond basic network visualization and node/graph-level measurements, and provide methods for testing the statistical significance of relationships between observed and hypothesized social network structures. This chapter focuses on the use of these methods for modelling exchange-based relationships that existed in the Kuril Islands of Far Eastern Russia in the North Pacific Ocean, where foraging groups lived for more than 4,000 years in an isolated environment prone to stochastic natural events and resource unpredictability.

12.2 EXCHANGE AS AN ADAPTIVE SOCIAL BEHAVIOUR

Exchange can be defined as a form of material transfer with social as well as economic properties that reflects relationships at a range of social levels (individuals, groups, societies). Early archaeological observations in Europe, Asia, Oceania, and the Americas identified the movement and transfer of materials in the past, but it was the work of historians and economic anthropologists that related trade and exchange to issues such as social complexity, distribution of resources, and wealth (Oka and Kusimba 2008). Researchers of exchange such as Malinowski (1922) and Mauss (1990) saw exchange as a way to create and strengthen relationships between people based on the socially defined and enforceable obligations of reciprocity.

The critical aspects of material exchange are fundamentally based on information: information about the types of materials to exchange, information about the way exchange takes place, information about the physical routes and meeting places for exchange (Smith 1999). Knowledge, ideas, and relationships are passed between individuals and groups just as physical resources are, and these immaterial resources may actually be more important than the
physical materials that are traded, in terms of what is gained by participating in an exchange network. Strategies for obtaining information will vary given the scale of information required and ability or ease of acquiring it. At a local level, individuals can use multiple methods to gain information such as obtaining it for themselves or tapping into within-group information sharing. At a regional level, individuals will have incomplete knowledge about the state of the regional environment, and must depend on information-sharing networks with regional contacts (Moore 1981). Participation in networks plays a role in helping foragers reduce the uncertainty of having incomplete information about relevant environmental or social phenomena.

Personal relationships provide a social means for circumventing the local subsistence and material resource constraints that are inherent in geographically isolated environments (Mackie 2001). These social ties also have the effect of distributing environmental risks and benefits among regional participants, providing channels of communication about environmental conditions at different spatial scales, and defining lines of fusion and fission for cycles of spatial aggregation and dispersion of human groups (Braun and Plog 1982; Whallon 1989). It is expected that some form of social network can be found on every populated physical landscape due to the unpredictability of all natural environments and the need to propagate (Anderson and Gillam 2001; Wobst 1974). Of importance to the study of hunter-gatherer networks is the scale of social integration among human groups, which will have implications for the structure of networks that are created and maintained, and the type of information that is exchanged (Fitzhugh et al. 2011).

Establishing and maintaining inter- as well as intra-group social ties can be viewed as a form of optimal adaptive behaviour in terms of mitigating the risks associated with environmental unpredictability. In more formal biological terms, the development and maintenance of social networks through exchange interaction between individuals is an adaptive trait that has the potential to increase the fitness of the individuals participating in the network (Hill 2009). Such networks should then be a prerequisite for colonizing and maintaining a long-term presence in insular and unpredictable environments, enabling a form of adaptive flexibility to deal with events that cause environmental and/or social uncertainties (Fitzhugh 2004; Kirch 1988). However, network participation may also place constraints on individuals or groups in the form of social obligations that must be honoured and maintained, since human relationships are not static entities but are dynamic connections that are constantly being negotiated. The concept of exchange among hunter-gatherers becomes more interesting not only as an optimal behavioural strategy for procuring material resources, but also because participation in exchange relationships can be linked to more anthropological issues of human interaction such as territoriality, cultural transmission, and social integration over long distances.
Social network analysis (SNA) is a systematic approach that utilizes empirical datasets, mathematical and statistical models, and visualization to explore network structure and the effects of that structure on participants in a network (Freeman 2004; Mizruchi and Marquis 2006). Social network analysis focuses on actors and their social ties: actors are defined as network nodes representing individuals, communities, corporations, nations, etc., which are linked by network ties based on communication, economic transactions, kinship, etc. (Thompson 2003). Where conventional analysis of social science data compares actors based on their attributes, SNA compares actors based on their relationships (Hanneman and Riddle 2005). The SNA perspective views actors and their behaviour as interdependent, with ties between actors acting as channels for the flow of resources (material and immaterial). Network ties both enable and constrain actor behaviour, and network structure is seen as the 'enduring pattern of actor relationships' (Freeman 2004).

Social network analysis was pioneered in sociology and social psychology, but was also implemented in anthropology as early as the 1950s by J. A. Barnes (1954) and his studies of Norwegian church parish social classes (Wasserman and Faust 1994). Within archaeology the use of SNA is not well known, but over the last several decades a number of archaeologists have begun to apply network structure and analysis methods to archaeological datasets, particularly in coastal and island regions. Hage and Harary (1991) examined network structure in their study of Oceanic exchange systems, and Hunt (1991) compared measures of island/site network position to explore models of Lapita culture exchange and communication networks across Western Polynesia, the Solomon Islands, and the Bismarck Archipelago. Also in the Pacific, Terrell (1976, 1986, 2010) has studied the impact of geographic distance on human interaction based on material culture and language groups along the Sepik Coast of Papau New Guinea, and on Pacific Islander genetic structure in Melanesia. In southern Europe, Knappett et al. (2008) generated optimization models for Bronze Age maritime-interaction networks among islands in the Aegean Sea.

Important to SNA is the idea that a network is not a metaphor for human interaction. It is a precise mathematical construct that is used to represent, analyse, and model those interactions which, for this study, are viewed as relevant to the ability of hunter-gatherer groups to survive and thrive in the Kuril Islands. Analytically, this technique provides a tool for measuring the characteristics of regional systems quantitatively, and in turn, for objectively comparing social systems with one another. Because networks are dynamic, and the types of interactions that produce network ties may shift over time, it is necessary to incorporate a diachronic element to the analysis and comparison of network structures (Neitzel 2000).
12.3.1 Structuralist and Individualistic Approaches to SNA

SNA approaches the study of networks from both the structuralist and the individualistic perspectives. The structuralist perspective focuses on the description and analysis of the larger network and all of its components, including the actors, their ties, and the patterns of relationships that are present in the network. The structuralist perspective ignores the agency of individual actors and is concerned with elucidating the structures of relationships within which the actors and their actions are embedded (Kilduff and Tsai 2003).

The most basic structural property measurement of a network is graph density. Density is a measure of the number of connections between actors in a network given the total number of possible connections. An analogy to graph density is that of a piece of woven fabric; the density represents how tightly the fibres are woven together. If all possible network connections are present in a network, it is described as a complete graph; conversely if no connections are present, it is an empty graph.

The individualistic perspective focuses on measuring the role and position of individual actors in a network. The actor may be an individual person, or an aggregation of individuals in some corporate organization; in either case, the methods and techniques of network analysis are applied in the same way. Social network studies assume that basic network principles, such as homophily, apply equally to individual people and large organizations.

Actor-level indices (also called node-level indices) measure the properties of an actors' position in the network as a way to describe the variability of the actors. Actor centrality measures are the most prominent node-level indices. Actors that are measured as being more 'central' in one way or another are perceived to have differential access to information or resources, and may have differential control over the flow of those resources through the network and between other actors (Freeman et al. 1991; Hanneman and Riddle 2005). There are several different types of centrality measures. Degree centrality measures the number of ties that an individual actor has to other actors, and is a measure of the actor's level of participation in the network. Betweenness centrality is a measure of the actor's position between third-party actors, and is related to an actor potentially being a bridge between two subgroups of actors and participating as a broker of information or resources between groups of actors. Closeness centrality measures how close an actor is to other actors and is measured by the shortest path distance between actors. Eigenvector centrality summarizes the other measures of individual centrality and reflects an actor's overall position within the network taking into account the degree measure of all the other nodes; higher scores are indicative of a more central position (Mizoguchi 2009). Social network theory assumes that the structure of a network impacts the behaviour of its actors, and centrality measures...
provide a key metric for identifying and quantifying the most important actors in a network based on their position and distance to other actors (Mizruchi and Marquis 2006; Wasserman and Faust 1994).

12.3.2 Network Testing and Modelling

In addition to describing network structures and the centrality of actors within networks, SNA provides several methods for statistically testing network hypotheses and for modelling the processes that lead to a network’s particular configuration and allow for the prediction of structured relationships. Null hypothesis testing provides a way to compare observed properties of a network against properties obtained from a distribution of randomly generated networks using a baseline model (Butts 2008a). The conditioned uniform graph (CUG) test procedure is one of the most useful for detecting structural biases in networks. The CUG test utilizes a baseline model of random social structure given some set of fixed constraints, such as the size of the network (number of actors), or density of the network (proportion of ties among actors present), which acts as the null hypothesis (Butts 2008b). A statistic from the observed network is compared against a distribution of values generated by the baseline model to determine if the observed statistic is significantly different from the random distribution. This is an initial step used to isolate bias in the network structure which can be used to model the stochastic processes that generated the network (Robins et al. 2007).

In contrast to testing observed network structures against random network distributions, network regression tests allow for testing the level of association between two networks. In other words, network regression seeks to test how well one network predicts another network given the same number of actors/nodes. This is accomplished by regressing each actor in a dependent network with each actor in the independent network. In order to estimate the standard R-square values and the regression coefficients used for hypothesis testing, a quadratic assignment procedure (QAP test) is utilized. In general, the process works by running 1,000 trials where the rows and columns of the dependent network are randomly shuffled while recovering the R-square and regression coefficients of these runs (Hanneman and Riddle 2005). These values are used to assemble a sampling distribution with which to estimate the association of the two networks under the null hypothesis of no association (Hanneman and Riddle 2005).

Network testing and modelling approaches to social network analysis, such as the CUG and network regression tests, have great potential for use in archaeological research. Based upon anthropological and ethnographic research such as Wiessner’s (1982) study of the hxaro trading system, archaeologists can develop a variety of network models that can be statistically
evaluated against networks developed from archaeological research such as artefact distributions derived from geochemical sourcing data.

12.4 THE KURIL ISLANDS

The Kuril Islands are an appropriate place to explore the limits of human adaptive behaviour through exchange-based social networks—not in the sense of treating the islands as pristine laboratories (the Kuril archipelago is remote and sparsely populated but is not untouched by modern human activity), but because the environmental and ecological conditions that could affect humans are so apparent there.

Stretching between the northern Japanese island of Hokkaido and the southern tip of the Russian Kamchatka peninsula, the Kuril archipelago is composed of thirty-two islands of varying size, environmental and ecological diversity, and primary productivity (Fig. 12.1). The islands at the southern and northern ends of the chain tend to be larger (up to 3,200 km² in area) and more productive and biologically diverse, while the centrally located islands are small (as small as 5 km² in area) and lie in a zone of lower primary productivity. The islands are separated by a number of straits between the Sea of Okhotsk and the North Pacific Ocean, several of which are over 70 km wide and may have, at times, represented significant barriers to the movement of people through the island chain.

The Kuril Islands lie along the tectonically active Greater Kuril Trench, which generates volcanic eruptions, submarine earthquakes, and tsunamis (MacInnes et al. 2009; Melekestsev 2009). These events occur stochastically but frequently today, and analysis of geological deposits from across the islands indicates that they were not uncommon in the past (MacInnes et al. 2009). The climate of the Kuril Islands is strongly affected by water currents in the North Pacific Ocean and the Sea of Okhotsk and by the weather patterns of continental north-east Asia, and can be generally characterized as severe and unpredictable. Winters are cold with heavy snow; summers are cool with dense fog that surrounds the islands.

While the Kuril Islands represent a geographically isolated and tectonically dynamic environment that would have posed a number of challenges to human colonizers, they also provided a rich subsistence base for human groups with the appropriate adaptations. Marine resources such as sea mammals, sea birds, and fish are abundant in the islands and would have been a significant draw for people to the region. The distribution of subsistence and material resources is highly heterogeneous across the island chain, requiring a variety of adaptive strategies and behaviours depending on the specific mix of island environmental and biological diversity and productivity.
Fig. 12.1. Map of the Kuril Islands. Map created by A. Freeburg.
The earliest inhabitants of the Kuril Islands are likely closely related to the Jomon groups that lived throughout the Japanese islands c.13,000 to 2900 BP (Aikens and Higuchi 1982). The presence of people in the southern Kurils during the Early Jomon period is not unexpected given their geographical proximity and environmental similarity to Hokkaido. Several archaeological sites in the southern Kuril Islands have been assigned to the Early Jomon based on cord-marked ceramic designs and microblade lithic tools that are present in Hokkaido at this time (Vasilevsky and Shubina 2006). Concentrated migrations into the Southern and Central Kurils began with the northern movement of Epi-Jomon groups around 2900 BP. The Epi-Jomon of Hokkaido represent the last remnants of the Jomon hunter-gatherers who were ultimately displaced by wet rice agriculturalists from mainland East Asia. Epi-Jomon pottery sites are distinguished by characteristic pottery that demonstrates a conical deep-bowl form similar to earlier Jomon ceramics and retaining the cord-marked and incised patterns that were long out of use on pottery from mainland Japan (Imamura 1996). Pottery designated as Epi-Jomon has been recovered in the Kuril Islands as far north as Shiashkotan Island, and generally dates to a period of time between 2900 to 1400 BP (Gjesfjeld 2010).

By 1400 BP, the Epi-Jomon had been replaced in the Kuril Islands by the Okhotsk culture group, a highly marine-adapted population with origins in the Sea of Okhotsk region (Yamaura 1998). The Okhotsk people colonized the entire length of the Kuril archipelago up to the northernmost island of Shumshu between 1400 to 800 BP, and likely interacted with populations and culture groups inhabiting southern Kamchatka at this time. Pottery made by the Okhotsk is sand-tempered and low-fired with flat to rounded vessel bottoms, and appears to share many traits with pottery found along the Amur River on the Far Eastern Russia mainland. Stylistically, Okhotsk pottery is often undecorated with a pronounced neck and shoulder making it distinctive from the conial form and cord-marked decorations identified on Epi-Jomon ceramics.

Initial research on Epi-Jomon and Okhotsk social networks in the Kuril Islands was based on the inferred trade/exchange of obsidian stone tool raw material (Phillips 2011). While obsidian artefacts are found throughout the Kuril archipelago, obsidian does not occur naturally in the island chain. The source provenance analysis of obsidian flake debitage recovered from Kuril Island archaeological sites demonstrated that obsidian was transported from geological sources in Hokkaido and Kamchatka and distributed extensively across the islands (Phillips 2010, 2011; Phillips and Speakman 2009). This finding suggests long-distance social networks that provided access to material resources and also likely information, potential marriage partners, and reciprocal relationships that could have acted as social safety nets in the case of severe environmental perturbations, existed in the Kuril Islands during the Epi-Jomon and Okhotsk periods (Phillips 2011). It is inferred that the formation and maintenance of these
social network relationships were an important adaptive strategy for long-term success in colonizing and occupying the Kuril archipelago, particularly in the Central Kuril Islands, which are more geographically isolated, less ecologically diverse, and where subsistence resources are less predictable.

12.5 ANALYSING NETWORK STRUCTURES: A CASE STUDY USING KURIL ISLAND CERAMICS

Previous research on Kuril Island obsidian procurement established that social relationships existed in the island chain as a means to access nonlocal material resources. However, because obsidian entered the Kuril Islands from source areas outside of the island chain, the obsidian data is more relevant to the network relationships located at the ends of the archipelago, and is less informative about the exchange relationships among sites within the island chain. For the present case study, ceramic artefacts provide an archaeological dataset that allows for the evaluation of network relationships within the Kuril Islands. Intra-regional network relationships are inferred because the significant majority of ceramics were produced from materials native to the islands and used within the island chain (Gjesfjeld 2010). Tracing ceramic artefacts to their clay sources and inferred locations of production provides a measure of the distance and direction of the trade/exchange of pottery between Kuril Island sites, and also provides a mechanism for establishing network ties between archaeological sites. This focus on ties between sites is important in the context of the role that social networks played at different points in the sequence of island colonization and occupation by Epi-Jomon and Okhotsk groups, and how the two culture groups’ networks of social relationships may have differed. Therefore, unlike obsidian which characterizes long-distance, non-local relationships (Phillips 2010, 2011; Phillips and Speakman 2009), social networks derived from ceramic source data can highlight the local, supra-local and regional exchange relationships within the Kuril Island archipelago better. Without prior knowledge of the exchange relationships that might have existed among past Kuril populations, generalized models of production and exchange are used to explore the structure of these relationships. These models include local production with limited exchange, local production with reciprocal exchange, and central place production with redistribution exchange. Each of the proposed models assumes ceramic production occurs within spatially discrete areas based upon the idea that ceramic production requires at least semi-sedentary settlement to complete the labour-intensive processes of raw material gathering, vessel formation and drying, and firing (Eerkens et al. 2002).
12.5.1 Models of Exchange and Predicted Network Structures in the Kuril Islands

In general, this study utilizes two sets of networks to infer exchange relationships. The first is a set of hypothesized networks derived from generalized ceramic exchange models and used as a baseline of network relationships (Local Production, Reciprocity, and Central Place). The second set of networks is derived from archaeological evidence using the distribution of ceramic artefacts within geochemically defined source groups to represent ceramic exchange relationships. The combination of both sets of networks allows not only the compilation of graph- and node-level measurements but also the structural evaluation of networks using network regression permutation tests. The integration of node-level and graph-level indices with structural hypothesis testing can provide by significant benefit by utilizing robust, statistical methods to evaluate the archaeological interpretations of social network models:

Model 1—Local production—The distribution of ceramic artefacts in geochemical source groups is representative of the network structure and reflects direct access to clay source material and localized production. We expect most ceramic artefacts recovered from the same archaeological site to be closely related in their geochemical composition. In other words, ceramic objects are made locally, used locally and discarded locally. Visually, the network structure of this model is a series of many isolates with only a few connections (see Figs. 12.2B and 12.3B). Individual actors in a local production network should have very low node centrality values and overall network density measurement close to zero.

Model 2—Reciprocity—The distribution of ceramic artefacts in geochemical source groups is representative of the network structure and reflects the local production and reciprocal exchange of ceramics with geographically close neighbors. We expect most ceramic artefacts recovered from the same archaeological site to demonstrate some geochemical variability with the ranges of geochemical compositions similar to ceramic artefacts recovered at nearby sites. Visually, the network structure of the model is characterized by sites with ties to their nearest neighbours (see Figs. 12.2C and 12.3C), and returning low individual actor centrality scores and a low network density value.

Model 3—Central place—The distribution of ceramic artefacts in geochemical source groups is representative of the network structure and reflects the regional pooling of materials and resources for the production of ceramics in a cooperative/collaborative effort. We expect most ceramic artefacts recovered from multiple sites to maintain geochemical similarity. In other words, ceramics are manufactured either by one group or by multiple cooperative groups in with exchange of ceramic objects between smaller populations. Visually, the network structure of this model is highly interconnected with each site maintaining ties with numerous other sites (see Figs. 12.2D and...
12.3D). This should result in higher actor-centrality scores and a higher overall network-density score.

In order to visualize these conceptual models as networks, we were required to set spatial parameters for each model. For the reciprocity model, exchange relationships are assumed to exist between island sites located within close geographic proximity to each other. Using estimates of daily travel derived from Turk’s (2005) kayaking expedition through the archipelago, each site maintains a local exchange radius of approximately 50 km (one day’s travel) with network ties drawn between sites within 50 km of each. For the reciprocity model, exchange relationships are considered to take place on more regional scale with connections drawn between sites less then 150 km away (three days of travel). For the central place model, major open-water straits act as natural biogeographic barriers and cleavage points that divide the island chain into three spatially distinct island groups. The Bussol Strait separates the southern Kuril Islands from the central Kurils, and the Kruzenstern Strait separates the central Kurils from the northern Kurils. Archaeological sites
A Case Study from the Kuril Islands

within an island group are linked to all other sites to mirror central place production or redistribution system.

Working from the premise that the formation and maintenance of social networks is an adaptive mechanism for mitigating environmental risk and uncertainty in the Kuril Islands, we can provide several basic expectations for regional network structures. During the Epi-Jomon period, migrating groups from Hokkaido colonized the southern and central Kuril Islands, and the majority of the Epi-Jomon sites that contribute to the artefact assemblage analysed in this study are located in the southern islands. The southern Kurils are larger, located close to Hokkaido, and can be characterized as having lower environmental risk due to higher levels of environmental and ecological diversity, resource predictability, and primary production. Given that participating in locally oriented regional networks is less important in the southern islands, it is expected that Epi-Jomon ceramic-based exchange networks will be less integrated (less dense), with fewer ties between southern Kuril

Fig. 12.3. Network of relationships for the Okhotsk cultural period. A: Observed ceramic exchange network derived from source provenance analysis; B: Local production exchange network model; C: Reciprocal exchange network model; D: Central place network model.
archaeological sites consistent with a local production model. Conversely, Okhotsk-culture sites are concentrated in the central and northern parts of the island chain. The central Kurils are smaller, steeper, located further away from mainland areas, and have lower levels of environmental and ecological diversity, and subsistence resource predictability and primary production. In this setting, maintaining a dense network of locally oriented relationships would be considered an optimal strategy for dealing with environmental variability. Okhotsk sites are expected to show a high level of connectivity in a dense, interconnected network structure representative of a reciprocity model. Several different methods of SNA analysis and testing will be used to evaluate these exchange model expectations of the networks derived from ceramic artefact data as outlined below.

12.5.2 Reconstruction of Kuril Island Exchange Networks Using Ceramic Artefacts

Overall, fifty-six ceramic artefact samples were submitted for ICP-MS (inductively-coupled plasma mass-spectometry) elemental analysis at the Institute of the Earth’s Crust, Russian Academy of Sciences-Irkutsk under the supervision of Dr. Sergei Rasskazov. The analysed assemblage included thirty-one Epi-Jomon and twenty-five Okhotsk ceramic artefacts. Cultural affiliation of the ceramic artefacts was determined through the identification of key diagnostic stylistic and morphological features, and radiocarbon dates obtained from associated charcoal samples recovered in the same excavation unit and stratigraphic contexts. Ceramic sherds were selected from seventeen sites on eleven islands to provide the broadest spatial coverage across the island chain.

Once the elemental concentrations were obtained through ICP-MS analysis, principal component analysis (PCA) was used to identify the major elements of interest for Epi-Jomon and Okhotsk classified ceramics. In order to integrate the ICP-MS data with previously performed pXRF analyses (Gjesfjeld 2010), elements evaluated by PCA were limited to those identified by both methods. The most significant elements for each ceramic set were identified and hierarchical clustering was used to identify preliminary source macro-group clusters. In order to derive a network structure from the ceramic source data, each site within the same geochemical source group was assumed to have an exchange relationship. A binary socio-matrix of the relationships between sites was then created and analysed using the statnet program (Handcock et al. 2003) in the R statistical environment (R Development Core Team 2010). By simple visual inspection of the artefact-derived networks (Figs. 12.2A and 12.3A), it is evident that Okhotsk network is clearly different from the Epi-Jomon network by demonstrating a higher number of links between sites. While visual inspection of a network is useful in preliminary interpretation,
more detailed interpretations networks must rely on the statistical evaluation of the individual and structural properties of the networks.

The preliminary visual interpretation of the ceramic source data tentatively confirms our expectations for lower density, locally isolated networks during the Epi-Jomon period, and higher density, locally connected networks during the Okhotsk period. This confirmation is based upon the differences in the diversity of sites represented in each of the cluster diagrams. For example, in the seven geochemical source groups identified in the Epi-Jomon cluster diagram, each source group can be tentatively associated with one particular site (using a 50 per cent majority rule). In contrast, only one of five source groups in the Okhtosk ceramic network has a site that can be considered as the majority.

12.5.3 Evaluation of Network Structures

In order to evaluate our preliminary expectations we will utilize individual and structural approaches of social network analysis. As discussed above, individualistic approaches focus on node-level indices (NLIs) and help to provide interpretations concerning the role and position of nodes in the network while structural approaches focus on graph-level indices (GLIs) to help identify broad trends of network relationships and test archaeological hypotheses.

Developing centrality scores for Epi-Jomon and Okhotsk networks based upon the ceramic artefact distribution in geochemical source groups can help explore nodes or sites that may be of most prominence in the network. Prominent nodes have been interpreted as key locations to the flow of information or goods in the network (Hunt 1991; Mizoguchi 2009). In evaluating the centrality scores of the Epi-Jomon and Okhotsk networks, clear differences between the networks can be identified (see Table 12.1). For instance, the Epi-Jomon ceramic source network demonstrates low degree-centrality among many of the archaeological sites with only the site of Kompaniskii showing slightly higher degree and betweenness centrality. In contrast, the Okhotsk network shows higher overall levels of degree centrality with six archaeological sites considered equally prominent in the network. While these centrality measures are informative, producing meaningful interpretations of the networks can be difficult as equally plausible reasons for centrality in the network could be considered. For example, are the higher centrality values for Kompaniskii due to its role as a central place market or is it a site that needs more network ties based upon the greater environmental risk of that local area?

In order to refine potential interpretations, it is necessary to examine the structural properties of networks in addition to node-level properties. In this research we emphasize the use of graph-level density, which provides a structural property that can further contextualize interpretations based upon node-level centrality measures. For instance, we can refine our preliminary
Table 12.1. Degree centrality measures for Epi-Jomon and Okhotsk sites

<table>
<thead>
<tr>
<th>Epi-Jomon Sites</th>
<th>Degree</th>
<th>Betweenness</th>
<th>Eigenvector</th>
<th>Okhotsk Sites</th>
<th>Degree</th>
<th>Betweenness</th>
<th>Eigenvector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ainu Creek</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Ainu Bay</td>
<td>6</td>
<td>7</td>
<td>0.366</td>
</tr>
<tr>
<td>Berezovka</td>
<td>2</td>
<td>2</td>
<td>0.2927</td>
<td>Ainu Creek</td>
<td>6</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Chirpoi</td>
<td>2</td>
<td>5</td>
<td>0.439</td>
<td>Baikova</td>
<td>4</td>
<td>0</td>
<td>0.288</td>
</tr>
<tr>
<td>Kompaninskii</td>
<td>4</td>
<td>13</td>
<td>0.488</td>
<td>Bolshoy</td>
<td>6</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Kubyushevskaya</td>
<td>2</td>
<td>5</td>
<td>0.439</td>
<td>Drobnye</td>
<td>6</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Olya</td>
<td>1</td>
<td>0</td>
<td>0.293</td>
<td>Ekarma</td>
<td>6</td>
<td>7</td>
<td>0.366</td>
</tr>
<tr>
<td>Rasshua</td>
<td>2</td>
<td>3</td>
<td>0.243</td>
<td>Rasshua</td>
<td>1</td>
<td>0</td>
<td>0.066</td>
</tr>
<tr>
<td>Rikorda</td>
<td>1</td>
<td>0</td>
<td>0.293</td>
<td>Ryponkicha</td>
<td>2</td>
<td>0</td>
<td>0.066</td>
</tr>
<tr>
<td>Sernovodskoe</td>
<td>2</td>
<td>3</td>
<td>0.244</td>
<td>Vodopodnaya</td>
<td>12</td>
<td>1</td>
<td>0.4</td>
</tr>
</tbody>
</table>
interpretations of the Epi-Jomon network by examining the low graph density values (Table 12.2). The low structural density of the Epi-Jomon network suggests that Kompaniskii does not represent a central exchange location, as potentially interpreted from the centrality score, but rather a loosely connected reciprocal exchange network with one site maintaining a slightly greater number of ties. In other words, the Kompaniksii site is the most well-connected site within a very low connected network. On the other hand, the Okhotsk network demonstrates contrary properties to the Epi-Jomon network with a graph density value much higher and closer to the graph density values of the reciprocal or central place model networks. The higher overall density helps to reinforce preliminary interpretations of a more interconnected network, potentially a reciprocal or central place model, during the Okhotsk occupation of the central islands.

Table 12.2. Network density scores for the observed network derived from Kuril ceramic artefact provenance analysis and the hypothesized exchange models

<table>
<thead>
<tr>
<th>Network</th>
<th>Density</th>
<th>Network</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epi-Jomon Ceramic artefact provenance network</td>
<td>0.2222</td>
<td>Okhotsk Ceramic artefact provenance network</td>
<td>0.5833</td>
</tr>
<tr>
<td>Epi-Jomon Local exchange model</td>
<td>0.0833</td>
<td>Okhotsk Local exchange model</td>
<td>0.1389</td>
</tr>
<tr>
<td>Epi-Jomon Reciprocity exchange model</td>
<td>0.2222</td>
<td>Okhotsk Reciprocity model</td>
<td>0.3333</td>
</tr>
<tr>
<td>Epi-Jomon Central place model</td>
<td>0.6111</td>
<td>Okhotsk Central place model</td>
<td>0.4444</td>
</tr>
</tbody>
</table>

Producing interpretations based upon the descriptive statistics of node and graph level measures has been one of the most common uses of social network analysis in multiple fields of study. While these descriptive statistics are useful for exploratory analyses, the creation of robust interpretations requires a hypothesis-testing framework. Without a hypothesis-testing framework, evaluation of the network similarities and differences can be largely influenced by several forms of bias, including research priorities, excavation strategies, and sample size. For instance, the Epi-Jomon and Okhotsk networks are identified as having differences in centrality and density values, but it is difficult to evaluate statistically whether the difference between the networks is meaningful given that the differences exist in graph size and the ceramic samples used to construct the network graphs.

The implementation of a hypothesis-testing framework to evaluate interpretations of network data requires two analytical steps. The first step is to identify whether ties in the network can be considered as representative of social or exchange relationships rather than a random configuration of network ties. In order to evaluate the non-randomness of the networks the conditional uniform graph (CUG) test method is implemented. Results of the CUG test performed on the Epi-Jomon and Okhotsk ceramic source
networks reveal the definitive non-randomness of the Epi-Jomon network and the tentative non-randomness of the Okhotsk network (see Table 12.3 and Figs. 12.4 and 12.5). These results suggest that for the Epi-Jomon network we can interpret the distribution of ceramic artefacts in geochemical source groups as likely reflective of the mechanisms of ceramic production and exchange. For the Okhotsk network, this interpretation is not as definitive but the results generally tend towards linking the distribution of ceramic artefacts within geochemical source groups with ceramic production and exchange.

Once networks are demonstrated to tend towards non-randomness in their tie distribution, we can begin the process of evaluating multiple hypotheses/

<table>
<thead>
<tr>
<th>Network</th>
<th>Pr(X&gt;Obs)</th>
<th>Pr(X&lt;Obs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epi-Jomon (Graph Density/Size)</td>
<td>0.999</td>
<td>0.001</td>
</tr>
<tr>
<td>Okhotsk (Graph Density/Size)</td>
<td>0.216</td>
<td>0.868</td>
</tr>
</tbody>
</table>

Table 12.3. CUG test results

![Univariate CUG Test](image)

Fig. 12.4. Epi-Jomon CUG test results.
interpretations of ceramic exchange using network regression. Here, the three models of ceramic exchange (local production, reciprocal, and central place) are regressed against the networks derived from ceramic source groups affiliated with the Epi-Jomon and Okhotsk occupations. Unfortunately, the results of the network regression tests (Table 12.4) are inconclusive in terms of associating the ceramic source networks with our generalized exchange network models since the probability values do not suggest any significant departure from the null hypothesis of no association. In other words, our network models of exchange (local, reciprocal, and central place) do not explain a statistically significant portion of our network based upon the distribution of ceramic artefacts in geochemical source groups. The inability to draw significance between the exchange models

Table 12.4. Network regression test results

<table>
<thead>
<tr>
<th>Network/Model</th>
<th>Pr(X&gt; = b)</th>
<th>Pr(X&lt; = b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epi-Jomon Ceramic artefact network/Local exchange model</td>
<td>0.496</td>
<td>0.504</td>
</tr>
<tr>
<td>Epi-Jomon Ceramic artefact network/Reciprocity exchange model</td>
<td>0.322</td>
<td>0.787</td>
</tr>
<tr>
<td>Epi-Jomon Ceramic artefact network/Central place model</td>
<td>0.282</td>
<td>0.742</td>
</tr>
<tr>
<td>Okhotsk Ceramic artefact network/Local exchange model</td>
<td>0.377</td>
<td>0.628</td>
</tr>
<tr>
<td>Okhotsk Ceramic artefact network/Reciprocity exchange model</td>
<td>0.609</td>
<td>0.406</td>
</tr>
<tr>
<td>Okhotsk Ceramic artefact network/Central place model</td>
<td>0.365</td>
<td>0.635</td>
</tr>
</tbody>
</table>
and ceramic source networks is not fully unexpected given the generic nature of our exchange models. Future work aimed at gaining explanatory significance using network regression likely needs to utilize more regionally specific models that incorporate the local and regional influences on exchange patterns.

12.6 DISCUSSION AND CONCLUSIONS

Archaeological research in the Kuril Islands has demonstrated that various systems of interpersonal relationships existed and were important for the procurement of raw material resources. In relatively isolated and environmentally unpredictable environments, the development and maintenance of social networks can be viewed as an adaptive strategy aimed at retaining a high level of cultural resilience in the face of change at varying scales, from short-term natural hazards to longer-term climatic shifts. The archaeological record provides the basis for evaluating ideas about the structure of Kuril Island social interactions and how they may have changed through time. Various SNA techniques and methodologies are available for not only describing and visualizing, but also statistically testing hypotheses derived from models of human exchange and interaction.

While node- and graph-level network measurements such as actor centrality and graph density are important initial steps for painting a broad overview of observed network relationships derived from artefact data, they cannot be relied on to explain the network structure, or to evaluate multiple interpretations of the behaviour represented in the network. Random graph modelling and network regression are two techniques that provide more appropriate quantitative methodologies for evaluating interpretations of network behaviour within a hypothesis-testing framework. These methods allow for the comparison of two (or more) networks in a way that has both conceptual as well as statistical significance.

In the present case study, network modelling and regression testing were used to evaluate models of ceramic production and exchange with social network structures in the Kuril Islands across two culture periods of island occupation in the archipelago. Exchange is often viewed as a direct proxy for social networking, and in some cases exchange relationships may provide a close approximation of social network structures. However, the network structures derived from the ceramic artefact record of the Kuril Islands are not well-explained by various models of ceramic production and distribution. A key conclusion drawn from this comparison is that we may not necessarily be able to rely on traditional models of exchange to explain network structure and behaviour. Additional work on exchange models emphasizing network relationships is warranted in the Kuril Islands.
and future work aims to increase data resolution through the ongoing analysis of island occupation sequences. These refinements should allow for the creation of a deeper and more detailed account of the role social networks played in the ability of people to survive and thrive in the Kuril environment.

The associations between human behaviour and its archaeological correlates have long been a central research goal of anthropological archaeology. Social network analysis provides a unique research framework that can evaluate models of personal relationships characterized in anthropological theory with archaeological evidence of human interactions. The integrative power of SNA makes it a useful set of conceptual and statistical tools that can not only evaluate specific models of interaction but also expand our conceptions of the archaeological record.

ACKNOWLEDGEMENTS

We would like to thank Carl Knappett for the opportunity to participate in this volume. Also thanks to Ben Fitzhugh at the University of Washington and the Kuril Biocomplexity Project for support of this research. Participation in the Kuril Biocomplexity Project was made possible in part by a grant from the US National Science Foundation (ARC-0508109; Ben Fitzhugh, PI) and various logistical and financial support from the University of Washington, Seattle, WA, USA; the IGERT Program from Evolutionary Modelling (Eric A. Smith and Tim Kohler, PIs); the Hokkaido University Museum (Sapporo, Japan); the Historical Museum of Hokkaido (Sapporo, Japan); the Sakhalin Regional Museum (Yuzhno-Sakhalinsk, Russia), and the Southern and Far East Branches of the Russian Academy of Sciences (IEC:Irkustk, IMGG: Yuzhno-Sakhalinsk, IVGG: Petropavlovsk-Kamchatsky, NEISRI:Magadan). Also, special thanks to those colleagues who personally helped with the Kuril Islands ceramic sourcing pilot study: Natalia Slobodina, Valery Shubin, Olga Shubina, Nadia Razjigaeava, Vladimir Popov, and Sergei Rasskazov.

REFERENCES


Gjesfjeld, E. 2010. 'Analysis of ceramics from the central and northern Kuril Islands', in A. Lebedintsev (ed.), *Proceedings of the Scientific conference in Honor of the 85th Anniversary of N.N. Dikov and the 50th Anniversary of NEISRI FEB RAS* (Russian Academy of Sciences, Far East Branch, North-East Interdisciplinary Scientific Research Institute, Magadan). [In Russian]


Hofman, C. L., Bright, A. J., Boomert, A., and Knippenberg, S. 2007. 'Island rhythms: the web of social relationships and interaction networks in the Lesser...
A Case Study from the Kuril Islands


Terrell, J. E. 2010. 'Language and material culture on the Sepik Coast of Papua New Guinea: using Social Network Analysis to simulate, graph, identify, and analyse social and cultural boundaries between communities', Journal of Island and Coastal Archaeology, 5: 3–32.


A Case Study from the Kuril Islands


