

AN ABSTRACT OF THE THESIS OF

Shane A. Scaggs for the degree of Master of Science in Applied Anthropology presented on November 13, 2018.

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Two striking characteristics of human beings are the diversity of resources that we use to sustain our lives and the extent to which we engage in coordinated, collective efforts to obtain and consume these resources. Together, these two characteristics are the foundation of human subsistence patterns. In many remote Alaskan villages, these features manifest through social networks of food sharing in which a small number of households harvest the bulk of the resources consumed by the local community. For subsistence researchers in Alaska, the productivity of these households is understood to be crucial to the food security of populations that depend on subsistence resources of the bulk of their nutrition. While the diversity of resources that these communities use is acknowledged, it has not been analytically investigated. This thesis applies the quantitative methods of social network analysis and multivariate statistics to a dataset containing information on food sharing connections, resource harvest levels and their species composition, and household demographic characteristics in 8 Alaskan villages on the Middle Kuskokwim River. The goal of this analysis is to better understand the diversity of species that are used in these villages and to test whether a household's position within a food sharing network is related to the diversity of their harvest.

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Subsistence Harvest Diversity in Alaskan Food Sharing Networks

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Shane A. Scaggs

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APPROVED:

Major Professor, representing Applied Anthropology

Director of the School of Language, Culture, and Society

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Shane A. Scaggs, Author

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1 INTRODUCTORY REMARKS

A striking characteristic of human beings is the immense diversity of resources upon which we subsist. Even within a single population, there exists a tremendous variety of dietary assemblages and strategies that are used to procure them. Processing and using a variety of resources is thought to be a hallmark of the human species and our proliferation into such a broad array of terrestrial landscapes is attributed to this ability to construct a broad ecological niche (Laland and Boogert 2010; Zeder 2012). To put it metaphorically, we are not giant pandas (*Ailuropoda melanoleuca*); endlessly tethered to the search for a specific quality of forage; obligated to reside in a specific kind of landscape. We are the grizzlies (*Ursus arctos*) of the primate order; seeking out tubers, berries, vegetation, and meat in vast and variable terrains.

A second, but related characteristic is the extent to which humans engage in coordinated, collective action to acquire this incredible diversity of resources. These networks of interaction are fundamental to the organization of human societies at a myriad of scales. From collaborative labor networks in which people plant, hunt, harvest and process foods (Downey 2010), to food sharing networks of informal resource distribution (Gurven 2004), to the meals that we share as households (Ziker and Schnegg 2005), the impressive diversity of resource uses exhibited by *Homo sapiens* are manifested via social networks.

Broadly speaking, this thesis is concerned with both of these fascinating characteristics within the context of Alaskan subsistence food systems. The topic that is studied in order to better understand these characteristics is food sharing. Studies of food sharing have a rich history in anthropology, especially among ecological anthropologists, as they are an appropriate locus of human-environment interactions. To the extent that foods can be shared, they must be produced and humans do so using a suite of interrelated foraging behaviors and practices (Nolin 2010). While the focus of much study in anthropology has been on the sharing of meat (Gurven 2004; Koster 2011; Ziker 2006), the topic of food sharing broadly encompasses all possible harvested resources that are exchanged between households.

The objectives of this thesis are to examine the diversity of resources used by residents of Alaska's middle Kuskokwim River and attempt to understand how variation in harvest diversity is associated with the structure of Alaskan food sharing networks. In pursuit of these objectives, I

employ perspectives from social network analysis (SNA), ecological anthropology, and systems ecology in a quantitative approach to Alaskan subsistence harvests. In the final sections of this chapter, I dissect the anthropological and social science literature to ascertain what is meant by the term *subsistence*. I go on to briefly describe the role of social networks in Alaskan villages and subsistence research in the North. In chapter 2, I describe the application of SNA to food sharing networks and develop a series of exponential random graph models (ERGMs) to test whether sharing connections between households can be explained by the diversity of household harvests. In chapter 3, I step away from inference with the goal of describing the variation in species that compose subsistence harvests in 8 Alaskan villages.

1.1 The dimensions of subsistence

Any organism that uses resources to maintain growth and survival can be thought to subsist. Indeed, to live is to subsist. The term subsistence, however, has been applied so broadly in social and natural sciences that it resists an unambiguous definition. What is more, a definition of human subsistence is particularly tenuous because it must at least encompass an intersection of ecological, social, and economic dimensions. My intention in this review is to be explicit about how subsistence has been characterized in anthropological literature by paying close attention to these three dimensions. By dissecting the term subsistence along these axes, I seek a holistic definition of the concept.

1.1.1 The ecological axis

1.1.1.1 Classic ecological anthropology

The tendency of early ecological anthropology was to categorize subsistence “strategies” by associating aspects of human material culture with properties of the local environment. The cultural ecology of Julian Steward (1963), for example, conjectured that the environment, loosely defined as an ecosystem, prescribed the potential resources that a human group inhabiting that environment could subsistence upon. It was therefore argued that the material cultural or technology associated with a given human group was necessarily derived from the suite of resources available to them and the methods people have developed to obtain and use those resources.

Researchers following Steward's approach made it their goal to inventory the technologies used by human groups, document the local environmental parameters which these groups encountered, and ethnologically compare these domains and the correlations among them. The result was a typology of "modes of subsistence" that were often interpreted within a progressive evolutionary framework as different stages of complexity that closely aligned with Karl Marx' ideas about "modes of production" (Ellen 2002). While Steward himself was critical of this linear approach, instead favoring what he called "multilinear evolution", the basic methodology of categorizing modes of subsistence remained. While many contemporary ecological anthropologists and evolutionary theorists have abandoned this linear stance of progression from one stage of complexity to the next, the categories that emerged from this typological approach (e.g., hunter, gatherer, collector, cultivator, *et cetera*) remain important categories for describing human subsistence.

Not long after Steward, Roy Rappaport (1967) published what became a seminal study of ritual practice, animal husbandry, and swidden (i.e., slash-and-burn) agricultural among the Tsembaga Maring people of New Guinea. Rappaport's work was innovative in that it incorporated ecological concepts like carrying capacity and plant succession that had been previously unappreciated by anthropologists. Moreover, Rappaport sought to ascribe ecological function to the seemingly separate, symbolic realm of human culture that was embodied in Tsembaga rituals. Rappaport observed that the Tsembaga would engage in a ritual cycle of warfare, planting, and pig slaughter that mapped onto stage of forest succession and population growth. He concluded that these cultural practices had the capacity to reduce forest and soil degradation, redistribute resources, and avoid social fallout between neighboring groups as they approach the environmental carrying capacity (Rappaport 1967, 28–29). Based on this, one could argue the ways in which human culture could regulated ecological dynamics.

1.1.1.2 Evolutionary anthropology

During this same time, evolutionary biologists outside of anthropology had developed formal mathematical models of animal cooperation (Hamilton 1964a, 1964b; Trivers 1971) based in part on economic models of decision making. Key to these models were the gauging costs and benefits of engaging in altruistic behavior – parameters that were conditioned by environmental conditions – that could be used to conceive of the evolution of social behavior. These formal

models spawned a new field of mathematical ecology and behavior that was rich with hypotheses to test in just about any social species. These simple models eventually lead to the development game theory (Axelrod and Hamilton 1981), a modeling procedure that was used to identify evolutionarily stable behavior strategies (Dawkins 1976).

An anthropological subfield that grew out of this paradigm was human behavioral ecology (HBE). Subsistence strategies are one of three primary topics of research in HBE (E. A. Smith 1992); the other two being reproductive ecology and the evolution of human cooperation. In some sense, HBE was a merger of evolutionary biology and the field of ethology¹ that attempts to explain how natural selection operates on phenotypic (i.e. behavioral) variation in humans (Cronk 1991). Through the application of game theoretic and optimization models of animal behavior, human behavioral ecologists have highlighted “conditional [behavioral] strategies” that tend to maximize individual fitness under the pressure of social and ecological constraints (E. A. Smith, Borgerhoff Mulder, and Hill 2001). Within this neo-Darwinian framework, human behavioral ecologists have focused on two of Niko Tinbergen’s four ethological questions (1963): the *proximate* mechanics of behavior and the *ultimate* adaptive consequences of behavioral variation (Cronk 1991). The pursuit of these complementary levels of explanation has culminated in a *foraging theory* that “has been successfully applied to the behavior of humans that rely directly on natural resources for subsistence” (Borgerhoff Mulder and Coppolillo 2005).

Two foundational assumptions of HBE are that 1) an organism’s life can be viewed as periods of reproductive and somatic effort (Cronk 1991) and 2) natural selection exert tremendous pressure on the reproductive success of different phenotypes (e.g., the ‘phenotypic gambit’). In his review, Cronk (1991) situates ‘resource acquisition’ and ‘resource distribution’ under the umbrella of somatic effort (30-34), defined as energetic investments in the maintenance of growth and development. Following this logic, the spatial and temporal structure of an ecosystem places ecological constraints on the energetic budgets of the organisms that inhabit it and use its resources. These constraints condition the relative costs and benefits of allocating effort to various kinds of resources. It is therefore argued that over time, individuals with a consistently low cost-benefit

¹ In Tinbergen’s 1963 publication “On the aims and method of ethology”, he outlined four complementary lines of inquiry about the cause of animal behavior. In addition to proximate and ultimate, he identified ontogeny, the life-cycle and development of an organism, and phylogeny, the organism’s evolutionary history and lineage as being qualitatively different explanations of behavior. In anthropology and archaeology, phylogeny has come to include historical causes of human behaviors. These four causal question came to be known as levels of analysis in the study of behavior (Cronk 1991).

ratio should have ample resources to invest in somatic and reproductive growth, resulting in higher fitness and the transmission of more genetic material into the next generation.

A consequence of applying the optimization framework to a complex phenomenon like subsistence is that resource decisions must be reduced to their relevant costs and benefits. This approach stands in stark contrast to other evolutionary researchers that seek the genetic or neurobiological determinants of behavior (E. A. Smith, Borgerhoff Mulder, and Hill 2001). Moreover, the value of this reductive process is born out of their failure to account for complexity and context (Cronk 1991). Indeed, it is their simplicity that makes models useful for generating hypotheses and tractable for analysis and interpretation.

1.1.1.3 Systems ecology

Key to the HBE approach to subsistence is methodological individualism – an empirical assumption that each research participant is an independent and that the category of “individual” provides the most valid evidence about behavior and especially, evolutionary change. Indeed, the analytical simplicity that this assumption carries is what has made the proliferation of empirical tests possible in HBE.

However, methodological individualism also brings certain limitations. For instance, the reduction of behavior down to costs and benefits, described in the previous section, means that the environmental constraints are assumed, if only for convenience, to be static. Of course, this assumption contradicts the dynamic feedbacks that are observed between species and that are characteristic of ecological communities (Fitzhugh et al. 2018). A static environment also flies in the face of the sweeping impacts of human actions that have defined the Anthropocene (Latour 2014). What is clear is that the researchers that employ methodological individualism are simply preoccupied with decision-making mechanics and their consequences (Orr, Lansing, and Dove 2015). Limitations aside, this lineage of investigation provides an important piece of theory for understanding bottom-up system dynamics, even if these mechanisms miss the mark when it comes to societal complexity or tipping points and transitions at the level of ecosystems or landscapes (Bliege Bird 2015).

Following from this latter view, it is clear that systems ecology in anthropology begins to ask different questions. Where HBE seeks to understand the optimal subsistence strategy for maximizing fitness (i.e. reproductive output), systems ecology would seek to clarify how resource

use by one species feeds into the trends of another species. One key distinction is that systems ecology attempts to characterize patterns by making attending to the interactions between multiple scales of a phenomenon whereas HBE seeks explanations that are largely at a single scale (e.g., individual) or the tensions that arise between individuals and groups (Bliege Bird 2015). Thus, systems ecology necessarily erodes the concepts of individuality, a perspective that is increasingly garnering empirical and philosophical support (Gilbert, Sapp, and Tauber 2012).

1.1.2 The social axis

The materialist foundation of early explanations of subsistence has been widely criticized. A noteworthy criticism comes from Tim Ingold (1986) who pointed out that descriptions of subsistence had often conflated technology and the knowledge required to apply a technology to a particular environment. Expanding on this, Roy Ellen (2002) has argued that “modes of subsistence, no less than separate technical practices or tool-using behaviours, are necessarily embedded in particular webs of social and ecological relations” (198). Rappaport acknowledged this distinction in the conclusion of his 1967 publication, noting that “[the] relations of the Tsembaga within their environment have been analyzed as a complex system composed of two subsystems” (28). Like Ellen, Rappaport distinguishes ecological relations (e.g. “local subsystem”) and social relations (e.g. “regional subsystem”) that together constitute a system of subsistence relations.

It has also been rightly pointed out that subsistence activities, and the practices and social relations they entail, do more than provide a meager sustenance or baseline levels of survival (Magdanz et al. 2016; Schumann and Macinko 2007; Wheeler and Thornton 2001). Subsistence is a vibrant and dynamic process of acquiring resources that also structures processes of independent and social learning (Lew-levy et al. 2017; Mesoudi 2017), fortifies individual and cultural identity (Barber et al. 2015), and shapes institutions and norms around resource use, distribution, and general social behavior (West and Ross 2012).

1.1.2.1 Subsistence and social learning

Hunting, gathering, and foraging cannot be learned from a text – effective and successful subsistence necessitates participatory social learning. To this end, Mesoudi (2017) summarizes an experimental study that found social learning to be more prevalent among pastoralists than among

horticulturalists, who are thought to rely more heavily on individual innovation. Mesoudi concludes by suggesting that subsistence is an underappreciated driver of variation in learning processes across cultures (2).

In their meta-ethnography, Lew-Levy et al. (2017) review ethnographic research on hunter-gatherers that studied how children learn subsistence techniques. They found that across many human groups, children learn to forage via observation and imitation, play, hands-on participation, and vertical transmission (378-380), emphasizing that efficient foraging necessitates that these social learning processes begin at an early age. They also note that groups whose children were engaged in Western schooling exhibited marked social learning differences that included overimitation, reduced participation in subsistence, and the tendency to defer based on age (385). In their view, age related deferral may demonstrate a shift away from a more egalitarian social organization in which age, gender, and other prescribed social categories have less impact on how cultural is transmitted. The finding that formal education obscures subsistence participation is also consistent with findings in Alaska, that link “youth detachment” from subsistence to the enforcement of Western education and the pursuit of cash income (Fienup-Riordan, Brown, and Braem 2013).

1.1.3 The economic axis

Understanding subsistence, as an economic endeavor, takes us directly into the subsistence research paradigm of the arctic and subarctic. Indeed, subsistence is defined in Alaska a kind of economic system (Wolfe and Walker 1987) marked by a particular set of characteristics, many of which, have been studied at length in anthropology. For instance, subsistence economies are characterized by localized use of resources (Magdanz et al. 2016), a condition that has been key to the application of foraging theory by human behavioral ecologists (Borgerhoff Mulder and Coppolillo 2005). Subsistence economies rely on traditional institutions and norms, often embodied in ritual, to manage common property resources (Ostrom 1990; West and Ross 2012). Resources produced in subsistence economies are distributed through informal distributional networks (e.g., food sharing networks), as opposed to formal and contracted supply-chains, in which cash is used primarily as a supplementary currency (BurnSilver et al. 2016; Collings 2011). The knowledge of how to produce subsistence resources is highly dependent on intergenerational

local ecological knowledge that is obtained through participation and observation (Peloquin and Berkes 2009).

The impetus for defining the properties of Alaskan subsistence comes from legislation in the 1970s and 80s. The Alaska Native Claims Settlement Act (1971) known as ANCSA put forth by President Nixon sought to end land claims disputes indefinitely between indigenous Alaskans and sport hunters and fishers (Wheeler and Thornton 2001). The mandate set aside a meager portion of the Alaskan landscape for subsistence use and legally incorporated indigenous Alaskans as shareholders of the natural resources these landscapes harbor. However, as Wheeler and Thornton (2001) point out, ANCSA did little to ensure subsistence *rights* to lands; it only ended land claims. Moreover, the Alaska National Interests Lands Conservation Act (1980) went on to acknowledge rural, non-indigenous grievances over their inability to access subsistence resources. Following these federal mandates, the state of Alaska went on to clerically define the properties of subsistence in order for subsistence users, indigenous or otherwise, to demonstrate their subsistence needs.

In Alaska, these “economic” characteristics of subsistence are key to defining, managing, and legitimizing indigenous rights to resource use. Thus, the economic axis of subsistence is principally defined by the economic valuation of subsistence. Put differently, defining subsistence in economic terms is tenuous at best, but it is done in Alaska in order to manage subsistence users and their resources (Wheeler and Thornton 2001).

1.1.4 *The three axes*

What this brief review fundamental demonstrates is that subsistence is a process of inhabiting, using, and transforming the environment. The bounds of the process are due, in large part, to the limitations of human cognition, which relies largely on symbolism and categories to process the complexity of social-ecological systems (Kohn 2013). Thus, when I analyze resource diversity and food sharing in an attempt to understand subsistence, the outcome will be only a snapshot of this process.

1.2 Social networks in the North

A defining feature of Alaskan subsistence is the way that resources are produced and distributed. While some market integration has led to the consumption of market food in Alaska (Ballew et al.

2006), subsistence foods that are harvested from the landscape are the dominant components of rural Alaskan diets. Unlike market based societies, in which the people that consume resources are not the same individuals that produced them (Wheeler and Thornton 2001), subsistence resources in Alaska are distributed locally through food sharing networks.

Subsistence researchers in Alaska (Baggio et al. 2016; BurnSilver et al. 2016), Canada (Collings 2011; Collings et al. 2016; Ready 2018; Ready and Power 2018), and Siberia (Ziker and Schnegg 2005; Ziker 2006, 2007) have utilized SNA to quantify food sharing relationships in a variety settings. Subsistence researchers in Alaska are some of the first to use social networks in an applied setting (Magdanz, Utermohle, and Wolfe 2002) as a basis for natural resource management. Social networks are seen as potential solution to the problems that are associated making resource management decisions based on aggregating community harvest through averaging or summation. For example, it is through a network perspective that researchers recognized that Alaskan households do not operate independently as economic units, but through extended kinship networks (Wheeler and Thornton 2001). Often it is the most productive subnetworks that produce the bulk of resources used in northern villages and these key households have been termed “super-households” (Wolfe 1987).

This thesis draws on this rich tradition of food sharing research by applying innovative analytical techniques from SNA to reappraise a previously collected dataset. Using network data collected by the Division of Subsistence – a branch of the Alaska Department of Fish and Game – I will use ERGMs to test hypotheses about the positionality of households within food sharing networks and consider subsistence harvest patterns at household and village levels.

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2 HARVEST DIVERSITY, PRODUCTIVITY, AND RECIPROCITY IN AN ALASKAN FOOD SHARING NETWORK

2.1 Abstract

In this article we report a social network analysis (SNA) of an Alaskan food sharing network in Aniak, Alaska. We use exponential random graph models (ERGMs) to test whether the structure observed in this empirical network can be explained in associated with the productivity and diversity of a household's harvest profile. We first construct a control model and then include vertex-level attributes for household productivity and diversity. Furthermore, we test these hypotheses using both binary and valued ERGMs as a methodological comparison of the effects of adding weights to the edges between households. The results show that harvest productivity and diversity are associated with increased sharing activity. Edge formation was most likely when shares were reciprocated. The strength of these effects were diminished in the valued ERGMs but the overall pattern remained. Our analysis reinforces the notion that existing social networks and food sharing practices are vital institutions for resilient Alaskan communities.

2.2 Introduction

In remote villages throughout the northern latitudes, human groups continue to subsist predominately on hunted and gathered foods. Household participation in harvesting and processing activities forms the basis of a persistent subsistence economy (Magdanz et al. 2016) that has been remarkably resilient to market integration, rapid globalization, and a shifting climate. In the midst of this “total environment of change” (Moerlein and Carothers 2012), mixed cash-subsistence economies with complex and adaptive dynamics have emerged in many northern regions (BurnSilver et al. 2016; Collings 2011; Kofinas, Chapin III, et al. 2010; Peloquin and Berkes 2009).

What is clear about these subsistence-oriented systems is that they are organized into social networks of interacting households that work together to harvest and process a diverse set of resources for local consumption (Usher, Duhaime, and Searles 2003). The practice of sharing harvested foods is a vital institution that undergirds the formation of these networks by reinforcing existing kinship, friendship, and other social partnerships, and by extending support and provisions to those in need (Collings et al. 2016; West and Ross 2012). For some households, food sharing

networks are the only way to access nutritionally and culturally preferred foods (Reedy and Maschner 2014) and are an avenue to receive aid after environmental or economic disturbances (Howe et al. 2016).

It is also evident that the bulk of the subsistence resources that are consumed in a given community were obtained and distributed by a small subset of “super-households” (Wolfe 1987) that together harvest as much as 70 to 80 percent of the wild food consumed by the community at large. These key households are positioned to influence the connectivity of food sharing networks (Baggio et al. 2016) and their productivity levels can determine the surplus of food that is available for secondary and tertiary distributions within the local community (Wolfe and Walker 1987). In other words, the patterns exhibited by food sharing networks are linked to the productivity levels of these core households.

However, the resources that make up a productive harvest vary considerably. Though some resources may be ranked more highly than others, the diversity of a household’s harvest is a nontrivial characteristic that warrants greater analytical attention in subsistence research. Ethnographic accounts, for instance, attest to the importance of targeting a variety of species in fluctuating arctic and subarctic environments (Charnley 1984; Fienup-Riordan 1986). Maintaining a broad ecological niche is a hallmark of human ecology (B. D. Smith 2015) and is a likely driver of human integration with a wide range of social-ecological environments (Zeder 2012). Moreover, theoretical insights into the adaptive capacity of social-ecological systems point to diversity as a key feature that enables resilient ecological communities and human societies to respond to and reorganize in the wake of environmental disturbances (Leslie and McCabe 2013; Ives and Carpenter 2007).

Given that a variety of resources are harvested and used Alaska, we propose that the centrality of a household in a food sharing network may also be associated with their *resource diversity*. In this article, we report a social network analysis (SNA) of an Alaskan food sharing network in which we use exponential random graph models (ERGMs) to test whether the centrality of household is related to the productivity and diversity of their harvest. We begin by describing the method of SNA and the ERGM framework and move on to review theoretical contributions to the food sharing literature that have utilized these methods. To expose our rationale for considering harvest diversity in these networks, we then describe the concept of the super-household. We then summarize our analytical methods and proceed with a presentation of our modeling results. First,

we present a baseline control ERGM and then we focus on the effects of three covariates: *diversity*, *productivity* and *reciprocity*. We assess the effects of these covariates under both binary and valued ERGM conditions as a methodological comparison and then conclude with a theoretically driven discussion.

2.3 Social networks and exponential random graph models

2.3.1 Social networks

A social network is a graphical representation of a set of social relations that occur within a group of socially interacting agents (Robins 2015). Social agents can be any number of intermingling entities such as persons, organizations, populations, species, *et cetera*. Each social agent is visualized in a graphical space as a *vertex*. The presence or absence of a relationship between two vertices is represented by the presence or absence of an *edge* connecting them. A network graph must therefore be constructed based on *relational data*; information that relates one social agent to another (Marsden 2011). The configuration that these relations take constitutes the network graph that is displayed visually using edges and vertices (Luke 2015).

The edges in a social network may be either directed or undirected. *Directed* edges are those that depict flows and transactions that are directional, whereas *undirected* edges depict relations for which there is no clear directionality. A network collected to document which individuals feed at the same food patches, for example, could be considered undirected, as there may be no clear direction of influence on each feeding event (Makagon, McCowan, and Mench 2012). On the other hand, a network of which individual primates share food with one another could be directed, to depict the possible reciprocal flow of resources between them (Brent 2015). Though it is common for each edge to be measured as either present or absent, edges can also be measured using a broader range of values collected by ranking interactions or counting their frequency (Krivitsky and Butts 2017). Networks of this kind are referred to as *valued* networks as they are composed of edges that have been weighted (Newman 2017; Krivitsky 2012) by these values to capture additional social complexity.

One advantage of quantifying social interactions using relational data is that it allows researchers to characterize a specific social agent's relative position and influence in a particular social process (Makagon, McCowan, and Mench 2012). A variety of *centrality* measures are used to gauge the position of a social agent as being more central or peripheral relative to other agents

in the network. One metric that is of interest in this analysis is *degree* centrality, defined as the sum of edges that are connected to each respective vertex. In a directed graph, both *in-degree* and *out-degree* are calculated to distinguish between incoming and outgoing edges (Robins 2015). The distribution of these degree scores is one way to illustrate or diagnose the connectivity of a social network.

A second advantage of conceptualizing sociality in this way is that SNA is a non-linear method that emphasizes the interdependence of social agents. This is to say that SNA differs philosophically and empirically from other modes of analysis. For instance, if we use an edge to represent a social process, such as persons A and B sharing a meal, then it is the case that such an edge cannot exist without the presence of two vertices, (i.e., a dyad), and therefore the social process we seek to understand cannot be empirically monitored by attributing any edge (i.e., a shared meal) to any single person. Thus, any individual outcomes of this process, such as the number of meals that person A eats, depends on the meals eaten by person B, and *vice versa*. In this sense, the outcomes of every individual are *interdependent* and *interrelated* to some extent.

2.3.2 Exponential Random Graph Models

Exponential Random Graph Models (ERGM) are a family of statistical models that have been applied to network specifically to tease apart the dependencies described at the end of the last section. The dependencies that are characteristic of relational data pose problems for conventional bivariate and multivariate statistical methods. For the reasons described in the previous section, social network data violate the assumption that each observation is independent (Marsden 2011). Overcoming this limitation is key since it is the dependence of observations – the pattern of edges among the vertices – that researchers seek to explain when conducting a SNA (Apicella et al. 2012; Nolin 2010).

In essence, an ERGM is designed to predict the presence or absence of an edge (i.e., a dependence) between two vertices. In some sense, ERGMs are a method of pattern recognition (Robins 2011) that involves searching a network for common patterns of edge connection that “structure” the network. Some patterns may be related to the attributes of the vertices such that a dyad with similar attributes (i.e., homophily) or different attributes (i.e., heterophily) may be more likely to connect. Other patterns, such as triads or stars, extend beyond the dyad to include multiple vertices. These network “building blocks”, also called structural dependencies, allow researchers

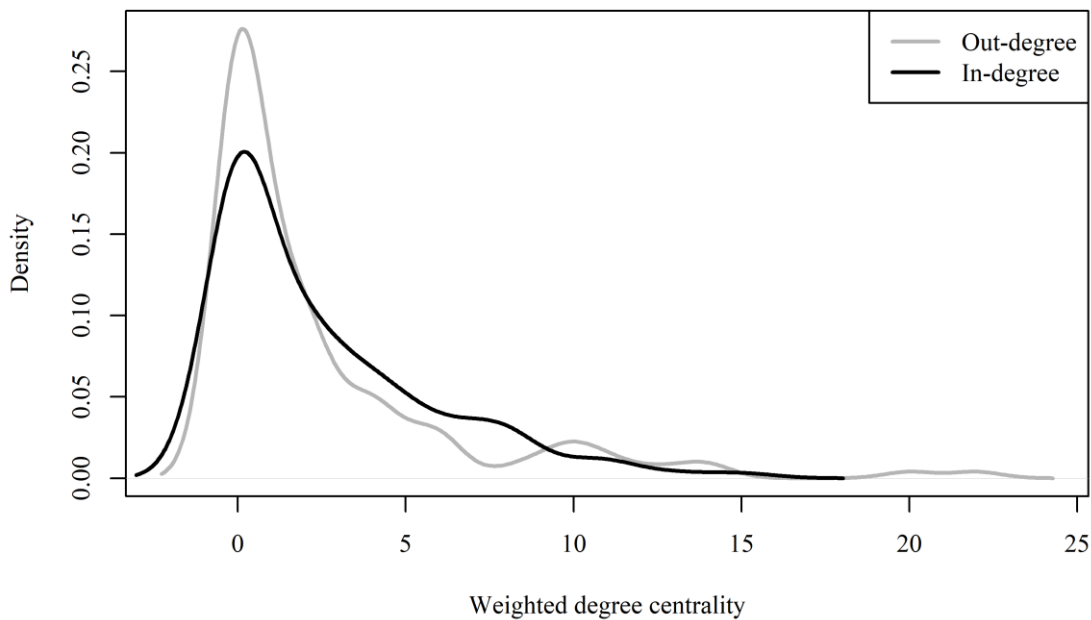


Figure 2-1. In-degree and out-degree distributions for the Aniak food sharing network. Both distributions are heavily skewed, indicating that most vertices are isolated or only connected a small number of other vertices.

to examine patterns of social organization like hierarchy and connectivity (Bodin and Crona 2009; Downey 2010). Searching for patterns in this way creates a “sampling space” that contains all of the possible network configurations and the probabilities associated with each configuration (Pilny and Atouba 2018).

The principle advantage of using ERGMs over other multivariate techniques is that researchers can specify model parameters corresponding to dyadic dependencies, structural dependencies, and vertex attributes can all be included into a network model as predictors (Morris, Handcock, and Hunter 2008). In many cases, vertex attributes are surveyed characteristics about each social agent, such as age, education level, income, or other vertex activities. Each of these parameter types is entered into the model framework as “sufficient statistics” (Krivitsky 2012). The inclusion of each of these parameter types produces a statistical coefficient in the form of log-odds and their statistical interpretation is similar to the interpretation of coefficients in logistic regression (Ready and Power 2018).

In binary networks, the task of an ERGM is to compare the sampling space of the observed network to a series of random network(s). Parameters for dyadic and structural dependences, as

well as vertex attributes (Apicella et al. 2012) are passed into the model, in an attempt to explain the pattern of edges in the observed network. Whether or not the “sampling space” of the observed network differs significantly from that of random networks is computed using maximum pseudo-likelihood estimation (Morris, Handcock, and Hunter 2008). The probability that the parameters passed into the model capture aspects of the underlying network structure is calculated using a Markov Chain Monte Carlo² (MCMC) procedure (Nolin 2010) which is used to detect autocorrelation among the simulated networks (Goodreau, Kitts, and Morris 2009). An ERGM with parameters that *can* be found in the sampling space will “converge”, and those that do not can be assessed for model degeneracy using MCMC diagnostics.

In valued (i.e., weighted) networks, this task is more complicated because the sampling space must accommodate a range of weights for each edge (Pilny and Atouba 2018). Accurate estimates depend on the specification of a reference distribution that closely matches the distribution of edge values (Krivitsky and Butts 2013). Still, goodness of fit tests for binary networks are far more developed than those for valued networks, but the fit of the latter can still be assessed by simulating new networks and comparing latent (i.e., un-modeled) network properties (Pilny and Atouba 2018).

Valued ERGMs are appealing because measured edge information that was once lost by dichotomizing the network for a binary ERGM is instead kept intact (Krivitsky 2012). For instance, in a food sharing network, a binary ERGM estimates the likelihood that an edge between two vertices is absent, indicating that they have shared nothing, or whether it is present, indicating the two have shared anything. In a valued ERGM, this estimation is based on whether two vertices shared nothing, shared once, or shared twice, *et cetera*. In this particular network, the edge values

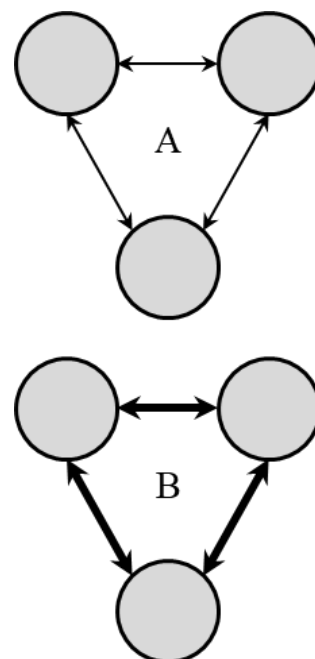


Figure 2-2. An illustration of two triads. Triad A and B both have the same number of edges but the addition of weights in triad B makes this network denser.

² MCMC can be more clearly understood by breaking apart the acronym. “Monte Carlo” refers to a randomization procedure, popular in a Bayesian statistics, that uses iterated random trials to calculate a probability distribution. The procedure is analogous to “bootstrapping” in frequentist statistics, but it can accommodate more complex distributions. A “Markov Chain” is also known as a “random walk”. When calculating the probability distribution, Markov Chains are implemented to account for dependence in many multivariate and network datasets. To exemplify the process, imagine that you are going for a walk around your neighborhood. At each intersection, you use a purely random logic (i.e., Monte Carlo) for choosing which direction to walk next. You will inevitably reach the same intersection more than once, and each time that you do, you will have more information to make your next decision (i.e., Markov Chain).

correspond to different types of resources. It is implied that a household that shares multiple resource types must have a more diverse harvest. This makes valued ERGMs especially suited for the task of examining the effect of harvest diversity on network structure.

2.4 Food Sharing

Food sharing is a topic with tremendous anthropological and ecological interest, especially among scholars who seek to clarify the evolution of animal cooperation and roots of human prosociality (Gurven 2004). A full review of the topic is beyond the scope of this report but for recent reviews of food sharing in primates and in hunter-gatherer societies, see Jaeggi and van Schaik (2011) or Gurven and Jaeggi (2015), respectively. The focus here is on food sharing that has been studied using SNA.

2.4.1 Network approaches to food sharing

In the context of food sharing studies, SNA has been used to disentangle several hypotheses invoked to explain the evolution of cooperative behavior that hinge on partner selection, such as inclusive fitness (Hamilton 1964a) as well as direct, indirect, and generalized forms of reciprocity (Bshary and Bergmüller 2008; Trivers 1971). By using SNA, the dyadic dependencies that make aggregate patterns of cooperation observable are made explicit (Apicella et al. 2012), making a nuanced analysis of contingent or preferential sharing a newly tractable endeavor in evolutionary anthropology (Nolin 2010).

In the Taimyr region of Siberia, Ziker (2006) used SNA to demonstrate that meat sharing occurs predominately between close genetic relatives and that shares of meat are often preferentially directed to elders, children, or households in need. In a related study, Ziker and Schnegg (2005) showed that overall meal sharing in Ust'-Avam is highly asymmetric in that a small number of households share most of the meals in the community. However, reciprocity is most common among these generous households who bear the costs of hosting meals by taking turns doing so. In a study of meat sharing, reciprocity was found to be most common among the most skilled and successful hunters (Ziker, Nolin, and Rasmussen 2016). Likewise, Koster (2011) reported support for a kin-biased explanation of sharing but he also noted that the most productive Mayangna and Miskito hunters always shared the most, regardless of the breadth of their respective kinship networks. Among the whalers of Lamalera, kinship and reciprocity were shown to have

interactive effects on the likelihood that two households shared food (Nolin 2010) and that after controlling for these, high status individuals accounted for the residual sharing behavior (Nolin 2013). Ready and Power (2018) demonstrated that in Kangiqsujaq, kinship and reciprocity also have strong effects on the log-odds of sharing relationships but that household heads also share food to improve their social or political standing. In Kaktovik and Wainwright, Alaska, the households that shared the most were those that were in the highest income and harvest levels (BurnSilver et al. 2016), echoing a similar observation that was found a decade and a half earlier in Wales and Deering, Alaska (Magdanz, Utermohle, and Wolfe 2002).

Two themes are eminent in the food sharing network literature explored here that come to bear on our analysis. The first is that reciprocity has a strong effect on the likelihood that two households exhibit sharing edges, even among households that are close genetic kin. Although kinship may initially be a key factor in determining the target of sharing (Nolin 2010), reciprocity clearly has pronounced multiplicative effects. Secondly, the degree distributions in these networks reveal a pattern of inequality that manifests as asymmetric transfers of foods. These exchanges tend to originate in sub-networks that are composed of the most productive households (BurnSilver et al. 2016; Koster 2011; Ready and Power 2018) and resources tend to flow downstream from these households to those experiencing circumstances that limit their capacity to harvest (Ziker 2006). Furthermore, these sub-networks are structured by kin relations (Magdanz, Utermohle, and Wolfe 2002) and by patterns of reciprocity among the most skilled, productive harvesters (Koster 2011; Ziker, Nolin, and Rasmussen 2016).

2.5 Harvest productivity and diversity

In this section, we provide an overview of the super-household concept in subsistence research conducted by the Alaska Department of Fish and Game. We focus on productivity, noting the influence of highly productive households on the food security of subsistence-oriented populations. We then consider how productivity has been measured in many of these analyses and describe a rationale for considering harvest diversity in tandem with productivity.

2.5.1 *Super-households*

The concept of the super-household emerged from research by the Alaska Department of Fish and Game's (ADFG) Division of Subsistence (hereafter, the Division). In a regional analysis of

subsistence economies, Wolfe and Walker (1987) recognized a widespread pattern of harvest inequality in rural Alaska. Specifically, they noted that in subsistence-oriented populations, a small proportion of households, usually fewer than 30 percent, were identified as the source of the resources that were being used by most of the households the local community (~70%). This pattern became known as the “30-70 rule” and super-households were highlighted as the productive core of mixed cash-subsistence economies. The anatomy of the super-household was fleshed out in the subsequent two and a half decades and a rigorous articulation with SNA was formulated by the Division in the 1990s and early 2000s (Wolfe and Magdanz 1993; Magdanz, Utermohle, and Wolfe 2002).

Super-households likely contain “keystone individuals” (Modlmeier et al. 2014) who exert tremendous influence over network connectivity, altering the flow of subsistence resources. A super-household might be conceptualized as a “strongly-interacting” household just as keystone species interacts strongly across trophic levels (Granovetter 1973; Soulé et al. 2017). Indeed, it is the *direct* and *indirect* effects of these core subsistence producers which make them highly influential and strengthen their edges. For example in Alaska, Baggio *et al.* (2016) pointed out that the loss of “key households” can be disastrous to the food security status of subsistence-oriented populations since these households are the origin of many secondary and tertiary food distributions. In some communities, this pattern of asymmetry is even more pronounced, with as few as 10% of households doing the majority of the harvesting, making these communities especially vulnerable to the loss of key households (Natcher 2015). Indeed, assessing food security in the northern latitudes cannot be accomplished without considering the productivity of super-households and the distribution networks in which they are embedded (Loring and Gerlach 2009; Ready 2016).

2.5.2 Productivity and the rationale for harvest diversity

In subsistence-oriented communities, household harvest productivity is a key metric for prioritizing subsistence uses and setting fishing and hunting quotas on recreational and commercial activities. One way that productivity has been appraised in subsistence research is by using an estimate of the total biomass of a household’s harvest. The Division uses a standard conversion of units to pounds, that is then summed and used to estimated usage by non-response households (Caroline L. Brown et al. 2012) In some network studies, productivity levels are broken into

terciles of lower, moderate, and upper harvest productivity (BurnSilver et al. 2016; Ready and Power 2018). Thus, households in the upper-tercile are expected to be more central, exhibiting a greater number of edges that involve exchanges of surplus resources to other households.

There may be multiple pathways to a large, productive harvest and the composition of resources that are harvested are indicative of a household's subsistence strategy (Hansen et al. 2013). To illustrate this, consider households A and B. Household A may have a more *dominant* harvest that is composed of massive abundances of commercially favored species, such as salmonids (*Oncorhynchus* spp.) or moose (*Alces alces*). Household A may use cash from commercial fishing employment or guiding to supplement subsistence foods with market goods or maintain subsistence equipment. In contrast, household B may continue to participate in a seasonal round (Charnley 1984), harvesting a broader array of species but at lower abundances. Household B also obtains a productive harvest, but doing so requires local ecological knowledge and the seasonal flexibility needed to target each species (Ford, Smit, and Wandel 2006). In this way, household B obtains a *diverse* harvest rather than a dominant harvest.

Harvest diversity is acknowledged in the formulation of the super-household perspective (Wolfe and Magdanz 1993; Magdanz, Utermohle, and Wolfe 2002), though its treatment in subsistence research has largely been a matter of ethnographic inquiry. Across arctic and subarctic North America, ethnographers have repeatedly described the diverse constellation of resources that are used by subsistence-oriented populations (Charnley 1984; Fienup-Riordan 1986; Magdanz, Utermohle, and Wolfe 2002; Magdanz et al. 2016). Participation in seasonal rounds or at seasonal harvesting and fishing camps (Charnley 1984) have made it possible for residents of central Alaska to access resources that fluctuate seasonally and from year-to-year (Fienup-Riordan 1986). These fluctuations are dramatic, and many species are not consistently abundant, emerging only for a brief time when biophysical parameters are favorable. Thus, a diverse harvest is one way to construct a broad niche (B. D. Smith 2015) that may buffer households against dramatic changes in seasonal abundance (Penn, Gerlach, and Loring 2016).

Whether diversity facilitates resilience in Alaska is a timely question since the northern latitudes are the most vulnerable to the impacts of global climate change (Duarte et al. 2012).

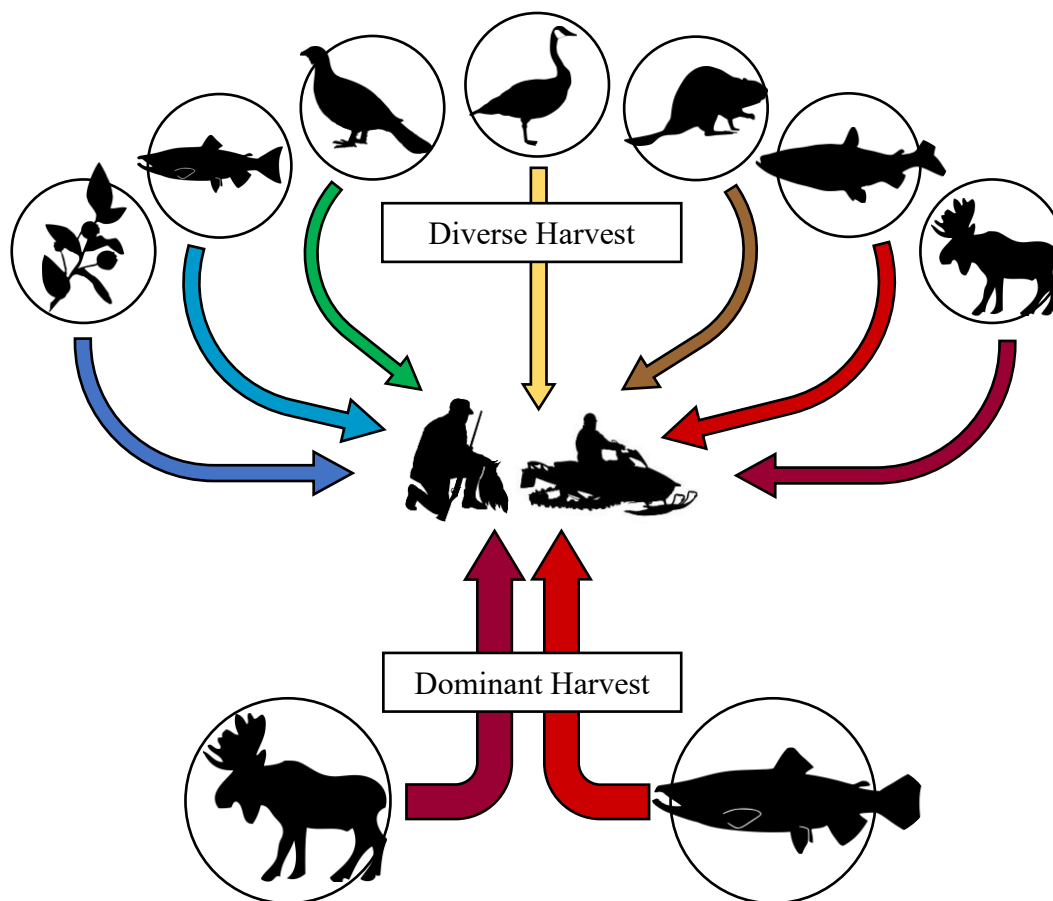


Figure 2-3. Two pathways to a productive harvest. A diverse harvest obtains a variety of seasonally available resources, including those that are commercially profitable. A dominant may largely target these favored species. Though both pathways are likely crucial for food security in Alaskan villages, a household with a diverse harvest can share a broader range of resources. This may manifest as valued edges in a food sharing network.

Warming trends that are accelerating ice loss, sea level rise, and coastal erosion across Alaska (Hovelsrud et al. 2011) also have dramatic effects on species abundances (Brinkman et al. 2016), resource access (Fall et al. 2013), forest succession patterns and wildfire severity (Kofinas, Chapin III, et al. 2010), and the timing of hydrological and phenological cycles (Bieniek et al. 2011; Leblond and Côté 2016). These biophysical and ecological trends, however, cannot be decoupled from ongoing social, cultural, and economic shifts (Moerlein and Carothers 2012). Further integration with markets and centralized governments has been shown to reduce youth participation in subsistence (Fall et al. 2013), increase reliance on fossil fuels and cash income to pursue subsistence resources (Collings 2011), and lead to resource use restrictions and top-down management of subsistence priorities (Loring 2013, 2017). The impacts of some of these changes on subsistence are ameliorated by ecosystem management (Berkes 2012) at the local level, that builds on existing social networks within a community (Parlee, Berkes, and Council 2006).

Amid these complex changes, we expect that a diverse harvest not only lends dietary and nutritional flexibility at the household level, but it may also facilitate response diversity (Leslie and McCabe 2013). Together, resource diversity and food sharing networks are the foundations of a social organization that boasts thousands of years of resilience and adaptation in the arctic and subarctic (Kofinas, Chapin III, et al. 2010; Sakakibara 2017; Wexler 2014). In some cases, diverse harvests may support village welfare via food sharing (Chapin et al. 2010), though in others it may provision more discrete subnetworks (Koster 2011) or be utilized as a means to garner political influence and social capital in changing socioeconomic contexts (Ready and Power 2018; Ready 2018). Substantive nuances aside, it is clear that the effect of diversity on network structure warrants further investigation.

2.6 Methods

2.6.1 Site description

In this analysis, we consider data from Aniak, a subarctic Alaskan village of 195 households located at the confluence of the middle Kuskokwim and Aniak Rivers (Krauthoefer, Brown, and Koster 2015). A complete census of the village was attempted, yielding responses from 141 households (Caroline L. Brown et al. 2012). The village is primarily composed of indigenous Yup'ik peoples and non-Native residents (Brelsford, Peterson, and Haynes 1987) that have remained since colonization in the late 19th century (Funk 2010).

Aniak households subsist and collaborate as economic units and many residents participate in subsistence activities, but do so with less seasonal movement than in previous decades (Charnley 1984). Fish make up 92% of the total weight harvested by Aniak residents and 79% of households reported using fish (Caroline L. Brown et al. 2012). Among the most heavily harvested species are Chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*) and Coho salmon (*O. kisutch*), moose (*Alces alces*), and burbot (*Lota lota*), but residents of Aniak in this data collection reportedly made use of more 60 subsistence resources, including many species waterfowl and migratory birds, small land mammals and furbearers, and edible plants and greens. (see Table S1). Amid this variety, there remains a preference for species that can be smoked, dried, or frozen for storage until the

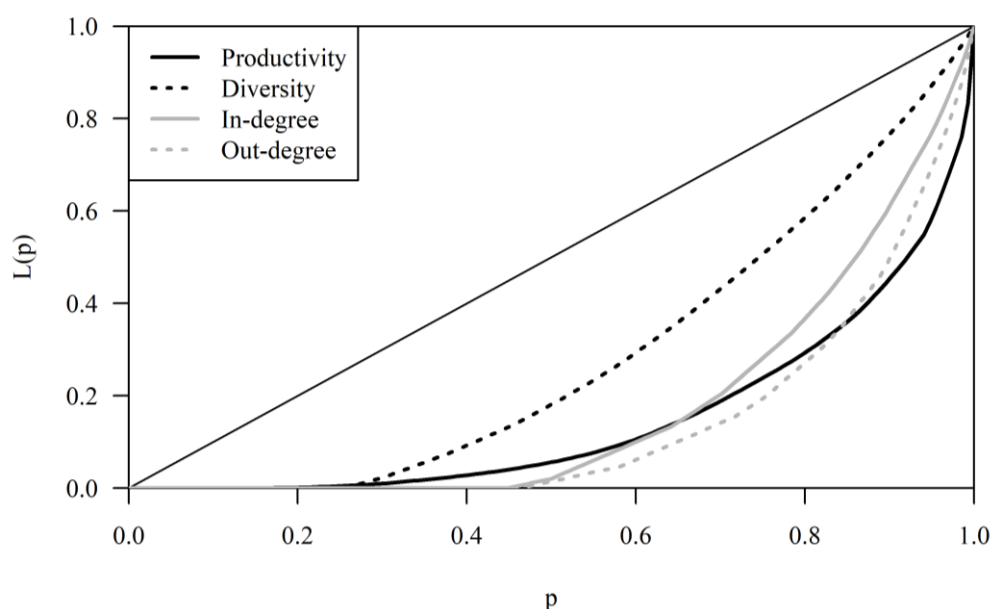


Figure 2-4. Lorenz curves demonstrate inequalities in harvesting and in network connection in Aniak. The straight line indicates no equality. The more curved the line is toward 1, the more inequality is present for that measure.

leaner winter months arrive (West and Ross 2012). Harvest levels exhibit clear inequalities, making this site a suitable context for our analysis (Figure 2.4).

2.6.2 Data collection

The data for this analysis was collected in 2009 by the Division as part of an assessment funded by Donlin Creek LLC (Caroline L. Brown et al. 2012). The data are analyzed here as part of a data sharing agreement with the ADFG that was approved by both the ADFG and the Institutional Review Board at Oregon State University. A full description of the survey instruments can be found in the appendices of Brown *et al.* (2012) as part of a Technical Paper Series produced by the ADFG's Division of Subsistence.

After community review and approval by the tribal government, these data were collected using an in-person household survey that was administered after informed consent was provided by one or more household heads, who then reported information for all permanent residents (> 3 months) of the household. The survey contained modules that were used to document household demographics, employment and income, food security and resource concerns, and subsistence participation by household residents, as well as a comprehensive harvest assessment intended to

estimate the usage rates of all species that compose a household's harvest. The survey also included a section on networks, that will be described further below.

2.6.3 *Productivity, diversity, and reciprocity*

Using the comprehensive harvest assessment, we calculated harvest productivity and harvest diversity for each household and included both of these metrics as vertex attributes in our analysis. We first calculated household productivity by summing the estimated pounds harvested of each species to reach a total weight for the household.

To assess harvest diversity we calculated the Shannon-Wiener Index (i.e., H') on a matrix of 141 households $\times$ 62 resources, following the equation given in McCune and Grace (2002, 25–27):

$$H' = - \sum_i^S p_i * \ln p_i \quad (1)$$

where p is the proportion of species i out of the total biomass of the harvest. S is species richness; the number of unique species represented in the harvest. The Shannon-Wiener Index is essentially a measure of uncertainty or entropy (Jost 2006), and the interpretation in ecology is based on information theory (Shannon 1948). It is described as “drawing individuals at random from a community. The higher the diversity, the more uncertainty you will have about which species you will draw next” (McCune and Grace 2002, 26). The Shannon-Wiener index is preferred in this analysis over other measures of diversity, such as Simpson's Dominance, because it is sensitive to both the rarity and evenness (i.e., relative abundance) of each species in a sample unit (Jost 2006; McCune and Grace 2002).

We parameterize reciprocity in our model as a dyadic dependence that cannot be attributed to any single household. Thus, in models that include all main effects, reciprocity is interpreted as an odds-multiplier on the existing log-odds of edge formation between different harvest and diversity levels. In other words, productive households are likely to have one-way transfers, an example of hierarchy, but these transfers may be even more likely when reciprocated (multiplier effect).

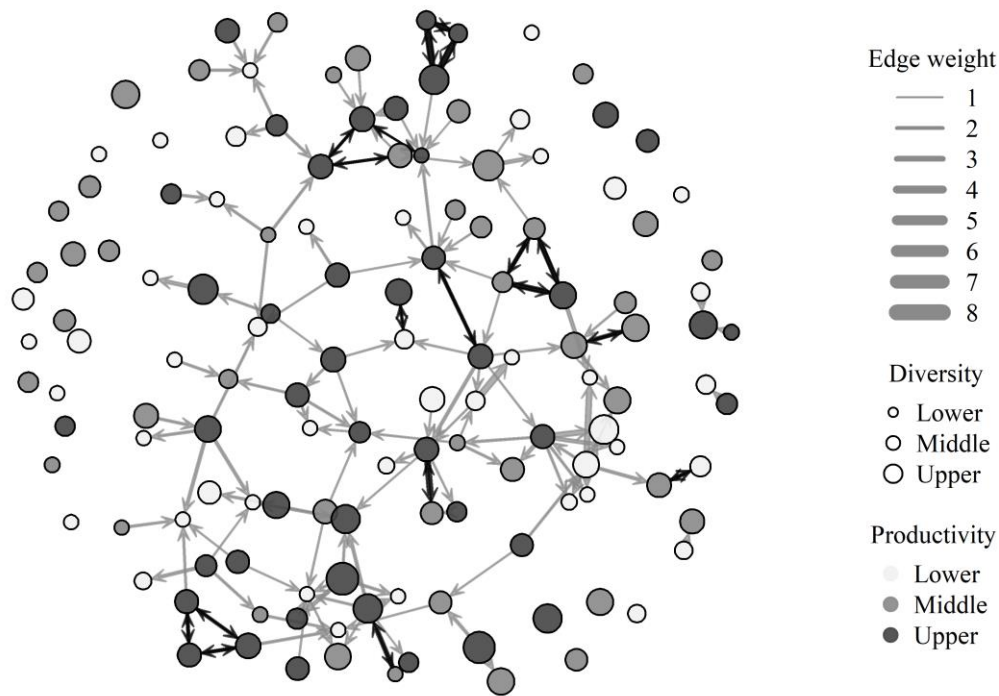


Figure 2-5. The Aniak food sharing network. The diameter of each vertex is scaled by diversity and shaded, with the darkest being the most productive households. An arrow is fastened to the ends of the edges to indicate their direction, and edges that are colored black represent instances of reciprocity. The thickest edges are those with heavier weights, indicating the transfer of multiple resource types between two households.

2.6.4 The social networks

The survey instrument used by ADFG also contained a section on networks, in which respondents were asked to recall the households that had harvested and/or processed food and shared it with them in the past year. With the limitations of memory recall (Bernard 2011), the networks in this analysis are likely composed of the most memorable primary and secondary transfers of food that they received (Nolin 2010, 2013). When identifying these exchanges, respondents were asked to clarify the kind of resource that was shared with them³.

Of the 141 households surveyed, 133 participated in the network portion of the survey and their responses were used to create *two directed networks*. Both networks contained 149 edges, making them incredibly sparse, with a density of 0.8% of the maximum possible edges. In the first network, edges values are disregarded, and the network edges are dichotomized. In the second, we

³ Respondents were asked to identify exchanges of 10 resources: *salmon, whitefish, moose, ducks, caribou, berries, non-salmon fish, trout, marine mammals, birds, grouse, and wood*.

apply a valued weight to each edge that corresponds to the number of resources that were shared, creating a *valued* network. Analyzing networks in concert allows us to discern the effect of vertex attributes on general sharing behavior (i.e., binary ERGM) and on shares of multiple resource types (i.e., valued ERGM). Together, these two networks constitute the dependent variables of the analysis and are used to engage the following research questions:

- 1) Are households with diverse harvests associated with increased food sharing activity?
- 2) Are sharing connections in this network patterned by reciprocity?
- 3) Do these dynamics differ under binary and valued ERGM conditions?

2.7 Results

All of the procedures in this analysis were performed in R (R Core Team 2017) using the *igraph* (Csardi and Nepusz 2006), *vegan* packages (Oksanen et al. 2017), and the *statnet* suite of packages, including *ergm* (Handcock et al. 2016) and *ergm.count* (Krivitsky 2016). We developed and compared binary and valued ERGMs for the Aniak food sharing network to test the effects of two vertex covariates, *productivity*, *diversity*, and one dyadic dependence covariate, *reciprocity*, on the odds of in-degree edge formation between vertices. Each set of models (Table 2-1 and Table 2-2) begins with a control ERGM and then walks through the main effects of these covariates and their pairwise conditions. We present these models under binary (Table 2-1.) and valued (Table 2-2) ERGM conditions.

2.7.1 Binary ERGMs

2.7.1.1 Control model

The binary control model contains two structural parameters that control for edges and isolates in the network. The edges term in an ERGM is analogous to the intercept term in a logit based regression (Ready and Power 2018). An edges-only model produces a single coefficient can be used to find the density of the network when it is exponentiated. This is the same as converting the log-odds estimate in of the edge-only model into an odds-ratio (OR; $e^{-4.776}$). The isolates parameter adjusts the log-odds of an edge based on the condition that a vertex is not an isolate (i.e., in-degree and out-degree = 0). As expected, not being an isolate has a positive effect on the log-odds of edge formation (1.333; $p < 0.001$).

Table 2-1. Binary ERGM Comparisons

Models ^A	Coefficients ^B								
	<i>Edges</i>	<i>Isolates</i>	<i>Sex of HH head</i>	<i>Total subsistence activities</i>	<i>HH jobs ratio</i>	<i>Percent Alaska Native</i>	<i>P</i>	<i>D</i>	<i>R</i>
BC	-6.062*** (0.490)	0.849** (0.294)	0.286 (0.167)	0.038*** (0.007)	0.064 (0.136)	0.314* (0.147)			
BCP	-6.065*** (0.014)	0.873*** (0.017)	0.242*** (0.050)	0.030*** (0.007)	0.102 (0.072)	0.315** (0.109)	0.0001** (0.000)		
BCD	-6.368*** (0.499)	0.738* (0.293)	0.244 (0.165)	0.030*** (0.007)	0.015 (0.137)	0.338* (0.152)		0.559*** (0.139)	
BCR	-6.192*** (0.463)	0.485 (0.286)	0.310 (0.176)	0.032*** (0.006)	0.048 (0.128)	0.284* (0.144)			3.524*** (0.318)
BCPD	-6.360*** (0.017)	0.778*** (0.021)	0.212 (0.162)	0.023** (0.007)	0.054 (0.080)	0.337* (0.133)	0.0001* (0.000)	0.532*** (0.136)	
BCPR	-6.236*** (0.016)	0.501*** (0.015)	0.272*** (0.039)	0.024*** (0.006)	0.101 (0.069)	0.278* (0.110)	0.0001** (0.000)		3.545*** (0.010)
BCDR	-6.550*** (0.458)	0.354 (0.290)	0.285 (0.173)	0.025*** (0.007)	-0.003 (0.125)	0.302* (0.146)		0.604*** (0.142)	3.594*** (0.322)
BCPDR	-6.569*** (0.017)	0.375*** (0.021)	0.265*** (0.045)	0.017* (0.007)	0.039 (0.078)	0.302** (0.109)	0.0001** (0.000)	0.587*** (0.138)	3.610*** (0.011)

^A Model main effects: *B* binary, *C* controls, *P* productivity, *D* diversity, *R* reciprocity. Modeling was conducted in statnet (Handcock et al. 2016).

^B Bold values are log-odds estimates with standard errors in parentheses.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

The control model (Model BC, Table 2-1) includes 4 vertex attributes that have been discussed in subsistence research: 1) the sex of the household head; 2) the total number of subsistence activities; 3) the household jobs ratio; and 4) the percentage of household residents reporting that they are Alaskan Native. Attributes 2 – 4 were modeled without any in-degree or out-degree expectations (Table 2-1). Attribute 1, however, was model as a vertex in-covariate, with the expectation that household's with a female head are like to be the recipients of shares (West and Ross 2012; Ziker 2006). The percentage of household residents that reported being Alaska Native (0.314, $p = 0.032$) and the number of subsistence activities (0.038, $p < 0.001$) had a positive effect edge on formation. A household was 1.3 times more likely to receive food if the head of the household was a female (0.286, $p = 0.087$).

2.7.1.2 Productivity model

We compared the effects of different productivity levels on the likelihood of in-coming edges by computing odds-ratios. The effect size estimated for productivity (Model BCP, Table 1.1) is based on the scale at which productivity was measured. In this case, productivity was measured as the total weight of all species harvested, with a range from 0 to nearly 15,484 pounds. To give a comparative example, the odds of an outgoing edge are nearly 2 times greater for a household that harvested 8,000 pounds than for a household that harvested 50 pounds [$OR = e^{(0.00007845215 \cdot 8,000) - (0.00007845215 \cdot 50)} = 1.9$]. For reference, the average harvest weight in Aniak is estimated 892 pounds (Caroline L. Brown et al. 2012) while the median harvest is 230 pounds.

2.7.1.3 Diversity model

Like productivity, we compute ORs for various levels of harvest diversity using the coefficient estimate in Model BCD (Table 1.1). Here, a unit increase in diversity results in a 0.558 increase in the log-odds of an outgoing edge. The values of diversity were computed using Shannon's index and, in this network, they range from 0 to 2.395. For comparison, an outgoing edge is 3 times more likely for a household with $D = 2.25$ than for a household where $D = 0.25$ [$OR = e^{(0.5577452 \cdot 2.25) - (0.5577452 \cdot 0.25)} = 3.1$]. Since this is a measure of entropy, the units of diversity are more easily interpreted when they are compared with species richness (Figure 2.5). For example, harvest richness in the most diverse harvests ($D > 2.25$) ranges anywhere from 12 to 33 species, whereas low diversity harvests ($D < 0.25$) tend to be only 2 or 3 species.

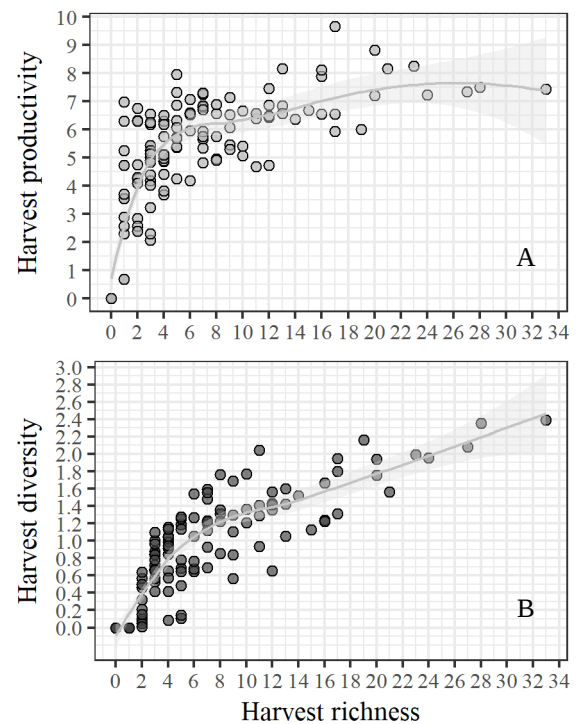


Figure 2-6. Harvest richness, productivity, and diversity. Two scatterplots that demonstrate the relationships that harvest richness (i.e., the number of unique species in a harvest) has with A) productivity and B) diversity in the village of Aniak. In A) productivity has been log transformed.

2.7.1.4 Reciprocity model

Including the reciprocity parameter has the largest effect on the control model (3.524, $p < 0.001$). Model BCR (Table 1.1) shows that an edge from

household $A \rightarrow B$ is 35 times more likely when there is a reciprocating edge from $B \rightarrow A$, compared to a scenario where a reciprocating edge is absent [$OR = e^{(3.524*1) - (3.524*0)} = 34.7$].

2.7.1.5 *Pairwise models*

Models BCPD, BCPR, and BCDR (Table 1.1) contain pairwise combinations of productivity, diversity, and reciprocity. However, the model parameters for productivity and diversity are both computed from the same harvest matrix, albeit with different analytical techniques. To diagnose whether this introduces collinearity, we used a method by Duxbury (2018) to calculate a variance inflation factor (VIF) for each parameter. The cutoff levels for VIFs in ERGMS are larger than those used to diagnose linear models. According to Duxbury's method, model parameters with VIF scores greater than 20 are concerning and scores above 100 are considered to be highly collinear. Using this criteria, we found no collinearity issues when combining productivity and diversity (VIFs: $P = 1.402$; $D = 2.284$).

When productivity and diversity are entered together (Model BCPD), the effect of diversity diminishes slightly (0.558 vs. 0.538). The inclusion of reciprocity with either productivity or diversity (Models BCPR and BCDR, respectively) results in a modest increase in the log-odds of outgoing edges related to productivity and diversity. The log-odds for reciprocity are greater when combined with productivity (3.524 vs. 3.545) or diversity (3.524 vs. 3.594).

2.7.1.6 *Combined model*

When all of the main effect parameters are entered into a combined model, the odds of reciprocity increases (3.610, $p < 0.001$), suggesting that reciprocated edges have a greater effect when at increased levels of productivity and diversity.

2.7.2 *Valued ERGMS*

2.7.2.1 *Control model*

Table 2-2 presents the results of our valued ERGMs and, as before, we begin by specifying a control model. Since each edge in the valued ERGM is now weighted, the edges and isolates controls are replaced by the sum and nonzero parameters which together adjust the density of the network based on the summation of all the edge weights. Since the density cannot be calculated

Table 2-2. Valued^A ERGM Comparisons

Models ^B	Coefficients ^C								
	<i>Sum</i>	<i>Nonzero</i>	<i>Sex of HH head</i>	<i>Total subsistence activities</i>	<i>HH jobs ratio</i>	<i>Percent Alaskan Native</i>	<i>P</i>	<i>D</i>	<i>R</i>
VC	-0.466* (0.228)	-6.365*** (0.165)	0.091 (0.067)	0.011*** (0.002)	0.124* (0.054)	0.268*** (0.066)			
VCP	-0.525*** (0.017)	-6.352*** (0.008)	0.069** (0.022)	0.009*** (0.003)	0.151*** (0.033)	0.277*** (0.046)	0.00002* (0.000)		
VCD	-0.533* (0.233)	-6.303*** (0.167)	0.068 (0.068)	0.008** (0.003)	0.092 (0.060)	0.264*** (0.078)		0.224*** (0.055)	
VCR	-0.366 (0.199)	-6.128*** (0.166)	0.101 (0.064)	0.008*** (0.002)	0.082 (0.045)	0.200** (0.073)			1.657*** (0.133)
VCPD	-0.567*** (0.018)	-6.292*** (0.009)	0.063*** (0.013)	0.006* (0.003)	0.118*** (0.021)	0.253*** (0.011)	0.00002* (0.000)	0.218*** (0.051)	
VCPR	-0.387*** (0.018)	-6.117*** (0.008)	0.092*** (0.006)	0.005 (0.002)	0.111*** (0.014)	0.176*** (0.009)	0.00003** (0.000)		1.672*** (0.009)
VCDR	-0.533** (0.194)	-6.060*** (0.177)	0.08 (0.069)	0.004 (0.002)	0.065 (0.044)	0.215** (0.069)		0.238*** (0.054)	1.653*** (0.133)
VCPDR	-0.587*** (0.017)	-6.047*** (0.007)	0.071*** (0.006)	0.001 (0.002)	0.088*** (0.013)	0.215*** (0.008)	0.00003** (0.000)	0.242*** (0.006)	1.677*** (0.009)

^A Valued ERGMs include a specification of a zero-inflated Poisson reference distribution (Krivitsky 2012).

^B Model main effects: V valued, C controls, P productivity, D diversity, R reciprocity. Modeling was conducted in statnet (Handcock et al. 2016).

^C Bold values are log-odds estimates with standard errors in parentheses.

*p<0.05; **p<0.01; ***p<0.001

without information on the total vertices and edges, parameter *N* also controls for the network isolates.

2.7.2.2 Productivity model

In the valued productivity model (Model VCP, Table 2-2), a unit increase in pounds harvested results in a 0.00002 ($p < 0.029$) increase in the log-odds of forming an outgoing edge. Continuing with the Model BCP comparison, Model VCP shows that a household that harvests 8,000 pounds is as likely to have an outgoing edge as a household that harvests 50 pounds [$OR = e^{[0.0000165619361*8,000] - [0.0000165619361*50]} = 1.1$]. Even household that harvests the maximum weight observed in this dataset (15,484 pounds) is only 1.3 times more likely. Recall that in the binary version (Model BCP, Table 2-1) the odds-ratio was ~3 time more likely.

2.7.2.3 Diversity model

In the valued diversity model (Model VCD, Table 2-2), the log-odds of an outgoing edge increase with each unit change in diversity by a factor of 0.0224 ($p < 0.001$). For example, a household with a harvest diversity of $D = 2.25$ is almost 1.6 times more likely to form an outgoing edge than a household with a diversity of $D = 0.25$ [OR = $e^{(0.0224*2.25) - (0.0224*0.25)} = 1.6$]. In the binary ERGM, harvest diversity also had a positive effect on out-degree, though the strength of this effect was smaller in the valued ERGM.

2.7.2.4 Reciprocity model

In a valued ERGM, there are multiple options for calculating reciprocity (Krivitsky 2016). We chose to use the default option: to take the minimum number of reciprocated edges. Under these conditions, reciprocity still has a positive effect on the odds of edge formation (1.657, $p < 0.001$). Specifically, an edge is more than 5.2 times more likely to form from $A \rightarrow B$ when a reciprocating edge from $B \rightarrow A$ is present.

2.7.2.5 Pairwise models

When productivity and diversity are entered together (Model VCPD, Table 2-2) the independent effects diminish slightly but remain significant. Similar to the binary ERGMs (Table 2-1), reciprocity has a strong effect in the presence of productivity or diversity (1.657 vs. 1.672 or 1.652).

2.7.2.6 Combined Models

The outcome of the combined model in the valued ERGMs (Model VCPDR, Table 2-2) continued the theme of the previous valued models; a strong effect of reciprocity (1.676, $p < 0.001$) and dampened but significant effects for productivity (0.00003, $p < 0.004$) and diversity (0.242, $p < 0.001$).

2.7.3 Model selection and fit

Of the models presented in the previous sections, we selected the binary and valued ERGMs with the lowest Akaike Information Criterion (Table 2-3) and used these ERGMS to simulate networks to assess model fit. The binary and valued ERGMs with the lowest AIC contained all combined

Table 2-3. Binary and Valued ERGMs Ranked by Akaike and Bayesian Information Criterion

<i>Binary Models^A</i>	<i>AIC</i>	<i>BIC</i>	<i>Valued Models^B</i>	<i>AIC</i>	<i>BIC</i>
BCPDR	1,571	1,641	VCPDR	-33,883	-33,813
BCDR	1,575	1,637	VCR	-33,817	-33,763
BCPR	1,586	1,648	VCDR	-33,814	-33,752
BCR	1,592	1,646	VCPR	-33,813	-33,751
BCPD	1,650	1,713	VCD	-33,756	-33,701
BCD	1,653	1,708	VC PD	-33,749	-33,686
BCP	1,664	1,718	VC	-33,723	-33,676
BC	1,668	1,715	VCP	-33,691	-33,637

^A Binary (B) model parameters: *C* control, *P* productivity, *D* diversity, *R* reciprocity

^B Valued (V) model parameters: *C* control, *P* productivity, *D* diversity, *R* reciprocity

parameters (Model BCPDR, AIC = 1,571; Model VCPDR = -33,879). In both binary and valued ERGMs, the models with the second lowest AIC contained only the main effects of diversity and reciprocity (Model BCDR, AIC = 1,573; Model VCDR, AIC = -33,883). The valued ERGMs, VIF remained below the threshold of 20.

One method that is used to assess the fit of an ERGM is to simulate a series of networks using that particular ERGM and compare the characteristics of the simulated networks to those in the observed network. We used our lowest AIC binary and valued ERGMs to simulate 600 networks (300 binary, 300 valued) for comparison. Using these simulated networks, we calculated hierarchy and connectedness for each. We define hierarchy and connectedness following the application of the organizational hierarchy model (Krackhardt 1994) to social network analysis (Wasserman and Faust 1994). *Hierarchy* is defined as the proportion of non-null *asymmetric* dyad; that is, the proportion of edges that are both unreciprocated and that fall on a one-way path through the network (see Figure S1). A hierarchy value of 1 indicates that every edge is asymmetric. *Connectedness* refers the portion of dyads i,j in which a directed edge is observed from i to j . In other words, in a completely connected network (connectedness = 1), the minimum number directed paths needed to connect all vertices are observed. In contrast, a network made up of several distinct and disconnected subnetworks or that contains many isolates will have a lower measure of connectedness.

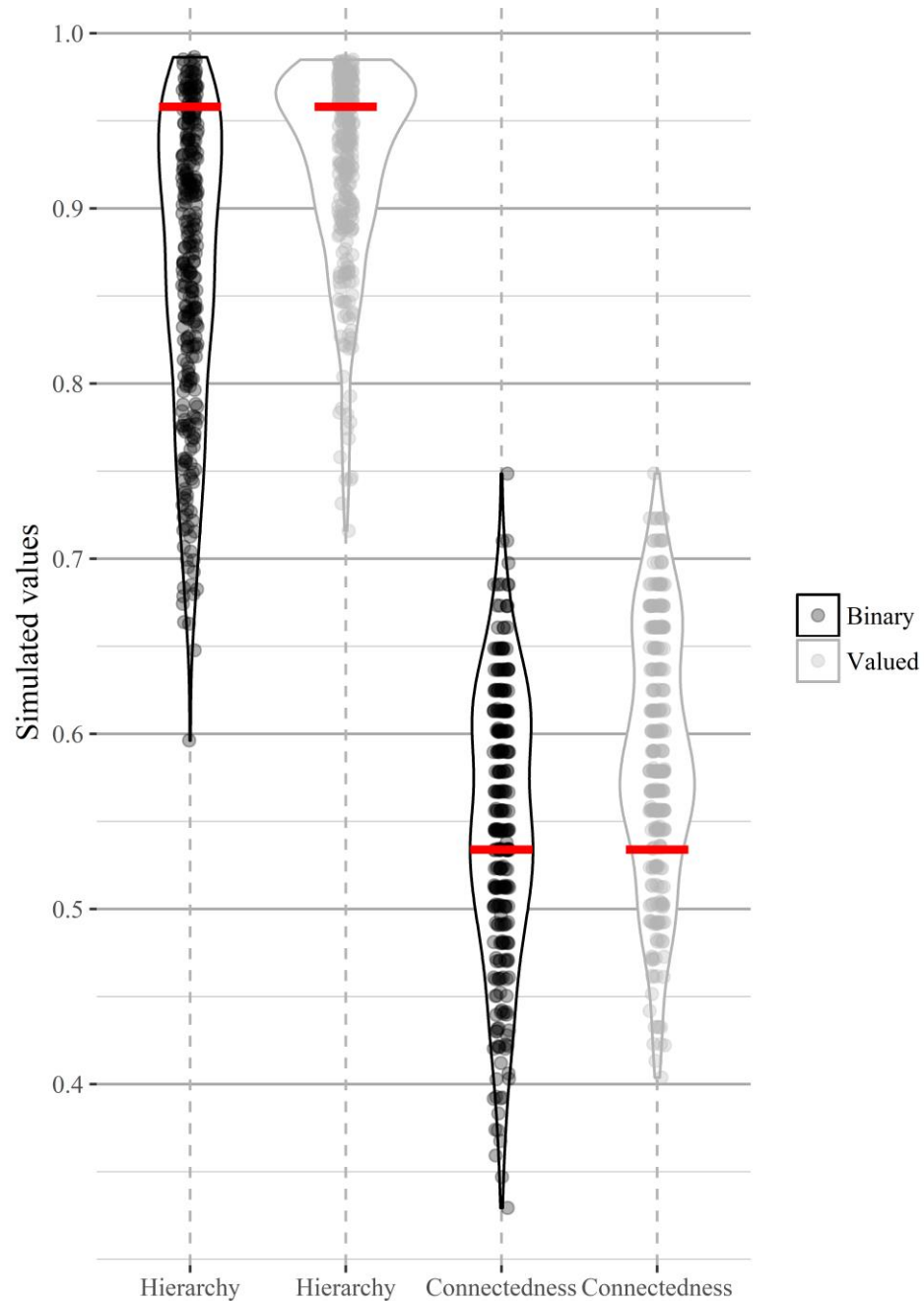


Figure 2-7. Violin plots demonstrating the range of hierarchy and connectedness values from 600 networks (300 binary, 300 valued) simulated using the binary and valued ERGMs with lowest AIC values (Model BCPDR and VCPDR, respectively). The border around the points (the “violin”) illustrates the density; the wider the violin, the more densely clustered are the points within it. The red lines denote the observed hierarchy (0.958) and connectedness (0.534) values from the Aniak food sharing network. The violin plot demonstrates that the valued ERGM provides a tighter range of predicted values. A small amount of jitter is added to better distinguish the points.

2.8 Discussion

2.8.1 *Limitations*

Before going on to discuss the ERGM models presented in the previous sections, we must make note of some analytical limitations. First, our models do not contain any measures of kinship or proximity between household. Elsewhere, kinship and distance have been found to have effects on the likelihood of sharing connections (Nolin 2010; Ziker and Schnegg 2005). The effect of kinship is especially crucial for distinguishing between adaptive hypotheses. However, our aim in this analysis is to clarify how ecological properties, like biodiversity, affect network structure. We do not attempt to make explicit claims about the inclusive fitness of this Alaskan network. Distance may have a neighbor-to-neighbor effect in these models. However, the context in Alaska differs in that residential mobility can be restricted and households are relatively collocated. A second limitation is that this analysis relies heavily on quantitative approaches and interpretation. Any evidence reported in this analysis should be interpreted modestly and used as a launching point for further inquiry. Given the lack of ethnographic data in this specific dataset, we have relied on a rich ethnographic record and lineage of research in Alaskan, the availability of which is due especially to the arduous work of the Division of Subsistence and ADFG.

2.8.2 *Productivity, diversity and reciprocity*

Recall that food sharing networks are informal distribution networks (Ziker 2007). One function of these networks is to make surplus resources available to other households. Networks of this kind are crucial to the food security of remote, subsistence-oriented populations (Baggio et al. 2016). One goal of this analysis was to test the assumption that highly productive households, who harvest a surplus of resources, take up central positions within these food sharing networks. We tested this assumption against a similar but slightly different one: households with highly diverse harvests take up central positions in food sharing networks.

Our results provide moderate support for the idea that harvest diversity may be a different but complementary way of characterizing the productivity of harvests in Alaska and other subsistence food systems. Our best fitting models were those that included productivity, diversity, and reciprocity (Model BCPDR and VCPDR). Though the effect size was modest, productivity and diversity still signaled an increased likelihood of out-degree edges in a sparse network. Food

sharing networks that document a more comprehensive set of network edges (e.g., species shared rather than resource “types”) may observe stronger effects of diversity on sharing behavior. Moreover, sharing networks that document resource flows in terms of the volume of each resource shared (i.e., pounds shared of resource x , pounds shared of resource y , *et cetera*) will likely have effect sizes that more accurately reflect the influence of “super-households” (for example, see BurnSilver et al. 2016).

One takeaway from this analysis that contrasts previous studies of productivity in subsistence networks was that productivity, overall, was not a better predictor of network edges than diversity. To be clear, the two measures are fundamentally linked – a harvest cannot be diverse without first being produced. However, a telling vignette related from this analysis is that the household with the greatest number of out-degree edges (22 edges) falls in the lowest tercile of harvest productivity.

As in other food sharing studies that employ SNA (Nolin 2010; Ready and Power 2018; Ready 2018; Ziker and Schnegg 2005; Ziker, Nolin, and Rasmussen 2016), this analysis found that reciprocity was a driver of the observed network pattern. Similar to Nolin (2010), we found that reciprocity had an extraordinarily large effect of on the odds of predicting edges. It is tempting to conclude that, like Ziker, Nolin, and Rasmussen (2016), reciprocity is most common among productive households. Taking limitations into account, we prefer a conservative interpretation in which households in Aniak that exhibit reciprocity are likely collaborators in subsistence activities. Even so, estimates of reciprocity increased when productivity and diversity were added to the models, suggesting that reciprocity is more frequent among harvesting households.

2.8.3 Binary and valued networks

We compared binary and valued ERGM networks in with the intention of understanding the effects of productivity, diversity, and reciprocity on network structure. The valued networks provide a unique analytical challenge as the methodology behind model fitting has lagged behind the innovation of modeling a weighted network. We do not provide such advancement here, rather, we provide a commentary on some model dynamics.

The underlying pattern in the binary ERGM was retained in the valued ERGM, however, the strength of effects were diminished in the valued ERGM. This is likely due to the preponderance of weights in the network that were equal to 1. In networks with values that exhibit

a geometric or binomial distribution (Pilny and Atouba 2018), a valued ERGM may pick up a qualitatively different pattern than a binary ERGM. Even so, networks simulated using the valued ERGMs predicted a smaller, and more densely clustered range of hierarchy and connectedness values than the binary ERGMs.

One issue that may arise in valued networks is multicollinearity. We recommend utilizing a method developed by Duxbury (2018) to screen for multicollinearity using an ERGM adapted VIF procedure. Multicollinearity is likely to arise in ERGMs seeking to disentangle multiple social processes that lead to qualitatively similar patterns (for example, see Nolin 2010). Other network approaches which may ameliorate this issue may shift from valued networks to multiplex or multilevel networks in which multiple edges in a dyad can be independently modeled (Baggio et al. 2016; Bodin and Tengö 2012). However, it remains the case that valued ERGMs are an active area of research that, as it develops, is likely to advance the capacity for many researchers to study complex networks without shifting toward multilevel network graphs.

2.9 Conclusion

Our analysis had two overarching goals. The first was to engage with a longstanding explanation for sharing behavior in Alaskan food sharing networks – that household that the most central household are those with the capacity to produce a surplus of subsistence resources that can then be shared. While we believe that productivity among super-households is crucial for the food security of many Alaskan households, we were motivated to assess the importance of harvest diversity. The basis for our expectation that diversity may predict sharing patterns is based on rich ethnographic research conducted by independent ethnographers (Fienup-Riordan 1986) and researchers affiliated with the Division of Subsistence, ADFG (Charnley 1984; Magdanz, Utermohle, and Wolfe 2002).

To test the hypothesis, we used an inferential network approach. We developed measures of diversity using biomass estimates of 68 distinct species and incorporated these into ERGMs as vertex attributes. Our best models were those that included household productivity, harvest diversity, and reciprocity.

Our second goal was to compare ERGMs in a novel empirical test of the differences between using binary and valued networks as a model outcome. Through our comparison, we found that valued ERGMs provided more modest effect sizes. When using these models to simulate artificial

networks to assess goodness of fit, we found that valued ERGMs provide tighter estimates of observed network measures like hierarchy and connectedness.

A modest conclusion to this analysis is that diversity and productivity are complementary perspectives for understanding subsistence dynamics in Alaska. We speculated that diversity will likely become more important as Alaska undergoes rapid climatic change. At the very least, our results reinforce ethnographic accounts that demonstrate the use diverse, seasonally abundant species. At most, they suggest that the pattern of sharing networks, which are the basis for how many human populations are organized, is empirically linked to the biodiversity of the broader landscape.

2.10 References

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3 SUBSISTENCE CONSTELLATIONS IN RESOURCE SPACE: LINKING HOUSEHOLD DIVERSITY TO VILLAGE LEVEL PATTERNS

3.1 Introduction

Characterizing the production and distribution of hunted and foraged resources in subsistence-oriented populations is a foundational topic of study among researchers working in the northern latitudes (Baggio et al. 2016; Collings 2011; Collings et al. 2016; Howe et al. 2016; Ready and Power 2018; Ziker and Schnegg 2005; Ziker 2006, 2012). The prevailing narratives in this body of work describe a variety of social-ecological systems through which flows of energy and nutrients, in the form of harvested species and material resources, are channeled from local ecosystems, concentrated and processed in the most productive households, and then generously shared through food sharing networks. For many village residents, access to subsistence foods depends on the specialization and productivity of a small number of strongly-interacting households who harvest and distribute more than 70 percent of the resources consumed by the village at large (BurnSilver et al. 2016; Natcher 2015; Wolfe 1987). Food sharing in this context may be a strategy to buffer against future risks (Kaplan et al. 2012), to garner political support and influence (Ready and Power 2018), or provision households that may be incapable of producing their own harvests (West and Ross 2012).

Though it is evident that the volume of resources harvested by a household (i.e., productivity) plays a role in the patterning food sharing networks (Baggio et al. 2016) and the way that a SES is structured (Janssen et al. 2006), it is also clear from ethnographic research that inhabitants of the arctic and subarctic make use of a striking diversity of resources (Charnley 1984; Fienup-Riordan 1986). One explanation for this variety is that by targeting a diverse profile of species, households may be buffered against the extreme seasonal and year-to-year fluctuations in species abundance that are characteristic of the northern latitudes (Fienup-Riordan 1986). Moreover, rapid climatic changes have led to frequent environmental perturbations for subsistence users that create challenging and uncertain conditions for maintaining a supply of harvested foods (Kofinas, III, et al. 2010; Moerlein and Carothers 2012). Decisions to pursue more diverse harvest

profiles, comprised of lower-ranked species, and alter patterns of resource sharing may be responses to these directional changes (Chapin III et al. 2006; Hansen et al. 2013).

An applicable framework for interpreting patterns of diversity and network structure in human-environment interactions is through the lens of complex systems theory (Lansing 2003). Proponents of the complex adaptive systems (CASs) approach have argued that having a diverse set of options, such as a variety of seasonally available species, affords a diversity of responses to environmental perturbations (Leslie and McCabe 2013). Aggregate trends from more specialized toward more generalized subsistence harvest profiles may be indicative of critical system transitions (Lansing et al. 2012). Rebounding from these “tipping points” without qualitatively changing the properties of CASs is a hallmark of system *resilience* – a system with the capacity to absorb and reorganize after experiencing an environmental disturbance (Folke 2006).

Networks of interactions, such as those that emerge through food sharing, are core features of CASs (Holland 1995). Networks that exhibit properties of hierarchy and reciprocity (Downey 2010) are argued to be more effectively connected than either highly dense or highly sparse networks, and are therefore expected to be a marker of resilience (Luthe, Wyss, and Schuckert 2012; Janssen et al. 2006). It is already clear that food security and access to subsistence in Alaskan villages depends on a diverse form of productivity that generates flows of resources (Magdanz, Utermohle, and Wolfe 2002; see also Chapter 2) through decentralized, but nonetheless hierarchical, food sharing networks (Baggio et al. 2016). A network pattern of this type is expected to be effectively connected, facilitating the flow of resources from household to household. Thus, the resilience of a subsistence food system may largely depend on network connectivity and resource diversity.

If diverse harvests *are* a strategy for coping with fluctuating conditions, then an in-depth exploration of harvest diversity and food sharing networks may uncover insightful details about the resilience of subsistence-oriented populations. In this article, we present an exploratory analysis of subsistence harvests and food sharing networks in 8 Alaskan villages. In it, we use indicator species analysis (ISA) and nonmetric multidimensional scaling (NMDS) to describe variation in household and village level diversity. Additionally, we conduct a social network analysis (SNA) to describe and quantify food sharing relationships in each village. We compare network and diversity properties in each of these villages. Thus, there are two overarching objectives of this analysis:

- 1) To describe variation in harvests at the household and village levels
- 2) To examine and compare patterns of food sharing

3.2 Methods

The data used in this analysis were collected by the Division of Subsistence, a state research agency that operates under the Alaska Department of Fish and Game (ADFG). The data were collected with the consent of 8 Alaskan villages residing on the central Kuskokwim River. The survey instrument contained modules that comprehensively documented resource harvesting and use⁴, clarified household compositions and village demographics, and characterized interhousehold food sharing and resource exchange. All data here were reported by one or more household heads on behalf of all permanent household residents (>3 months).

3.2.1 *The harvest matrix*

The primary object of study in this analysis is a *harvest matrix*. Using the comprehensive harvest assessment, a matrix of 360 households $\times$ 111 resources was constructed. Each row of the harvest matrix is a profile of every resource harvested by a household n , and each column, a profile of the quantities of a resource m that were harvested across all households. Each cell contains a biomass estimate of the total pounds (i.e., resource biomass).

The following adjustments were applied to the harvest matrix prior to analysis. Of the 360 households represented in this data collection, those that did not harvest anything were removed ($n = 34$) from the final harvest matrix in order to calculate pairwise dissimilarity. Likewise, resources that were not harvested by any households were omitted. One extreme outlier was also removed – a single household that harvested a Beluga whale (*Delphinapterus leucas*). This reduced the dimensions of the harvest matrix to 326 $\times$ 78. Because resource biomass ranged from 0 to 9,648 pounds, a monotonic log+1 transformation was applied to the matrix cells.

⁴ The survey included a comprehensive harvest assessment that attempted to document harvest and use of all available subsistence and commercial species. A table indicating harvest levels (in pounds) for all species in this analysis is provided in the Appendices.

3.2.2 Analytical procedures

We conducted this analysis using PC-ORD (McCune and Mefford 2016), a statistical software developed for studying community ecological data. The software offers a myriad of multivariate statistical and ordination techniques including NMDS, cluster analysis, ISA, and habitat modeling, among others. All other data screening and preparation was carried out in R (R Core Team 2017). The construction of network graphs and the calculation of network metrics was done using the R *igraph* (Csardi and Nepusz 2006) and *statnet* (Handcock et al. 2016) suite of packages.

3.2.2.1 Nonmetric multidimensional scaling

NMDS is a method of ordination in which a set of sampled units are ranked based on their dissimilarity and placed into an ordered sequence (Rencher and Christensen 2012). To determine this sequence, a distance measure is calculated between each pair of sample units on every dimensions in the data matrix. Each variable on which the sample is measured is a *dimension* within which the units can be compared, and their distances computed. The Euclidean distance between pairs of samples that are measured on two variables, for example, is simple to ascertain and can be visualized in a graphical space as a scatter of coordinate points with the *x* and *y* axes of the coordinate space representing the two respective variables. Points that cluster near one another are interpreted as more similar.

In more complex datasets, a myriad of relevant variables may be measured, each with a corresponding dimension. Beyond 3 or 4 dimensions, understanding and interpreting meaningful patterns of variation becomes substantially more difficult, even intractable without some form of strategic data reduction (McCune and Grace 2002). To this end, a goal of NMDS is to seek a low-resolution representation of the overall variation by calculating the distance between each pair with respect to every dimension (Rencher and Christensen 2012). The result is a low-dimensional solution with a small number of axes that best preserve the rank order of the distance between sample units.

NMDS is an appropriate method for distilling complex patterns of variation into a form that is suitable for descriptive analysis. In community ecology, for example, each sample unit may represent an individual forest plot, alpine lake, or intertidal zone and containing values that indicate the abundance of species or genera observed in the plots (McCune and Grace 2002). In this way,

NMDS can be used to identify clusters of biodiversity and “hotspots” of co-occurring species (Neitlich and Mccune 1997). What is more, NMDS integrate attributes about each sample unit that can be used to characterize environmental gradients (Talbot et al. 2010). NMDS has already been used to compare village level hunting and fish profiles across Alaska (Renner and Huntington 2014), demonstrating the applicability of this approach to subsistence research. The sample units in this analysis correspond to the 326 households, and each dimension (i.e., variable) is a resource harvested in one of the study villages. The positioning occurs in “resource space” since the dissimilarity among households is determined by a Sørensen⁵ distance measure applied to the resource harvests. Information about each household is used to identify households that harvest similar resources.

3.2.2.2 *Indicator species analysis*

To assess harvest diversity at the village level, we apply ISA to the harvest matrix. ISA is useful procedure for identifying the species that exclusive to a set of *a priori* groups of sample units (McCune and Grace 2002, 198–99). The *a priori* groupings for this analysis are the villages of Aniak, Chuathbaluk, Crooked Creek, Sleetmute, Red Devil, Upper Kalskag, Lower Kalskag, and Stony River. Following from McCune and Grace, ISA first computes the relative abundance of each species and then proportional frequency of that species’ abundance in each grouping. These measures are combined and multiplied by 100 for rescaling. The final interpreted as an *indicator value*. To test whether indicator values could occur by chance, the ISA concludes with a Monte Carlo test, a procedure that randomly assigns the sample units to new groups to assess whether the value has statistical significance.

Combining *frequency* and *abundance* is the principle advantage of ISA. Though it is unlikely, a group containing a resource with an indicator value of 100 would mean that it heavily abundant and exclusively found in that group. McCune and Grace (2002, 199) note that “[because] the component terms are multiplied, both indicator criteria must be high for the overall indicator value to be high. Conversely if either term is low, then the species is considered a poor indicator.”

⁵ Sørensen distance is a proportional “nonmetric” measure of dissimilarity that contrasts with “metric” distances like correlations or Euclidean distances. It is chosen here because it represents the shared species abundance between two households relative to the maximum abundance in the sample. This makes distances between households in resource space meaningful shifts toward or away from the maximum. For a thorough discussion of distance measures in ecology see McCune and Grace (2002, 45–51).

3.2.2.3 Social network analysis

Respondents in the survey were asked to identify the households that harvested the food that their household consumed. If a connection was reported, the respondent was asked to clarify which types of resources the household shared⁶. We used the responses to this portion of the survey to construct 8 directed networks for each Alaskan village. Each “edge” in the network represents a directed flow of resources in a household dyad. Edge arrows flow from the source household to the recipient household. Thicker edges represent more heavily weighted exchanges of multiple resource types.

From these networks, we calculated network summary statistics at the village level and centrality measures at the household level. We calculated *in-degree* and *out-degree centrality* for each household (i.e., the sum of incoming and outgoing edges, respectively) to assess household connectivity and positioning in the network. At the village level, we calculate *network density*, the proportion of observed edges out of the maximum possible; *reciprocity*, the portion of reciprocated edge out of the total observed; and *hierarchy*, a measure of how asymmetric the flow of resources is in the network. High values of this measure indicate greater asymmetry. For clarity, reciprocity and hierarchy are contrasting measures. Since hierarchy is calculated based on one-way connections, greater levels of reciprocity necessarily reduce hierarchy, and *vice versa*. For a thorough description of these dynamics in terms of resilience, see Downey (2010).

3.2.2.4 Diversity measures

We calculated three measures of *alpha* diversity on the harvest matrix. For comparison with network measures at the village level, we take the average of these two diversity measures. The first is *species richness* (S); a count of the unique species represented in a harvest profile, regardless of their abundance. Richness is an intuitive measure that is commonly used in community ecology (McCune and Grace 2002). The second measure is the *Shannon-Wiener Index* (H'); a measure of uncertainty or entropy (Jost 2006) that is calculated following McCune and Grace (2002):

$$H' = - \sum_{i=1}^S p_i \ln p_i \quad (1)$$

⁶ Resource categories: *salmon, whitefish, trout, non-salmon fish, moose, caribou, marine mammals, grouse, ducks, other birds, barriers, and wood.*

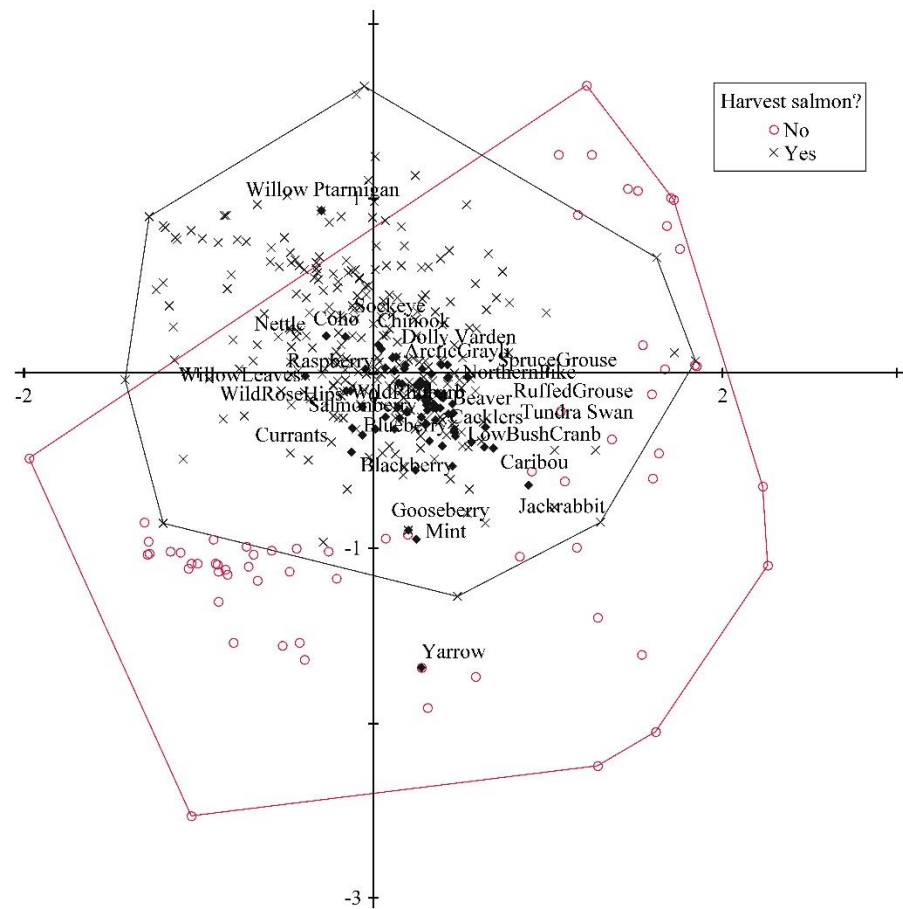


Figure 3-1. The 2-dimensional solution for the nonmetric multidimensional scaling procedure (nonmetric $R^2 = 0.964$, final stress = 18.898). Each symbol is a household from one of the 8 study villages. The weighted mean harvest level of each species is indicated with a black point. Selected labels are provided that have been adjusted slightly to improve legibility. Household clustering near a resource point suggests a greater than average harvest of that resource, but not necessarily a harvest that is dominated by that resource.

where S is species richness and p_i is the proportion of species i in the harvest profile. A household that harvests a single species has a Shannon-Wiener Index of 1. As additional species are added the harvest profile, H' increases, indicating less certainty about a randomly chosen species from the harvest.

3.3 Results

3.3.1 Ordination axes

The NMDS procedure resulted in a 2-dimensional solution which characterizes the variation in the harvest matrix across all 8 villages. For clarity, the NMDS scatterplot (Figure 3.1) visualizes the

Table 3-1. The 10 most positive resource relationships with each axis.

NMDS 1				NMDS 2			
Resource	Scientific Name	Pearson's r	Kendall's τ	Resource	Scientific Name	r	τ
Moose	<i>Alces alces</i>	0.383	0.382	Coho Salmon	<i>Oncorhynchus kisutch</i>	0.344	0.165
Spruce Grouse	<i>Falci pennis canadensis</i>	0.365	0.343	Chinook Salmon	<i>Oncorhynchus tshawytscha</i>	0.251	0.003
Canada Goose	<i>Branta canadensis</i>	0.249	0.282	Sockeye Salmon	<i>Oncorhynchus nerka</i>	0.220	0.089
Mallard Duck	<i>Anas platyrhynchos</i>	0.234	0.254	Willow Ptarmigan	<i>Lagopus lagopus</i>	0.075	0.071
Northern Pike	<i>Esox lucius</i>	0.229	0.285	Spruce Grouse	<i>Falci pennis canadensis</i>	0.045	0.000
Ruffed Grouse	<i>Bonasa umbellus</i>	0.223	0.217	Dolly Varden	<i>Salvelinus malma</i>	0.045	0.036
Willow Ptarmigan	<i>Lagopus lagopus</i>	0.210	0.213	Arctic Grayling	<i>Thymallus arcticus</i>	0.032	0.001
Broad Whitefish	<i>Coregonus nasus</i>	0.207	0.251	Nettle	<i>Urtica dioica</i>	0.028	0.019
Beaver	<i>Castor canadensis</i>	0.206	0.249	Sheefish	<i>Stenodus nelma</i>	0.026	-0.046
Cackling Goose	<i>Branta hutchinsii</i>	0.205	0.233	Pink Salmon	<i>Oncorhynchus gorbuscha</i>	0.009	-0.005

clustering of households in resource space. In other words, the position of each household in the scatterplot depends on the resources they reported harvesting and the similarity of those resources to those reportedly harvested by the other households per the harvest matrix. A household's position along each axis reflects the strength of that household's affinity for the resources which are associated with each axis. The black points in Figure 3.1 correspond to the resources in the harvest matrix and the position of these points indicates the average level of harvest. Table 3-1 and Table 2-2 summarize the 10 resources with strongest positive and negative relationships to each axis (x -axis = NMDS 1, y -axis = NMDS 2).

3.3.1.1 The first dimension

NMDS 1 is most strongly associated with migratory waterfowl like Canadian geese (*Branta canadensis*), cackling geese (*Branta hutchinsii*), and mallard ducks (*Anas platyrhynchos*), as well as non-migratory bird species like willow ptarmigan (*Lagopus lagopus*), ruffed grouse (*Bonasa umbellus*), and spruce grouse (*Falci pennis canadensis*). Intuitively, households who cluster further

Table 3-2. The 10 most negative resource relationships with each axis.

NMDS 1				NMDS 2			
Resource	Scientific Name	Pearson's <i>r</i>	Kendall's τ	Resource	Scientific Name	<i>r</i>	τ
Willow Ptarmigan	<i>Lagopus lagopus</i>	-0.023	-0.029	Tundra Swan	<i>Cygnus columbianus</i>	-0.122	-0.158
Currant	<i>Ribes</i> spp.	-0.027	0.007	High Bush Cranberry	<i>Viburnum</i> spp.	-0.131	-0.152
Willow Leaf	<i>Salix</i> spp.	-0.03	-0.035	Beaver	<i>Castor canadensis</i>	-0.132	-0.174
Nettle	<i>Urtica dioica</i>	-0.033	-0.049	Yarrow	<i>Achillea millefolium</i>	-0.137	-0.076
High Bush Cranberry	<i>Viburnum</i> spp.	-0.039	-0.005	Canada Goose	<i>Branta canadensis</i>	-0.145	-0.187
Wild Rose Hip	<i>Rosa</i> spp.	-0.056	-0.018	Wild Rhubarb	<i>Arctium minus</i>	-0.151	-0.193
Blackberry	<i>Rubus</i> spp.	-0.061	-0.018	Salmonberry	<i>Rubus spectabilis</i>	-0.232	-0.286
Raspberry	<i>Rubus idaeus</i>	-0.065	-0.056	Low Bush Cranberry	<i>Vaccinium oxycoccos</i>	-0.245	-0.257
Blueberry	<i>Vaccinium ovalifolium</i>	-0.159	-0.078	Blackberry	<i>Rubus</i> spp.	-0.382	-0.401
Coho Salmon	<i>Oncorhynchus kisutch</i>	-0.249	-0.098	Blueberry	<i>Vaccinium ovalifolium</i>	-0.436	-0.447

to the right on NMDS 1 are associated with more participation in aviation harvesting activities. NMDS 1 is especially associated with moose, suggesting it is harvested more exclusively.

Negative relationships with NMDS 1 (Table 3-2) were predominately berries and vegetation, especially alpine blueberry (*Vaccinium ovalifolium*). However, 8 of the 10 strongest negative relationships have correlations between 0 and -0.1. The strongest negative relationship with NMDS 1 is coho salmon (*Oncorhynchus kisutch*).

3.3.1.2 The second dimension

The resources with the strongest positive correlations to NMDS 2 (Table 3-1) were coho, chinook (*Oncorhynchus tshawytscha*), and sockeye salmon (*Oncorhynchus nerka*). All other species exhibited correlations between 0 and 0.1, although two of these were anadromous pink salmon (*Oncorhynchus gorbuscha*) and semi-anadromous Dolly Varden trout (*Salvelinus malma*). The strongest negative associations with NMDS 2 (Table 3-2) are species of gather berries and vegetation including alpine blueberry, blackberry (*Rubus* spp.), low bush cranberry (*Vaccinium*

oxycoccus), salmonberry (*Rubus spectabilis*), wild rhubarb (*Arctium minus*), and yarrow (*Achillea millefolium*).

3.3.1.3 Contour plots

Identifying the resources that are associated with NMDS axes 1 and 2 aids in characterizing the variation in resource harvests by household. Another consideration, however, is the household variables that are associated with these axes. We used contour plots as a method of mapping household variables onto the position of the points in NMDS resource space. The contour plot is interpreted in the same manner as a topographic map (or if you prefer, a 3-dimensional density plot) in which each contour line corresponds to a value (the “elevation”) for the variable being mapped. The “peaks” of the map, shown in the warmest colors, indicate the areas of the ordination which have the highest concentration of large values; the “valleys” indicate areas of low values. To move beyond visual inspection, a cross-validated R^2 can be calculated to determine how much variation in the ordination positions is associated with the variable under inspection. According to McCune and Mefford (2016), it is useful to think of each household point in the space as a known point on a map from which the elevation of a particular variable is interpolated.

We focused on four household variables: 1) *diversity* – the Shannon-Wiener index of a household’s harvest; 2) *productivity* – a natural log+1 transformation of a household’s total harvest weight; 3) *in-degree* – the total number of in-coming connections (i.e., food received); and 4) *out-degree* – the total number of number of out-going connections (i.e., food shared). Figure 3.2A demonstrates the distribution of diversity indices across the households as having a gradual slope, eventually reaching a flattened peak in the negative region of NMDS 2. Notably, this a region characterized primarily by berry and vegetation harvests, in contrast to the positive NMDS 2 relationships associated with salmonids. The contour plot for productivity suggests that harvest weight has a *non-linear* distribution (Figure 3.2B). As with diversity, productivity values gradually increase (e.g., light green) but a bimodal split occurs that suggests two peaks. The peak in the upper-right quadrant corresponds to those households that harvested moose and salmonids whereas the peak in the lower right quadrant corresponds households that have the most diverse households. Figure 3.2C and Figure 2D demonstrate the distribution of in-degree and out-degree degree centrality, respectively. In-degree peaks in the region of the scatterplot that is associated with

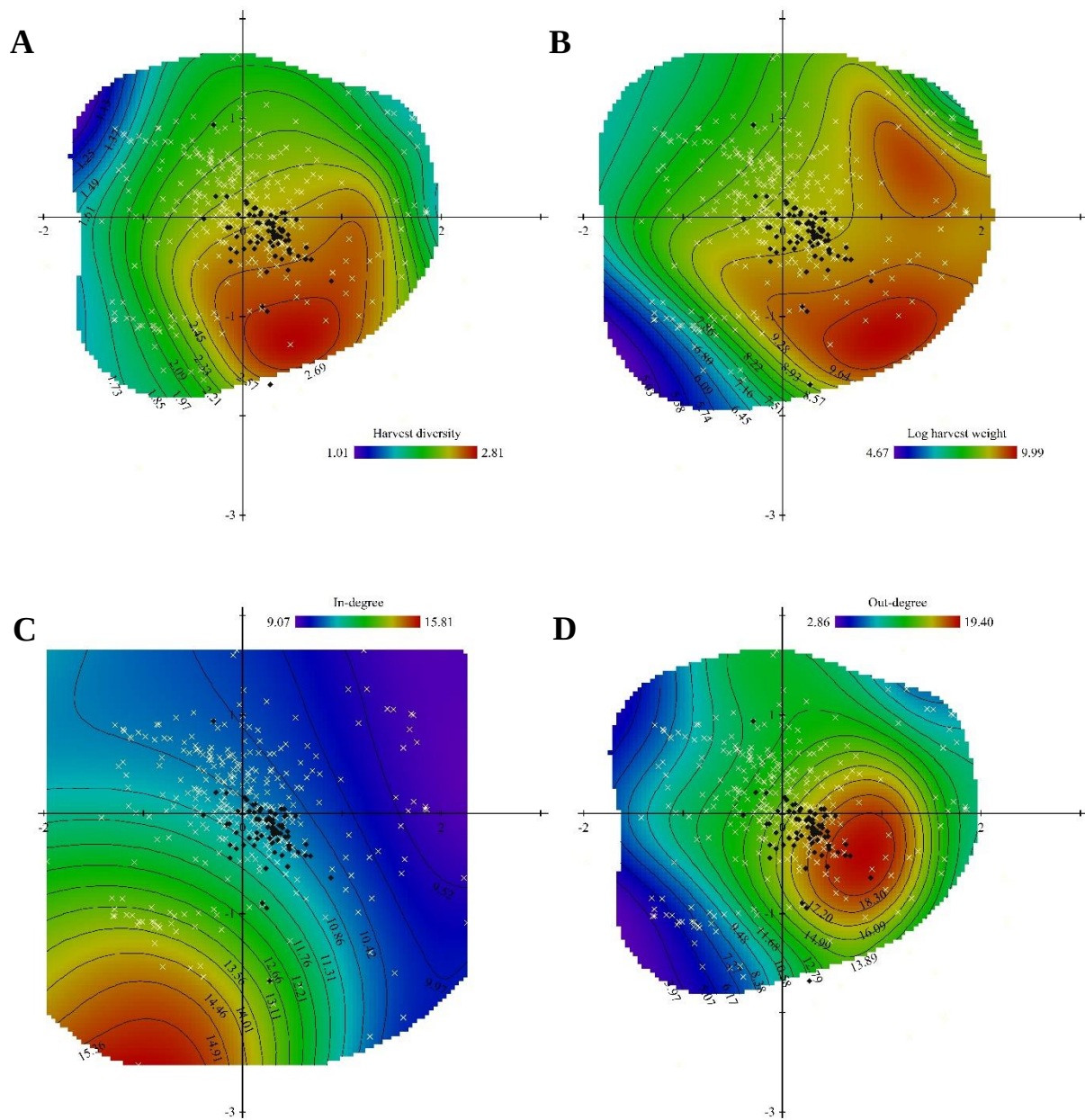


Figure 3-2. Contour plots described in text. Warm colors indicate peak values of the mapped variable. A) Diversity contour plot: cross-validated $R^2 = 0.530$. B) Productivity contour plot: cross-validated $R^2 = 0.732$. C) In-degree contour plot: cross-validated $R^2 = 0.004$. D) Out-degree contour plot: cross-validated $R^2 = 0.087$.

higher than average berry harvest, despite these being a resource harvested by most household. This region is distinguished from other households in the resource space that harvested salmon and moose. As a result, these household have some of the lowest harvest weights, as indicated by Figure 2B. Out-degree peaks in the regions that are indicative of diverse, high volume harvests.

3.3.2 Indicator species

The appeal of the NMDS is that it provides a comparative glance at how households align across multiple villages. To visualize multiple groups, aesthetic decisions can be made to distinguish among them, but this approach lends itself only to qualitative inspection. ISA provides us a rigorous and quantitative distinction among *a priori* selected groups, in this case, the 8 Alaskan villages.

Indicator values for species in the harvest matrix ranged from 0 to 35. To summarize the ISA, Table 3-3 contains all the indicator values >10 ($n = 23$). The village associated with the indicator species is reported in addition to the indicator value, the mean indicator value across all villages, and the p -value is calculated based on the Monte Carlo randomization test. By comparing the mean indicator value with the indicator value for the focal village, we get a sense of the effect size. For instance, arctic grayling (*Thymallus arcticus*), a stocked freshwater salmonid, has an indicator value of 35 in Red Devil but the average across all villages is 7 ($p < 0.001$). This suggests that arctic grayling is much more commonly harvested in Red Devil, a village located near the confluence of the Kuskokwim and Holitna Rivers. In contrast, an indicator value of 12 was calculated for chinook in Upper Kalskag compared to a mean value of 8 across all villages. Chinook is the most common salmon species harvested in this region (Caroline L. Brown et al. 2012), so it is unsurprising that the difference between Kalskag and the mean indicator value here is small and statistically insignificant ($p = 0.457$).

3.3.3 Social networks and diversity

Table 3-4 reports measures of density, hierarchy, and reciprocity calculated from the food sharing networks collected in each village. Table 3-4 also reports averages of three measures of diversity calculated on the harvest matrix. Note that each measurement is a stand-alone summary for that village and the aim of these summary statistics is mainly descriptive. A result worth noting is that the villages with the lowest average diversity (Aniak) and highest average diversity (Upper Kalskag) were associated with the highest levels of hierarchy. The smallest villages (Red Devil, Sleetmute) had the highest levels of reciprocity. However, this result is likely an artifact of calculating reciprocity on a small network. For example, 20% of the edges in Red Devil were reciprocated, though only 15 total edges were reported. The same level of reciprocity in Aniak

Table 3-3. Indicator species by village

Village	Indicator Species	Scientific Name	Indicator Value (IV)	Mean IV	P*
Aniak	Coho Salmon	<i>Oncorhynchus kisutch</i>	13	7	0.229
Crooked Creek	Wild Rhubarb	<i>Arctium minus</i>	11	5	0.169
Lower Kalskag	Black Scoter	<i>Melanitta perspicillata</i>	13	3	0.037
Lower Kalskag	Cacklers	<i>Branta hutchinsii</i>	11	3	0.088
Lower Kalskag	Canada Goose	<i>Branta canadensis</i>	12	4	0.081
Lower Kalskag	Tunda Swan	<i>Cygnus columbianus</i>	12	2	0.038
Red Devil	Arctic Grayling	<i>Thymallus arcticus</i>	35	7	<0.001
Red Devil	Dolly Varden	<i>Salvenius malma</i>	19	4	0.005
Red Devil	Round Whitefish	<i>Coregonus nasus</i>	27	3	<0.001
Red Devil	Spruce Grouse	<i>Falcapennis canadensis</i>	20	7	0.009
Sleetmute	Low Bush Cranberry	<i>Vaccinium</i> spp.	12	4	0.077
Sleetmute	Sheefish	<i>Stenodus leucichthys</i>	12	6	0.157
Sleetmute	Sockeye Salmon	<i>Oncorhynchus nerka</i>	15	7	0.085
Stony River	High Bush Cranberry	<i>Viburnum</i> spp.	20	4	0.008
Stony River	Pink Salmon	<i>Oncorhynchus gorbuscha</i>	13	3	0.024
Stony River	Ruffed Grouse	<i>Bonasa umbellus</i>	11	4	0.068
Stony River	Wild Rose Hips	<i>Rosa</i> spp.	22	3	0.004
Upper Kalskag	Alpine Blueberry	<i>Vaccinium ovalifolium</i>	18	8	0.018
Upper Kalskag	Blackberry	<i>Rubus</i> spp.	13	6	0.115
Upper Kalskag	Chinook Salmon	<i>Oncorhynchus tshawytscha</i>	12	8	0.457
Upper Kalskag	Humpback Whitefish	<i>Coregonus pidschian</i>	11	5	0.126
Upper Kalskag	Salmonberry	<i>Rubus spectabilis</i>	11	6	0.218

* P-value is based on a Monte Carlo randomization test with 4999 iterations.

would require 28 of the of the 149 reported edges to be reciprocated. This example highlights the sensitivity of small networks to the loss/formation of edges, echoing conclusions from other networks studies that emphasize the preservation of social networks in vulnerable villages (Baggio et al. 2016; Natcher 2015).

3.4 Discussion

3.4.1 Limitations

Before engaging in a discussion of the patterns observed in this analysis, some analytical limitations must be clarified. The clearest limitation is that these data were collected using memory recall and as such, any evidence pertaining to the networks or the harvest matrix should be treated modestly. Given the constraints of human memory, it is likely that the edges in the social networks

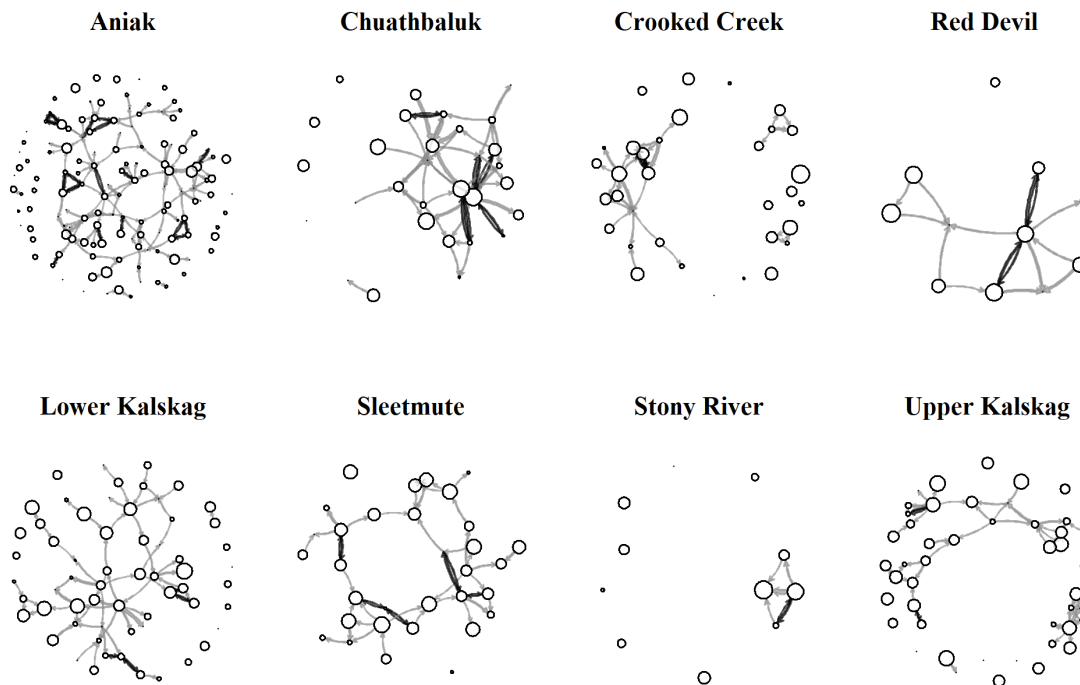


Figure 3-3. Food sharing networks from 8 Alaskan villages. The diameter of each vertex is scaled according to the household's harvest diversity. Black edges are instances of reciprocity. Thicker edges indicate that multiple types of resources flowing between two households.

represent the most important or common sharing partners (Bernard 2011). Food sharing networks that were documented ethnographically exhibit less sparsity than the networks reported in this analysis (see Nolin 2010; Ready 2018; Ready and Power 2018).

A second limitation of this analysis is that it uses standard conversions to estimate the biomass of each harvest (see Appendix C in Caroline L. Brown et al. 2012). While this is convenient for quantitative survey administration, it may miss key differences in morphology between individuals. These qualitative differences may prove insignificant for the statistical power of these analytical procedures. Nevertheless, as ecological and extractive conditions change, we should expect changes in species quality that are not addressed with conversions. This suggests a need for more ethnographic study, in which researchers and subsistence users cooperate and participate in the process of documenting harvests. Though these approaches are hallmarks of anthropology and of research carried out by the Division of Subsistence, ADFG (Charnley 1984; Hutchinson-scarbrough, Marchioni, and Lemons 2016), they are proving even more useful as subsistence-oriented groups grapple with climate change (Fienup-Riordan, Brown, and Braem 2013; Moerlein and Carothers 2012).

Table 3-4. Village level network and diversity measures.

Village	Diversity		Networks		Density	Reciprocity	Hierarchy
	Mean S	Mean H'	Vertices	Edges			
Aniak	7.0	1.477	134	149	0.008	0.013	0.958
Chuathbaluk	9.6	1.766	30	46	0.053	0.083	0.771
Crooked Creek	9.1	1.803	33	33	0.031	0.051	0.860
Lower Kalskag	10.8	1.903	61	64	0.017	0.031	0.938
Red Devil	10.4	2.001	11	15	0.136	0.200	0.889
Sleetmute	9.9	1.934	32	45	0.045	0.067	0.944
Stony River	10.4	1.994	11	6	0.055	0.073	0.833
Upper Kalskag	12.0	2.118	48	45	0.020	0.036	0.967

3.4.2 Household patterns

3.4.2.1 Moose

There are two likely reasons for distinct moose harvesting households in this analysis. The first is that moose harvests are costly, often requiring expenses paid for munitions, as well as snow machine fuel and maintenance (Ebbin 2002). The second is that prior to this data collection, declining moose populations and moose harvest levels (Krauthoefer, Brown, and Koster 2015) prompted hunting restrictions in Stony River, Red Devil, and Sleetmute (Caroline L. Brown et al. 2012). Intermittent moose hunting prohibitions over the last 20 years, thought largely for conservation purposes (Casey L. Brown et al. 2015), have created considerable conflict intervillage conflicts (Ebbin 2002, 2004).

Households that were unable to harvest moose may have exhibited what subsistence researchers have described as “prey switching” (Hansen et al. 2013), a strategy that in some cases may diversify a harvest profile, thought to determine this conclusively is beyond the scope of this analysis. A resilient scenario may involve increased sharing activity, especially when flows containing species whose abundance has declined are shared. Elsewhere, the absence of caribou has been associated with idiosyncratic shares of hunted meat between villages on the Alaskan peninsula, including an entire caribou (personal-communication). When asked why households shared food, West and Ross (2012) found that respondents highlighted the need to provision needy households during lean, winter months.

Diversification may not end on the landscape. Researchers note that in the absence of ungulate protein, households report more frequent purchases of meat, especially beef, from local sellers (Caroline L. Brown et al. 2012). It would be unwise to jump to assume that replacing hunted meat with store bought foodstuffs is a strategy to “diversify” one’s diet, nor should it even be considered a replacement. The costs of shipping meat to local vendors are massive and these high freight costs are passed on to local households. What’s more, purchasing costly meats reduces the amount of cash available needed to supplement subsistence activities (BurnSilver et al. 2016), effectively homogenizing diets, rather than diversifying or supporting them. The literature is wrought with studies condemning market based diets as an alternative to subsistence diets (Ballew et al. 2006; Fall et al. 2013; Loring and Gerlach 2009; Lynn et al. 2013).

3.4.2.2 Migratory and resident birds

One driver of the NMDS pattern observed in this analysis is whether the household targets migratory or resident birds. A clear phenological reason for this is that the migration of brants, ducks, and cygnets coincides with peak fishing months (Charnley 1984). Household members that are employed in commercial fishing during the summer months may face a trade-off (Caroline L. Brown et al. 2012). Nevertheless, migratory bird hunting has been a prominent feature of Yup’ik and Iñupiaq Eskimo subsistence that is embodied in artistic and expressive culture (Ikuta 2011). Year-round resident birds like grouse and ptarmigan are more likely to be taken during the late autumn and winter months as hunters shift their efforts towards moose, caribou, and trapping (Charnley 1983), especially as migratory species leave coastal floodplains (Charnley 1984).

3.4.2.3 Networks and diversity

The contour plots indicate that sharing activity was concentrated in the portion of resource space occupied by households with the most productive harvests. This result echoes the primary narrative in arctic and subarctic research in which sharing activity hinges on the harvesting activities of a small subset of households (Wolfe and Magdanz 1993; Magdanz, Utermohle, and Wolfe 2002). However, the pattern of sharing connections (i.e., out-degree) was especially concentrated in that regions where harvests were both productive and diverse. This finding suggests that the connectivity of food sharing networks is related to harvest diversity at the household level. At

most, such a result suggests profound connections between social organization and landscape level biodiversity. At the very least, it indicates a need to support household participation in seasonal rounds (Charnley 1984) which are thought to structure the harvest of species whose abundance fluctuates seasonally and from year-to-year (Fienup-Riordan 1986).

One level of support for harvest diversity may be resource management strategies that facilitate flexibility in time and space (Luthe, Wyss, and Schuckert 2012; Ford, Smit, and Wandel 2006). To be even more explicit, resource use restrictions that are rigidly tethered to broad time scale or spatial extents will thwart the flexibility needed to obtain diverse harvests. For instance, top-down management decisions, such as those handed down by the Boards of Fish and Game, occur at a scale that is insensitive to local fluctuations and resource assemblages (Loring 2013). In contrast, collaborative management and governance that is organized around the connections between landscape diversity and existing social networks (Kininmonth, Bergsten, and Bodin 2015; Salpeteur et al. 2017) and that incorporates local ecological knowledge which is sensitive to fluctuations (Alessa et al. 2015; Olsson, Folke, and Berkes 2004; Aswani and Lauer 2013) is more a resilient scenario for a changing arctic and subarctic.

3.4.3 Village patterns

3.4.3.1 Indicator species

Statistically significant indicator species were concentrated in Lower Kalskag, Stony River, and Red Devil. Lower Kalskag, one of the villages located closer to coastal floodplains, was associated with two migratory bird species that are accessible in this region: black scoter (*Melanitta perspicillata*, $p = 0.037$) and tundra swan (*Cygnus columbianus*, $p = 0.038$). The other two species associated with Lower Kalskag were also migratory birds – Canadian (*Branta canadensis*) and cackling geese (*Branta hutchinsii*) – though both were marginally significant ($p = 0.088$, $p = 0.081$, respectively).

Located further north near the confluence of the Kuskokwim and Holitna Rivers, the villages of Red Devil and Stony River were associated with riverine salmonids like Dolly Varden (*Salvelinus malma*, $p = 0.005$), arctic grayling (*Thymallus arcticus*, $p < 0.001$), and less preferred salmon species like pink salmon (*Onchorhynchus gorbuscha*, $p = 0.024$). Stony River was also

associated with high bush cranberry (*Viburnum* spp., $p = 0.008$) and wild rose hips (*Rosa* spp., $p = 0.004$).

3.4.3.2 Village networks

In general, the measures calculated on village sharing networks exhibited edge density dependent patterns (Wasserman and Faust 1994). Small villages appear to have more dense networks, more reciprocity, and less hierarchy. This description is fitting for a village Red Devil in which there is a single isolate. However, this result was more likely an artifact of small network size. Large networks, like Aniak and the Kalskags, were described as low in density and reciprocity, and greater in hierarchy. However, Aniak serves as the local hub for supplies and tourism (Caroline L. Brown et al. 2012) and all three villages are the closest to the region hub, Bethel. Thus, it is tempting to conclude that market influence drives these patterns since market integration can be associated with less participation in subsistence activities and the dissolution of informal social networks associated with subsistence (Gurven et al. 2015; Moerlein and Carothers 2012).

3.5 Conclusion

In this analysis, our aim was to describe patterns of resource use at household and village levels in 8 Alaskan villages. Using methods from community ecology, we found that variation in household harvests varied in the extent that they harvested commercially favored species of salmonids and ungulates. Households that harvest large volumes were likely to have harvested moose, but among the most productive harvests were households that target a diverse array of migratory and resident birds, anadromous and riverine fish, and species of berries and vegetation. These diverse harvest households were also the loci of much food sharing activity. At the village level, small villages that are located further from coastal floodplains stood out with respect to their harvests of riverine fish species. In contrast, villages near the coast showed a preponderance of migratory birds in their harvests. Broadly speaking, small villages were more connected, a pattern driven primarily by village size. Overall, our results paint a picture of diverse resource uses in Aniak. However, even within this small, regional dataset, there were clear distinctions drawn based on ecoregion and resource accessibility. In other words, resource use in context is important not just as a substantive or ethnographic question, but as an analytical one that requires rich, multivariate datasets and comprehensive harvest assessments.

3.6 References

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4 CONCLUDING REMARKS

4.1 Limitations

One of the most fruitful endeavors of any research projects is to reflect on the limitations that emerged as the project proceeded. At the very least, addressing limitations does the following: 1) empirically grounds the interpretation of results, and 2) takes the first steps toward designing additional research projects. As this is primarily an analytical thesis, I will focus on empirical and conceptual limitations.

4.1.1 *Empirical limitations*

The goal of my analyses was to examine harvest diversity at the household and village levels, and test whether the diversity of a household's harvest is associated with their position in a network. I am fortunate to have had a comprehensive harvest dataset at my disposal for both of these endeavors. However, there are important improvements to this dataset that would bolster my analysis.

First, the estimates of species abundance in the harvest matrix (Chapter 3, Section 3.2.1) are based on standard conversions carried out in the following way. Researchers ask participants to indicate how many individuals were harvested for a given species. This produces a count for each species documented in a harvest assessment (e.g., 1 moose, 20 sockeye salmon, 10 grouse, *et cetera*). The count is then multiplied by the expected weight of a typical specimen, resulting in an estimate of biomass. This is a convenient and validated approach, but there are reasons, beyond a desire for precision, to believe that actually weighing each specimen would influence results. In particular, changing ecological conditions are likely to alter the morphology and condition of each individual in a harvest. One example of this that I will mention briefly is related to fisheries-induced-evolution (Kuparinen and Merilä 2007).

Commercial fishing employs a variety of netting techniques with the goal of catching the largest fish possible, so as to obtain the greatest yield for their fishing quota. As fishing has reached industrial scales, this practice puts immense selection pressure on large fish, and those fish that are small enough to escape nets are more likely to continue on to spawn and reproduce. Since these spawning fish are the likely the catch of subsistence users operating upriver and closer to coastlines, it is likely that they must catch more fish of a smaller size to fill their harvest (personal-

communication 2017). Thus, standard conversions are likely to overestimate harvest sizes and miss importance biological trends.

Second, the network collected in these villages relies on data collected using memory recall, which is subject to error (Nolin 2010; Bernard 2011). While it is likely that these connections identified by study participants were not entirely false, this method likely underestimates the number of sharing connections present in a community. Thus, these networks should be interpreted as the most common or significant sharing partnerships.

Third, these networks were analyzed using a valued ERGM framework (Chapter 2, Section 2.3) in which each edge was weighted by the number of resource *types* that were exchanged. While this method certainly improves our understanding of network structure, there are ways to improve this understanding further. One approach would be to document every species shared as opposed to a resource category. This would allow further distinctions between commonly shared fish, birds, and so on. Another approach would be to estimate the volume of resource shared, in pounds. This method could build first off of standard weight conversions and, with the implementation of ethnographic and participatory research methods, could even measure the exact weights of each share. Indeed, this is the approach that most field anthropologists have used in food sharing studies (Koster 2011; Janssen and Hill 2014; Ziker 2006). By improving the measure of resource flow, our valued ERGMs can pick up more precise patterns of food sharing.

4.1.2 Conceptual limitations

As I have recanted in previous chapters, the study of food sharing has a rich tradition in anthropology and ecology. A myriad of food sharing networks have emerged from this that are conceptually distinct. For instance, some food sharing studies have focused on the sharing of meals, a process that involves a special kind of preparation. Often sharing meals requires collocating in an individual's residence or in a special location. This kind of network is quite distinct when compared to food shares that occur whilst hunting and gathering, food shares that have are given generously or based on solicitation, or food shares that are done ceremoniously or to garner political support.

While I have already described the empirical limitations related to how this network was documented, it is worth also noting that the result is particular kind of network that differs from many network studies. However, it is conceivable that many of these different food sharing

networks harbor similarities regarding why and how people share and especially, as I have focused on in this this thesis, who shares and the capacity for doing so.

4.2 Implications

4.2.1 *Resource management*

Among the purposes of documenting and analyzing how subsistence resources are used and shared by Alaskan households are providing appropriate recommendations for hunting and fishing quotas and a better understanding of the most pressing challenges faced by subsistence users (Caroline L. Brown et al. 2012; Wheeler and Thornton 2001). Past management decisions by the Alaska Board of Fisheries and Board of Game have received ample criticism due to the adverse consequences of top-down decision making (Loring 2013, 2017). State decisions to restrict subsistence use levels, limit hunting and fish permits, or prohibit the use of certain places or types of equipment for subsistence activities often go against the needs of subsistence users. The strain that these decisions place on Alaska Native communities is compounded by novel circumstances created by climate change and globalization (Fall et al. 2013; Moerlein and Carothers 2012).

One avenue for my own critique here stems from a history of basis subsistence needs and subsequent quotas based on modeling that attempts to forecast optimal harvest rates in order to facilitate the maximum sustainable yield. Such models tend to simplify ecological relations in complex ecosystems down to an ecosystem service for humans (Roughgarden and Smith 1996). Moreover, maximum sustainable yield primarily serves the interest of commercial fisheries as these industrial scales of fishing consuming the vast majority of salmonids and whitefish in Alaska (Loring 2013; Thornton and Hebert 2015). Using productivity as a primary indicator of subsistence food security, even when embedded in networks to avoid household per capita estimates of harvesting, fundamentally supports the perspective of maximum sustainable yield. The conclusion that super-households can provide resources purely based on the volume of their surplus forms the basis of managing and protecting only those species which contribute most to total harvest weight. For instance, if we conclude that salmon and moose are the most important, since they are harvested at the greatest levels, this provides an impetus to conserve only these species and ignore a suite of interconnected ecological relationships that together constitute a thriving ecosystem. It is for this reason that I emphasis the complementary emphasis on diversity.

The finding in Chapter 2 that diversity explains generous sharing behavior in Aniak suggests that effective resource management must pursue plans that manage for diversity. Managing for diversity requires a shift from managing species interactions to managing ecosystems (Khan 2014), a task that can only be carried out managing people (Theobald, Crooks, and Norman 2011). Diverse landscapes requires large swaths of intact habitats. Moreover, the connectivity of these habitats must be maintained in order to facilitate species dispersal and migration (Haber and Nelson 2015) – ecological patterns that especially pronounced in Alaskan and important for diverse subsistence harvests (Charnley 1984; Fienup-Riordan 1986). That we have been to connect diversity of social structure in this study only serves to reinforce this argument about the importance of biodiversity. Analyses like those in Chapter 3 provide a key quantitative exploration of what drives diversity in household harvest and how diversity varies from by village.

4.2.2 Future network studies in Alaska

Considering the results in this analysis and the aforementioned limitations, it is worth noting that a variety of data collection amendments may strengthen future analyses of this kind. One example of this is the need to document multiple currencies in networks. For researchers that are interested in mixed subsistence-cash economies, it is important to observe who shares non-food resources like cash, fuel, ammunition, information, and labor. If currently trends hold, we should expect further market integration and greater challenges to subsistence lifeways. By documenting the transfer of a variety of material resources, we gain a much more holistic picture of what is changing and the potential to support social networks.

Future network studies in Alaska should focus on targeting communities in which the baseline condition of networks is well documented. Rather than a regional sweep of networks that may not be directly comparable, funding should be allocated to projects that deeply consider a subset of interconnected village. For example, the Chignik region, encompassing the villages of Chignik Bay, Chignik Lagoon, and Chignik Lake, could benefit from additional network study. During my internship with the ADFG, we targeted these areas with the goal of documenting salmon sharing within and between villages. The result was insightful, illuminating many interdependencies between the villages. Expanding this approach to include a comprehensive harvest assessment and a comprehensive resource sharing network would be further enlightening.

Key to many food sharing networks are complimentary *cash sharing* networks. Although cash income in Alaska is a sensitive topic, documenting how households pool funds as well as species will be a crucial step toward explaining how processes like globalization come to bear on subsistence-oriented populations. This is especially important in Alaska mixed economies that, due to migration away from vulnerability, have expanded their networks to interface with urban areas. For example, as wage opportunities disappear or remain disparate in remote areas, some residents may move to urban centers while maintain food sharing connections. Indeed, many residents of Alaska ship subsistence foods large distances. Those that have moved to urban centers, who are likely recipients of these shipments, may provide cash support for subsistence efforts rurally.

What is clear about the future of research in Alaska is that more rigorous participation by scholars and residents alike is needed if we are to document the immense changes taking place. The ADFG and university scholars should reevaluate their relationships to rural communities with the goal of strengthening rapport and community support. By doing so, new networks are likely to unfold within which, the researcher is embedded.

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