Received: 7 August 2020 | Revised: 24 December 2020 | Accepted: 17 January 2021

DOI: 10.1002/ajhb.23573

SPECIAL ISSUE ARTICLE

American Journal of Human Biology WILEY

Linking subsistence harvest diversity and productivity to adaptive capacity in an Alaskan food sharing network

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Funding information
National Science Foundation, Grant/Award Numbers: DBI-1052875, GRF-1840998; National Socio-Environmental Synthesis Center

Note: in this article,
vertex = node
edge = link

Abstract

Background: Although anthropogenic climate change poses existential challenges for Indigenous communities in the Arctic, these challenges are not entirely unprecedented. Over many generations, Arctic peoples have developed a wide range of behavioral strategies to navigate environmental change and uncertainty, and these strategies provide a foundation for contemporary adaptation.

Aims: In this article, we focus on mixed cash-subsistence economies and the social networks that underlie them in Alaska. The patterns of food production, labor exchange, and food sharing in subsistence-oriented communities throughout Alaska are driven by the productivity of keystone households who regularly harvest and share resources within and between communities.

Materials & Methods: Building on previous research suggesting the critical importance of these networks to community resilience, we use network analysis to investigate whether patterns in resource transfers between households are associated with subsistence harvest diversity—the diversity of species harvested by a household unit. We use exponential random graph models to describe the structure of a sharing network from Aniak, Alaska, and model the links between harvest productivity, harvest diversity, and household position in this network.

Results: Our results indicate that both productivity and diversity are positively associated with network connections, and that productivity alone provides an incomplete model of network structure.

Discussion: We suggest that subsistence harvest diversity may play a unique role in supporting adaptive capacity and resilience by maintaining the productivity of keystone households despite changing environments and sustaining social network structures that circulate resources throughout the community. Harvest diversity may also serve as a broad indicator of Indigenous ecological knowledge and a tangible representation of cultural practices, values, and worldviews that underlie subsistence in Alaska.

Conclusion: Greater attention to harvest diversity is important for understanding how subsistence networks adapt to environmental change and uncertainty linked to social and ecological dynamics of anthropogenic climate change.

Note: in this article, vertex = node and edge = link

1 | INTRODUCTION

As in many Indigenous communities throughout the northern latitudes, Alaska Native communities rely heavily on wild foraged foods, drawing on generations of cultural knowledge and practice as well as contemporary experience and innovation to survive and thrive in challenging environments (Fienup-Riordan & Rearden, 2012). For most people in rural Alaska, harvesting and processing wild resources continues to form the basis of a persistent mixed cash-subsistence economy that combines food production with wage labor and other forms of monetary income (Fall, 2016; Magdanz et al., 2016). Social networks circulate food and labor among households, playing a crucial role in sustaining these mixed economies (BurnSilver et al., 2016; Collings, 2011; Kofinas et al., 2010; Peloquin & Berkes, 2009). As an adaptive strategy and way of life, subsistence economies and social networks in Alaska have been shaped by environmental change at multiple temporal and spatial scales, from the patchy distributions of resources across the landscape and the highly seasonal fluctuations in abundance to longer term climatic and ecological variation across years, decades, and centuries (Minc & Smith, 1989). While generations of colonization, market integration, and globalization have had significant negative impacts on mobility, Indigenous knowledge, native languages, health, and other important aspects of well-being in Alaska Native communities, subsistence economies, and social networks have proven to be remarkably resilient. As the forces shaping this "total environment of change" (Moerlein & Carothers, 2012) continue to accelerate along with anthropogenic climate change, understanding the ways subsistence harvests and social networks enhance the adaptive capacity and resilience of individuals, households, and communities in Alaska and throughout the Arctic is imperative. In this article, we seek to contribute to this challenge by building on previous research that suggests the resilience of subsistence economies is enhanced by access to diverse resources (Leslie & McCabe, 2013) and the structural patterns of social networks (Baggio et al., 2016; Janssen et al., 2006). Specifically, we investigate the relationship between subsistence harvest diversity and network position in a food sharing network from an Alaska Native village to better understand the relationship between harvest diversity and productivity in these mixed economies and explore the role of harvest diversity in adaptations to past, current, and future forms of environmental change.

Subsistence-oriented groups in northern regions are organized into social networks of interacting households who work together to harvest and process resources for local consumption (Usher et al., 2003). Sharing harvested foods is a vital cultural practice that maintains these networks by reinforcing existing kinship, friendship, and other social relationships, and by extending support and provisions to households in need (Collings et al., 2016; West & Ross, 2012). For some households, food sharing networks are the only way to access nutritionally and culturally preferred foods (Reedy & Maschner, 2014), making food sharing an avenue to extend aid to households and communities who are experiencing environmental or economic hardship (Howe et al., 2016). Although many households throughout the North continue to participate in subsistence activities, resources are typically harvested and distributed by a small subset of "super-households" (Wolfe, 1987; Wolfe et al., 2010) who together harvest as much as 70 to 80 percent of the wild foods consumed by the community at large. Key households are positioned to influence the structure of food sharing networks (Baggio et al., 2016) and their harvest productivity levels may determine the surplus of food that is available to other village residents (Wolfe, 1987). In this way, highly productive households may increase the adaptive capacity of less productive households by occupying central positions in subsistence networks and facilitating the flow of resources to other households within the community, particularly those in need.

The resources that compose a productive harvest can vary considerably. Although some resources like caribou (*Rangifer tarandus*) or salmon (*Oncorhynchus* sp.) may form the core diet, the diversity of a household's harvest is an important characteristic that warrants greater analytical attention, particularly in the context of environmental change and uncertainty. Ethnographic accounts from Alaska attest to the importance of harvesting a variety of species as a strategy for overcoming change and uncertainty in resource abundance in Arctic and sub-Arctic environments (Charnley, 1984; Fienup-Riordan, 1986). Archeological research suggests diversification and sharing are important strategies for coping with environmental change and uncertainty (Minc & Smith, 1989), and that maintaining a diverse ecological niche is a hallmark of human ecology (Smith, 2015) and a potential driver of human integration into a wide range of ecologies (Zeder, 2012). Theoretical insights about the adaptive capacity of social–ecological systems point to diversity as a key feature that enables resilient human societies to respond to and reorganize in the wake of environmental disturbances (Ives & Carpenter, 2007; Leslie & McCabe, 2013). Taken together, this research suggests a fundamental link between harvest diversity and harvest productivity, where diversity sustains productivity despite fluctuations in resource abundance across spatial and temporal scales. In the context of subsistence economies in Alaska, harvest diversity may enhance the productivity of "super-households" encountering environmental change and uncertainty. Given the central role of these households in subsistence networks, harvest diversity may in turn increase the adaptive capacity of less productive households by maintaining the flow of resources to those in need, particularly during times when resources are scarce or difficult to harvest.

Building on research that suggests a link between household productivity, social networks, adaptive capacity, and resilience, we propose that the centrality of a household in a food sharing network may be associated with their subsistence harvest diversity. In this article, we report a social network analysis (SNA) of a subsistence network in Alaska, using valued exponential random graph models (ERGM) to test whether households with diverse harvests are positioned centrally in the network. We begin by reviewing theoretical contributions to the food sharing literature that have used a network approach. To justify our focus on harvest diversity, we describe the concept of the super-household and examine the relationship between harvest productivity and diversity. We then summarize our analytical methods and proceed with our modeling results. We present a baseline control ERGM, then compare the performance of models that include different combinations of three covariates—diversity, productivity and reciprocity—on the structure of food sharing networks from the community of Aniak, Alaska. We conclude with a discussion of the limitations in our analysis, opportunities for future research, and the implications for understanding the ways harvest productivity and diversity may extend adaptive capacity among households via social networks, enhancing community resilience to environmental change and uncertainty.

1.1 | Network approaches to food sharing

SNA has been applied to studies of food sharing with the goal of disentangling several hypotheses about the social dynamics of cooperative behavior. Many of these hypotheses pertain to partner selection, such as inclusive fitness (Hamilton, 1964) as well as direct, indirect, and generalized forms of reciprocity (Bshary & Bergmuller, 2008; Trivers, 1971). By using SNA, the dyadic dependencies that make aggregate patterns of cooperation observable are made explicit (Apicella et al., 2012), allowing for a nuanced analysis of contingent or preferential sharing within these specific kinds of social partnerships (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 meal sharing in Taimyr is highly asymmetric because 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 et al., 2016). Likewise, Koster (2011) reported support for a kin-based 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, 2012). Ready and Power (2018) demonstrated that in Kangiqsujuaq, kinship and reciprocity also have strong effects on 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 et al., 2002).

Two themes are clear in the food sharing network literature explored here that come to bear on our analysis. The first is that reciprocity is a common factor motivating resource transfers, even among households that are already considered close 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 food. These transfers tend to originate in subnetworks that are composed of the most productive households (BurnSilver et al., 2016; Koster, 2011; Ready & Power, 2018) from whom resources flow downstream to those experiencing circumstances that limit their capacity to harvest (Ziker, 2006).

Frequently but not always, subnetworks are structured by patterns of reciprocity among the most skilled, productive harvesters (Koster, 2011; Ziker et al., 2016), despite these same networks being globally asymmetric. While this appears contradictory, this pattern suggests that core households may indeed be generous, evidenced by high out-degree centrality scores, while also engaging in reciprocity preferentially with other highly productive households (Ready, 2018). For example, productive hunters and fishers may exchange reciprocally while participating in harvesting events, and then go on to share with other households upon their return. An alternative interpretation is that these represent primary, secondary, or even tertiary distributions of resources (Nolin, 2012). Regardless of how they form, these productive subnetworks with higher rates of reciprocity may indicate the presence of super-households in resource transfer networks.

1.2 | Super-households

The concept of the super-household emerged from research by the Alaska Department of Fish and Game's (ADFG) Division of Subsistence (Wolfe, 1987; Wolfe et al., 2010). In a regional analysis of subsistence economies, Wolfe (1987) recognized a widespread pattern of harvest inequality in rural Alaska. Specifically, they noted that a small proportion of households, usually fewer than 30 percent, were responsible for harvesting the majority of resources used by the community. This pattern became known as the "30–70 rule" and super-households were highlighted as the productive core of these 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 (Magdanz et al., 2002; Wolfe & Magdanz, 1993).

Super-households may contain keystone harvesters and processors (Modlmeier et al., 2014) who, by pooling labor within the household, exert tremendous influence over network connectivity, thereby altering the flow of subsistence resources. A super-household might be conceptualized as a "strongly interacting" household just as keystone species interact strongly across trophic levels (Granovetter, 1977; Soulé et al., 2005). Indeed, it is the direct and indirect effects of these core subsistence producers which make them highly influential in shaping subsistence networks. For example, Baggio et al. (2016) pointed out that in Alaska 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 this way, highly productive households that are also active in subsistence networks may increase the adaptive capacity of less productive households and maintain the resilience of the community as a whole. However, the key role-played by highly productive households may become a source of instability under some circumstances. In some communities, the asymmetry between highly productive and less productive households 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).

1.3 | Subsistence harvest productivity and diversity

For those who manage the subsistence resources that are used by rural Arctic and sub-Arctic communities, subsistence harvest productivity is a household metric used to prioritize subsistence uses and set 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. ADFG uses a standard conversion of units to pounds, that is then summed and used to estimate resource use by nonresponse households (Brown et al., 2012). In some network studies, productivity levels are broken into terciles of lower, middle, and upper harvest productivity to capture the harvest inequalities underlying the super-household concept (BurnSilver et al., 2016; Ready & Power, 2018). Thus, households in the upper-tercile are expected to be more central in subsistence networks, exhibiting a greater number of connections that involve transfers of surplus resources to other households.

What is the relationship between subsistence harvest productivity and diversity? There may be multiple pathways to a large, productive harvest and the composition of resources that are harvested is indicative of a household's subsistence strategy (Hansen et al., 2013). To illustrate this, consider households A and B. Household A may have a harvest that is dominated by large quantities of species with high cultural and material value, such as salmon, caribou, or moose (*Alces alces*). Household A might use cash from wage labor 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, targeting highly valued species, as well as other species available at different times of year. Household B also obtains a productive harvest, but doing so requires different kinds of local ecological knowledge and the seasonal flexibility needed to target each species (Ford et al., 2006).

Subsistence harvest diversity was acknowledged in the formulation of the super-household concept (Magdanz et al., 2002; Wolfe & Magdanz, 1993), though its treatment in subsistence research has largely been a matter of ethnographic inquiry (see BurnSilver & Magdanz, 2019 for a notable exception). Across Arctic and sub-Arctic North America, ethnographers have described the diverse constellation of resources that are used by subsistence-oriented populations (Fienup-Riordan, 1986; Magdanz et al., 2016; Wolfe & Magdanz, 1993). Participation in seasonal rounds or at seasonal harvesting and fishing camps

(Charnley, 1984) have historically made it possible for residents of Alaska to access resources that fluctuate seasonally and from year-to-year (Fienup-Riordan, 1986). These fluctuations can be dramatic, and many species are not consistently abundant, emerging only for a brief time when environmental conditions are favorable. Thus, a diverse harvest may be one way to buffer households against dramatic changes in seasonal abundance (Penn et al., 2016) and serve as an indicator of adaptive capacity in uncertain environments.

Whether harvest diversity facilitates resilience in Alaska is a timely question because the northern latitudes are currently the most impacted by global climate change (Duarte et al., 2012). 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 et al., 2010), and the timing of hydrological and phenological cycles (Bieniek et al., 2011; Leblond et al., 2016). These biophysical and ecological trends, however, cannot be decoupled from ongoing social, cultural, and economic shifts (Moerlein & Carothers, 2012). Further integration with global capitalist markets and centralized regulatory authorities has been shown to reduce youth participation in subsistence (Fall et al., 2013), impact nutrition and health (Bersamin et al., 2007), increase reliance on fossil fuels and cash income to pursue subsistence resources (Collings, 2011), and lead to rigid resource use restrictions and top-down management that prioritizes commercial enterprise over subsistence livelihoods (Loring, 2017). The impacts of some of these changes on subsistence may be ameliorated by bottom-up ecosystem management (Berkes, 2012), which builds on existing social networks within a community (Parlee et al., 2006).

Amid these complex changes, we expect that diverse harvests are associated with a greater response diversity due to dietary redundancies (Leslie & McCabe, 2013) that enable adaptive responses to changing environments. Moreover, food sharing networks and diverse resource use are the foundations of a social organization with thousands of years of resilience and adaptation in the Arctic and sub-Arctic (Sakakibara, 2017; Wexler, 2014). If households with diverse harvests are able to maintain their productivity in the face of fluctuations in resource abundance and continue to occupy a central role in food sharing networks, the adaptive capacity supported by diverse harvests may extend to other households and support community-level resilience (Chapin et al., 2010). We analyze a crucial part of this link between a household's subsistence harvest, adaptive capacity, and community resilience by systematically examining the relationship between harvest diversity, productivity, and the structure of subsistence networks.

2 | METHODS

2.1 | Site description

In this analysis, we consider data from Aniak, a sub-Arctic Alaskan village located at the confluence of the middle Kuskokwim and Aniak Rivers (Krauthoefer et al., 2015). Aniak is primarily composed of Indigenous Yup'ik and Athabascan peoples and non-Native residents (Brelsford et al., 1987) that have remained since colonization in the late 19th century (Funk, 2010). In 2009 when the data were collected (Brown et al., 2012), Aniak had a population of 485 people living in 170households, with 73% of residents identifying as Alaska Native (predominantly Yup'ik). Like other communities in the region, Aniak is accessible only by plane, boat (summer), or snowmobile (winter). However, in contrast to nearby communities, Aniak is a regional hub, connecting local air transportation networks with Anchorage and drawing interest from nonlocal sport fishermen and hunters. As a confluence of travel and economic interaction, Aniak is larger than most other communities in the region, so the subsistence networks we analyze and the underlying social dynamics may differ from smaller communities.

Previous ethnographic studies suggest that many Aniak residents subsist and collaborate as household units and that many residents participate in subsistence activities but do so with less seasonal movement than in previous decades (Charnley, 1984). Fish make up 82% of the total harvest by weight for Aniak residents and 92% of households reported using fish, with an additional 15% of the total harvest coming from land mammals, which are used by 74% of households (Brown et al., 2012). The most heavily harvested species are Chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*) and Coho salmon (*O. kisutch*), moose, and burbot (*Lota lota*). Households surveyed in this project made use of 61 subsistence resources, including 17 fish species, 10 land mammals species, 1 marine mammal species, 17 bird species, and 16 species of edible plants and greens (see Brown et al., 2012 for comprehensive list of species). Amid this variety, there remains a preference for species that can be smoked, dried, or frozen so that they can be stored until the leaner winter months arrive (West & Ross, 2012). Harvest levels and sharing patterns exhibit clear inequalities, making this site a suitable context for investigating variation in household production and the network position of super-households (Figure 1).

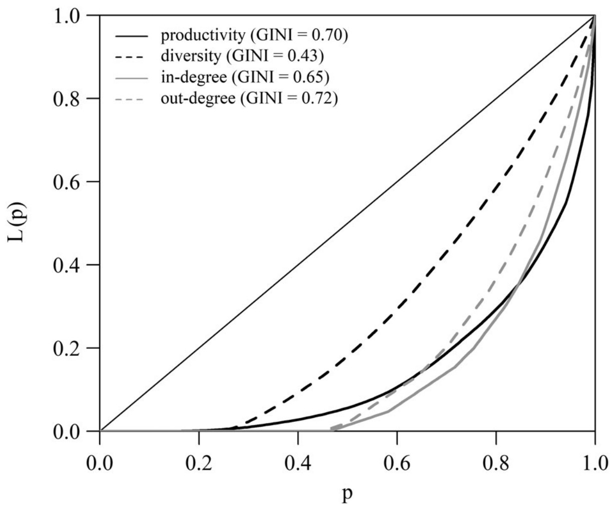

FIGURE 1 Lorenz curves suggest clear inequalities across household harvests and sharing connections (cf. Ready & Power, 2018)

2.2 | Data collection

The data[1] for this analysis were collected in 2009 by the ADFG Division of Subsistence. A full description of the survey can be found in the appendices of the project technical report (Brown et al., 2012). After community review and approval by the Aniak tribal council, 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 people residing 3 months or more in the household during the year of the survey. The survey contained modules that were used to document household demographics, employment and income, food security, 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. Importantly, the harvest assessment documents the number of species harvested (richness) and the pounds harvested for each species (abundance), making this data set well-suited for an analysis of subsistence harvest diversity. The survey also included a section on social networks, where households were asked to report other households in the community who harvested and processed 12 categories of resources used by the responding household in the previous year. A complete census of the village was attempted, yielding responses from 141 households (83% of the total). Of these respondents, our analysis uses data from 135 households that provided complete responses for subsistence harvests and social networks(Figure.1).

2.3 | Productivity, diversity, and reciprocity

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

To assess subsistence harvest diversity, we calculated Shannon's Index (i.e., H‘) on a matrix of 135 households × 94 resources, following the standard equation:

$$H‘ = -\sum_{i}^{S} p_i \ln p_i$$

In this case, p_i 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. Shannon's 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 et al., 2002, p. 26). Shannon's Index is preferred in this analysis over other measures of diversity, such as Simpson's Dominance or species richness, because it is sensitive to both the rareness and relative abundance of each species in a sample unit (Jost, 2006; McCune et al., 2002).

2.4 | Data analysis

The survey instrument used by ADFG asked respondents to recall the households that had harvested and/or processed resources and shared with them in the past year. Responses were collected separately for 12 categories of resources: salmon, whitefish, trout, other fish, moose, caribou, marine mammals, ducks/geese, grouse, other birds, berries/greens, and wood. With the limitations of memory recall (Bernard, 2017), the network in this analysis is likely composed of the most memorable primary and secondary resource transfers, rather than a comprehensive list. The network is also limited to resource transfers within the community, although some transfers between communities were reported in the survey (Brown et al., 2012) and are common throughout Alaska (Hutchinson-Scarbrough et al., 2020). We used these responses to create a directed network of 135 households, where a tie between two households exists when at least one resource was transferred between them. Following common terminology in social network analysis, we use the term "vertex" to refer to a household and "edge" to refer to a tie between households. This network has a total of 150 edges, and a density of 0.8% (Figure 2). We applied a value to each edge corresponding to the number of resources that were shared, creating a valued network (Krivitsky, 2012; Krivitsky & Butts, 2013). In this valued network, the 150 edges represent a total of 339 resource transfers between households. Table 1 contains descriptive statistics for measures of network position (degree centrality), edge values, harvest diversity,

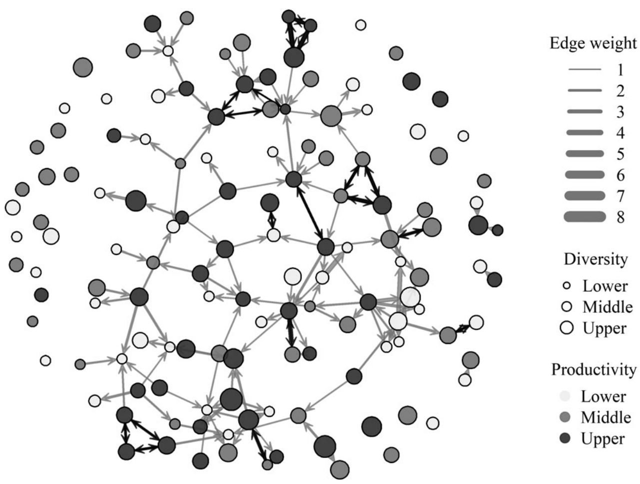

FIGURE 2 The Aniak food sharing network. The diameter of each vertex is scaled by a household's subsistence harvest diversity and shaded according to productivity, with the darkest being the most productive households. An arrow at the ends of the edges indicates direction, and edges that are colored black represent instances of reciprocity. The thickest edges are those with heavier weights, indicating the transfer of multiple resource types between two households

TABLE 1 Descriptive statistics

Variable	Median	*SD*	Range
In-degree	1.5	3.3	0–15
Out-degree	1	4.1	0–22
Edge weight[a]	2	1.6	1–8
Species richness	4	6.1	0–32
Harvest diversity[b]	0.8	0.6	0–2.4
Harvest weight (lbs)	228	1579.7	0–15484

[a]Edges weighted by number of resource categories: salmon, whitefish, trout, other fish, moose, caribou, ducks/geese, grouse, other birds, berries/greens, marine mammals, and wood. Of these, all but grouse, other birds, and wood were transferred in Aniak.
[b]Harvest diversity calculated using Equation (1) based on harvest weights reported for 94 species.

and productivity at the household level (Figure.2, Table.1).

All the procedures in this analysis were performed in R (R Core Team 2017) using the *igraph* (Csardi & Nepusz, 2006) and *vegan* (Oksanen et al., 2010) packages, and the *statnet* suite of packages, including *ergm* (Handcock et al., 2008) and *ergm.count* (Krivitsky, 2013). We developed and evaluated eight valued ERGMs for the Aniak food sharing network to test the effects of two vertex covariates, productivity and diversity, and one dyadic dependence covariate, reciprocity. We also included household demographic and economic survey variables in a control model, including income, household size, proportion of Alaska Native household members, marital status, and use of subsistence resources to feed sled dog teams. All variables in this analysis have been standardized to facilitate direct comparison. In the next section, we report full coefficient estimates for four of these models (Table 2) and provide a table that summarizes results from our model selection procedure (Table 3). We relied on AIC, analysis of deviance, and model simulation to select from among our candidate models. All the ERGMs were estimated using Markov Chain Monte Carlo algorithms embedded with the *ergm.count* package; using 100000 iterations; an interval step of 1000; and a 2500 iteration burn-in period. To estimate over-dispersed edge values, we applied a zero-inflated Poisson as a reference distribution.

3 | RESULTS

3.1 | Control model

Table 2 reports four models out of several that were analyzed, and for brevity, only the models with our focal covariates are included. The paragraphs that follow describe the results of the control model. The control model contains two structural parameters to estimate the weighted edge density and the inflation of zero-count edges in the network, as well as several control variables for vertex attributes. The structural parameters are labeled using the *statnet* (Handcock et al., 2008) terms "sum" and "nonzero." Since the model is standardized, the sum parameter indicates that the expected number of resources (i.e., edge value) transferred between two households is 1.6 (Odds-Ratio [OR] = 1.68, $p < .001$), when the other model coefficients are held constant. Within a model, we can interpret other coefficients of interest as either increasing or decreasing edge probability relative to the edge value (number of resources). In valued ERGMs, the nonzero term models zero-inflation, one type of

TABLE 2 Comparison of selected ERGMs

Parameters	Valued[a] *D*	*DR*	*PD*	*PDR*	Binary[b] *PDR*
Sum	1.55***	1.24*	1.50***	1.17	0.01***
(structural term)	(0.08)	(0.09)	(0.09)	(0.10)	(0.16)
Nonzero	0.002***	0.002***	0.002***	0.002***	1.53
(structural term)	(0.18)	(0.18)	(0.19)	(0.19)	(0.34)
Single female HH	1.16	1.23**	1.15	1.23**	1.88**
(node in-factor)	(0.08)	(0.07)	(0.08)	(0.08)	(0.23)
Estimated earnings	1.03	1.02	1.05	1.04	1.02
(node covariate)	(0.03)	(0.02)	(0.03)	(0.02)	(0.06)
HH size	1.03	1.02	1.02	1.01	1.16*
(node covariate)	(0.03)	(0.02)	(0.03)	(0.02)	(0.06)
Dog food	1.02*	1.02***	0.90**	0.90**	0.90
(node covariate)	(0.01)	(0.005)	(0.04)	(0.03)	(0.07)
Alaska Native	1.14***	1.10***	1.14***	1.10**	1.12
(node covariate)	(0.03)	(0.03)	(0.03)	(0.03)	(0.07)
Diversity (D)	1.19***	1.20***	1.14***	1.14***	1.49***
(node out-covariate)	(0.03)	(0.03)	(0.04)	(0.04)	(0.09)
Reciprocity (R)		5.67***		5.87***	46.12***
(structural term)		(0.13)		(0.14)	(0.35)
Productivity (P)			1.19***	1.20***	1.34***
(node out-covariate)			(0.05)	(0.04)	(0.10)

[a]Standardized coefficients reported here as odds-ratios, SE in parentheses.
[b]Binary version of the full PDR model for comparison. Note that binary ERGMs use Edges and Isolates terms in place of the Sum and Nonzero terms.
*$p < .05$,
**$p < .01$,
***$p < .001$.

TABLE 3 AIC, BIC, and model deviance

Model	AIC	BIC	Null deviance[a]	Residual deviance	DF (null)	DF (residual)
PDR	−33963	−33885.1	0	−33983	17822	17812
PD	−33834.3	−33764.3	0	−33852.3	17822	17813
DR	−33915	−33844.9	0	−33933	17822	17813
PR	−33949.6	−33879.5	0	−33967.6	17822	17813
R	−33896.1	−33833.8	0	−33912.1	17822	17814
D	−33821.2	−33758.9	0	−33837.2	17822	17814

[a]Null deviance in valued ERGMs is defined to be zero (see Krivitsky, 2013).

overdispersion, which in this context occurs when more edge counts are 0 (i.e., the two households in the dyad do not share any resources) than would be expected from Poisson-distributed edge counts. This manifests in the data with a sparse network and many isolated households. The low value of the nonzero parameter confirms that the network is zero-inflated (OR = 0.002, $p < .001$)(Table.2).

We analyzed whether the proportion of household members who identify as Alaska Native covaried with a household's sharing connections, based on ethnographic insights that suggest sharing is an important part of Yup'ik and Athabascan cultural practices (Charnley, 1984; West & Ross, 2012). We found that a larger proportion of household members who identify as Alaska Native had a positive association with resource transfers (OR = 1.15,

$p < .001$). We also controlled for the amount of harvested resources that were used to feed dog teams, finding that this had a negative but insignificant association with resource transfers. Modeled as a receiver effect (vertex in-factor), households headed by single females were 1.2 times more likely to receive food transfers compared with households with male or multiple household heads (OR = 1.18, $p < .05$). To understand effects of income, we included an estimated income variable, using median imputations to deal with missing values, as well as imputations one standard deviation above and below the median. We assessed models with different imputations, finding that in all model fits, estimated income had no effect on network structure or household position, though it is possible that the association between edge formation and income differs among households at different points along the income spectrum.

3.2 | Diversity, productivity, and reciprocity

We conducted nested comparisons of the covariates that are the focus of this analysis: harvest diversity, productivity, and reciprocity. We modeled the sender effect of diversity and productivity on resource transfers (i.e., vertex out-covariate). Our measure of diversity (Model D) was positively associated with transfers (OR = 1.20, $p < .001$). When compared with a household with low harvest diversity (two standard deviations below average), a household with high harvest diversity (two standard deviations above average) is 1.7 times more likely to have a sharing edge. As expected, harvest productivity (Model P) also has a positive effect on transfers (OR = 1.3, $p < .001$). When diversity and productivity are entered into the model together, productivity has a slightly stronger positive effect than diversity (Model DP). Importantly, although harvest productivity and diversity are fundamentally related due to the way Shannon's Index is calculated, we do not observe any issues of multicollinearity when using the Duxbury (2018) method. We find that reciprocity had a strong positive relationship in general (Figure 3), including when we modeled all of our focal covariates together (Model DPR, OR = 5.9, $p < .001$).

3.3 | Model selection and simulation

For any data set, there exists a universe of models that characterize some aspects of data structure but not others. No single model is true, but by exploring the universe of possible models and assessing them against observed data, we can uncover the patterns and limitations (Smaldino, 2017). Thus, a key step in any modeling framework is to compare models and assess model fit using a variety of strategies. An advantage of using ERGMs is that we can use conventional statistical methods of model comparison, like information criterion and analysis of deviance, as well as model simulation.

To determine which models best fit the structure of the Aniak subsistence network, we vetted each model by graphically inspecting the MCMC traceplots and diagnostic statistics. We then selected from among all the fitted models using Bayesian and Akaike Information Criterion (BIC, and AIC, respectively) and an analysis of deviance

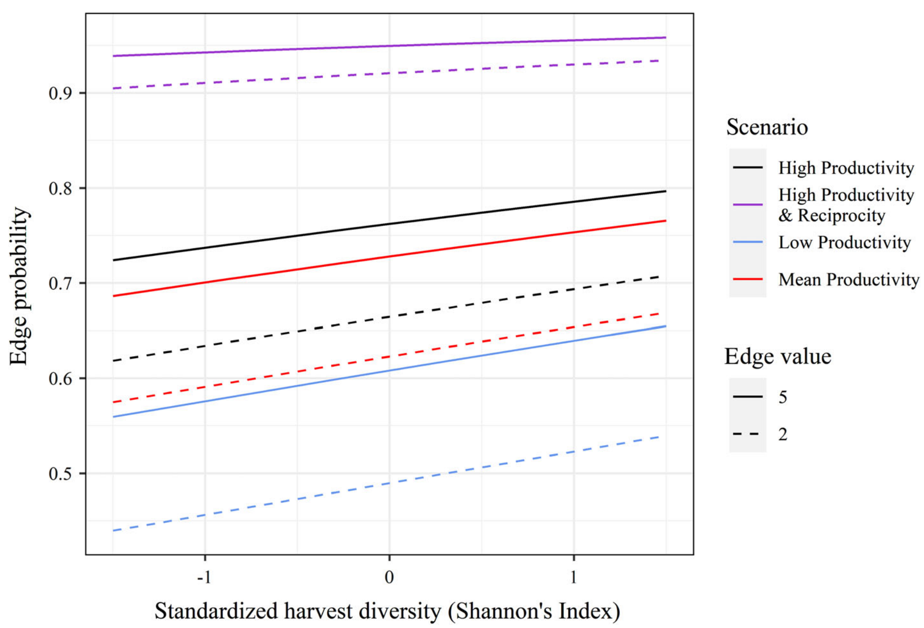

FIGURE 3 The predicted association between edge probability and subsistence harvest diversity at different levels of productivity and number of resources transfers (edge value) for model PDR (Table 2). "Low" productivity is two standard deviations below mean productivity and "high" is two *SD* above mean productivity. None of the scenarios include the effect of reciprocity on edge probability except "high productivity and reciprocity

(Table 3). Because null deviance is defined as zero for valued ERGMs (see Krivitsky, 2013), the residual deviance values are negative, and the models that further minimize deviance are a better fit. Overall, the only model that minimized deviance contained all parameters (Model PDR). When we ranked the models by AIC, we found that the model with all covariates (Model PDR) had the lowest AIC value, suggesting that it provided the best explanation for the data structure among the models we analyzed.

To further examine the model fit, we surveyed the sample space of the top four models (D, DR, PD, PDR) by simulating 1000 networks with each ERGM fit. We then calculated descriptive network statistics on the simulated models and compared them to the values of those statistics that were observed in the Aniak network (Figure 4). All the models tended to produce networks that were under-centralized compared with the observed in-degree and out-degree centralization statistics. In other words, the simulated networks show a more even distribution of ties among households than our observed networks. However, the DR model was a closer match than any of the other three. We compared the observed value of mutuality (0.127)—the proportion of observed edges that are reciprocated—in the Aniak network to the range of values derived from the networks that were simulated from each model. We should expect that models that contain a mutuality parameter would simulate networks with a level of reciprocity that is closer to what is observed. Therefore, it is noteworthy that models without the mutuality parameter overestimate levels of reciprocity. This may indicate some aspect of reciprocal transfers that is not well-captured by our model estimates of the impacts of harvest productivity and diversity on tie formation. Perhaps including additional parameters in the model, such as kinship or social status, might bring levels of reciprocity closer to observed values, even without the mutuality term (Table.3).

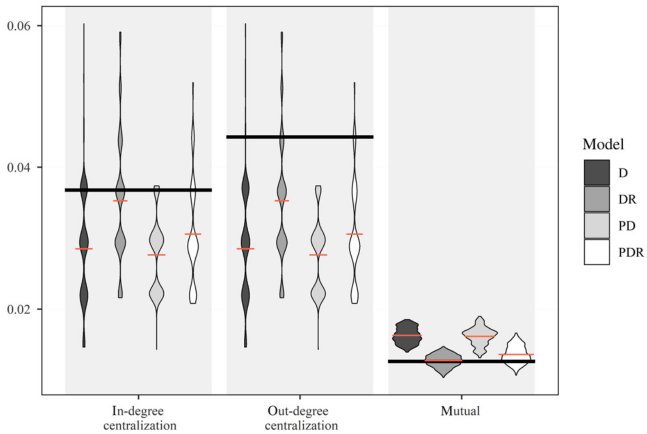

FIGURE 4 We used four models to simulate 1000 networks. All of these models contain our control variables and some combination of our focal covariates: Subsistence harvest diversity (D), productivity (P), and reciprocity (R). The x-axis shows three examples of descriptive statistics and the y-axis shows their simulated values. The bold black lines indicate the observed values of these statistics in the Aniak food sharing network and the orange lines indicate the mean value of the statistics generated from each of the four models. The mutual statistic, for example, indicates the proportion of reciprocated edges out of the maximum possible given the edges in the network. Models DR and PDR produce networks that better approximate the structure of the observed network. It is noteworthy that when productivity is included with diversity and reciprocity, the simulated networks slightly overestimate mutuality. Looking at centralization, we notice gaps in the estimated density that gives the appearance of a string of beads. This pattern arises in sparse networks because just a single difference in the number of edges across simulations will create clusters of networks with different density

4 | DISCUSSION

4.1 | Diversity, productivity, reciprocity, and adaptive capacity

Our analysis of the Aniak subsistence network shows a positive association between harvest diversity and network structure. Households whose harvests are more diverse (Shannon's Index) transfer a greater number of resource types to other households in the community. This result adds to previous research showing a positive association between harvest productivity and network structure (BurnSilver et al., 2016), a pattern also found in our analysis. Similarly, our analysis affirms the large number of studies showing the importance of reciprocity in food sharing networks (Nolin, 2010; Ready, 2018; Ready & Power, 2018; Ziker et al., 2016; Ziker & Schnegg, 2005). Using a model selection approach to explore the relative contributions of harvest diversity, productivity, and reciprocity to the structure of subsistence networks in Aniak, we found that reciprocity was a common feature of our best models, and that estimates of reciprocity increased when productivity and diversity were included. Models with both diversity and productivity also provided a better explanation for variation in network structure than models with only one of these variables. The model that contained all three variables (model PDR) performed best based on deviance statistics and information criterion. This full model, as well as the model that contained just diversity and reciprocity (model DR), simulated networks with similar statistics to the networks observed in Aniak. Taken together, we interpret this as evidence that while productivity has a clear impact on sharing connections, harvest diversity may play a unique and important role in shaping the networks of labor and resource exchange that underlie subsistence harvests in Alaska and perhaps throughout the Arctic and sub-Arctic.

Considering these results in relation to previous research suggesting a link between harvest diversity, adaptive capacity, and community resilience, we argue that harvest diversity may be an effective strategy for adapting to environmental change and uncertainty at multiple scales, from households to community. The adaptive capacity of households to absorb environmental shocks and sustain subsistence harvests is crucially important in Alaska, where both gradual changes and extreme events are increasingly common (Chapin et al., 2010). Elsewhere, researchers have argued that diversity is important for resilience because it may provide functional redundancies that buffer against these kinds of perturbations (Leslie & McCabe, 2013). In this way, subsistence harvest diversity can overcome fluctuations in resource abundance and strengthen food security at the household level. Indeed, this is the argument made by ethnographers and resource managers who have studied this region of Alaska (Charnley, 1984; Fienup-Riordan, 1986).

The benefits of harvest diversity for adaptive capacity can extend beyond a single household to other households in the community when households with more diverse harvests share resources with those who have less diverse harvests. From the perspective of adaptive capacity, such transfers are particularly important when they provide access to resources that are not otherwise accessible. In Aniak there is substantial variation among households in terms of the species harvested, but resource transfers between households reduce differences in the species households actually consume (Table 4). For example, consider how the benefits of harvest diversity circulate through subsistence networks for two key subsistence resources in Aniak: salmon and moose. Although salmon comprise the bulk of subsistence harvests and shape the structure of the subsistence network, this resource is widely accessible to many households, with 81% of households reporting salmon harvests. Still, an additional 12% of households did not harvest salmon but were able to consume it as a result of transfers, leaving only 7% of households without this crucial resource. The same general pattern holds for moose, but the extension of adaptive capacity via sharing networks is illustrated in sharper relief. Despite the practical and cultural importance of moose for subsistence in Aniak, only 21% of households harvested moose in 2009, perhaps due to declining moose populations, competition with nonlocal hunters, and subsequent restrictions on moose harvests (Brown et al., 2012). Yet, an additional 24% of households were able to consume moose via connections in the Aniak subsistence network (Figure 6). In this way, households that succeed in harvesting moose, whether through greater adaptive capacity, good fortune, or a combination of the two, share this success with other households, increasing access to food that has substantial practical and cultural value.

4.2 | Limitations

There are some important limitations in our analysis to consider. First, households that harvest a wider range of species have a greater opportunity to share a wider range of species, so it is possible the association we document between household harvest diversity and network structure is driven simply by differences in opportunity to share resources. In other words, it is more difficult for households to share resources they do not harvest. Although we cannot rule out this alternative explanation, we feel it is unlikely for several reasons. Our analysis shows a positive association between household harvest diversity, measured using Shannon's Index, and valued network ties, reflecting the number of transfers for

TABLE 4 Proportions of households ($n = 135$) who harvest, share, and receive resources in the Aniak sharing network

Resource edge	Harvest	Harvest and share	Harvest and receive	Receive, not harvest
Berries	0.57	0.13	0.07	0.04
Caribou	0.01	0.00	0.00	0.01
Marine mammals	0.01	0.00	0.00	0.01
Moose	0.21	0.16	0.09	0.24
Non-salmon fish	0.53	0.01	0.01	0.00
Salmon	0.81	0.36	0.31	0.12
Trout	0.12	0.01	0.01	0.01
Whitefishes	0.30	0.10	0.07	0.12

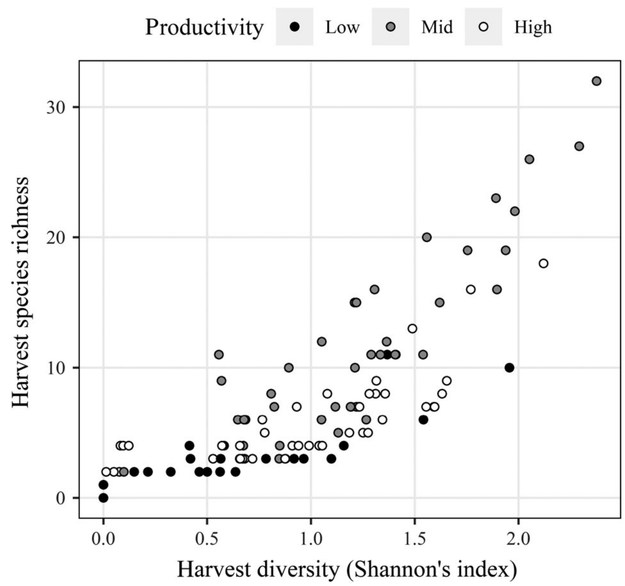

FIGURE 5 The association between harvest diversity and harvest species richness. Productivity terciles are indicated by the shade of each point

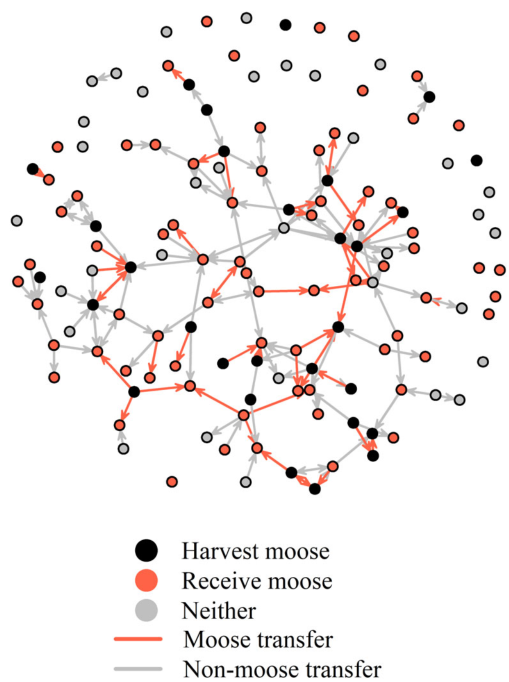

FIGURE 6 The Aniak food sharing network with edges colored red to indicate that moose was shared. Nodes that are colored red are those who indicated that they received moose but did not harvest it, including some households who either did not report from whom they received moose or who received moose from households outside Aniak

12 categories of resources. We chose to compute harvest diversity using Shannon's Index because it is sensitive to both the quantity of a resource harvested (abundance) and the presence of rare species in the harvest portfolio (richness), so this measure is fundamentally different from a simple count of the number of resource categories exchanged between households. Figure 5 visualizes the relationship between species richness, the total weight of all species harvested (productivity), and Shannon's Index. While there are clearly positive associations among harvest richness, productivity, and diversity, Shannon's Index incorporates information from both richness and productivity without simply reducing to either measure. Households with values for Shannon's Index that lie within the range of one standard deviation above and below the median value of 0.8 include households from all three terciles of productivity. Similarly, households with Shannon's Index values in this range also include some that specialized in harvesting a few species, along with others that harvested a dozen or more species. This suggests that households with a wide range of values for harvest diversity have sufficient access to a variety of resources and sufficient opportunity to generate a full range of valued ties in the networks we analyze. To consider the potential impact of differences in opportunity further, we conducted additional analysis with a binary version of our network, where a tie was recorded between two households if at least one resource was transferred between them. This simplified network reduces the possibility that the association between household harvest diversity and network structure is due to differences in opportunity, because this representation of the network treats sharing a single resource as equivalent to sharing many resources. Models of this network focus on the contrast between those who share and those who do not, reducing differences in opportunity between households with more and less diverse harvests. Analysis of these simplified networks using a binary ERGM shows similar associations between harvest productivity, diversity, reciprocity, and network structure as those reported for valued ERGMs (Table 2). Finally, comparing the proportions of households that harvest a resource to those that harvest but do not share that resource (Table 4), it is clear that harvesting a resource does not guarantee that a household will share it. In most cases, less than half the households that harvest a resource share that resource. This suggests that variation in the propensity to share resources exists beyond variation in opportunity to share. Together, we interpret these results as evidence that the associations between harvest diversity and network structure are driven by differences in the propensity to share resources between households with more and less diverse harvests, rather than differences in their opportunity to share resources.

A second limitation is that our analysis does not examine directly the impact of a household's harvest diversity on its adaptive capacity. Instead, we assume this link exists and investigate whether harvest diversity can extend adaptive capacity to other households in the community via network structure. Our assumption is based on theoretical research suggesting diversification as an effective strategy for adapting to environmental change and uncertainty (Leslie & McCabe, 2013), as well as ethnographic research from this region of Alaska, suggesting diversification has been used by generations of Indigenous communities to overcome fluctuations in resource abundance and access (Fienup-Riordan, 1986). Still, subsistence strategies are sufficiently complex that a household's harvest diversity may not be linked to its adaptive capacity in some circumstances. Households that specialize in a few highly valued resources may be prioritizing efficient harvest strategies under favorable conditions, while also maintaining the ability to diversify when conditions change. In this case, the ability to switch between specialist and diversified harvest strategies will likely depend on the extent that diversified strategies require extensive knowledge and experience tailored to different species that must be actively maintained to ensure success. Based on the wide range of species featured in Aniak subsistence harvests and our understanding of subsistence practices and social-ecological dynamics in this region, we believe households with more diverse harvests generally possess more extensive knowledge and experience about subsistence than households with less diverse harvests, but we acknowledge the possibility that some households with less diverse harvests may have the ability to diversify their strategies as conditions require. Another possibility is that a household's harvest diversity may reflect an inability to specialize in the most valued resources, indicating a lack of adaptive capacity. If this were the case, we might expect to see a negative association between harvest productivity and diversity; however, in Aniak we see a positive association (Figure 5). Because our data are cross-sectional, recording subsistence harvests and social networks over the course of a single year, it is difficult to evaluate these alternative explanations. Longitudinal data on household characteristics, subsistence harvests, and networks, combined with data on fluctuations in resource abundance, would support a more detailed analysis of the relationship between harvest diversity and adaptive capacity, and future studies could explore this in tandem with the extension of adaptive capacity within the community via social networks.

Finally, there are a number of other factors missing in our analysis that have been identified by other studies as important for understanding subsistence networks. Due to lack of available data, our analysis does not include kinship or spatial proximity between households, which have been found to affect the likelihood of sharing connections (Nolin, 2010; Ziker & Schnegg, 2005). Qualitative data from the ADFG project report (Brown et al., 2012) and ethnographic data from this region (Fienup-Riordan, 1986) both suggest kinship is an important factor that shapes subsistence networks, so including kinship in the analysis would likely improve our understanding of network structure. Conversely, the effects of distance on resource transfers in Aniak are likely to be limited to affinity between immediate neighbors. While people in Aniak may travel 30 or more miles outside the community to harvest resources, most households in the community are located less than a mile apart, suggesting distance should not limit the distribution of resources within the community. There are also a number of details missing in our analysis about the resource transfers that define subsistence networks in Aniak. Rather than using resource categories to classify transfers, it would be preferrable to know each species. Similarly, sharing networks that document resource flows in terms of the volume of each resource shared (i.e., pounds shared of resource x) will likely have effect sizes that more accurately reflect the influence of super-households (BurnSilver et al., 2016) and the role of subsistence harvest diversity, though it can be difficult to collect these data accurately. On a more general level, our analysis relies heavily on quantitative approaches and analysis of previously reported data. Any evidence reported in this analysis should be interpreted modestly and used as a launching point for further inquiry. Given the limited ethnographic data in this specific data set, we have relied on a rich ethnographic record in this region and insights from four decades of research on subsistence conducted by the ADFG Division of Subsistence throughout Alaska.

4.3 | Resilience in changing and uncertain climates

Food sharing networks are informal redistribution systems that make surplus resources available, supporting the food security of subsistence-oriented populations (Baggio et al., 2016; Ziker, 2006). Previous research suggests these networks are crucial for resilient communities in the Arctic and sub-Arctic, including evidence from Alaska (BurnSilver et al., 2016), Canada (Natcher, 2015; Ready, 2018; Ready & Power, 2018), and Siberia (Howe et al., 2016; Ziker & Schnegg, 2005). While much of this research focuses on the relationship between harvest productivity and resource transfers from highly productive "super-households," subsistence harvest diversity may also buffer individual households, and via sharing relationships, extend this adaptive capacity to the broader community. Greater attention to harvest diversity is important for understanding subsistence networks because households may reach similar levels of productivity by pursuing either a specialized or diversified strategy, and these different strategies may have implications for understanding adaptive capacity and resilience at multiple scales, extending from the household to the community as a whole (BurnSilver & Magdanz, 2019).

Harvest diversity and productivity are clearly associated, yet diversity may also shape subsistence networks in unique ways. A telling vignette from our study is that the household with the highest number of outgoing transfers—22 transfers of five different resources to seven household recipients—was in the highest tercile of harvest diversity and the lowest tercile of harvest productivity. Considered alongside our analysis of associations between diversity and network structure, we suggest that harvest diversity may not only influence a household's propensity to share resources, but may also serve as a broad indicator of a range of cultural practices, values, and worldviews that underlie subsistence in Alaska (Fienup-Riordan, 2005). Social networks do much more than provide food; they facilitate the transmission of cultural and ecological knowledge (Henrich & Broesch, 2011) and reaffirm social relationships and cultural identity (West & Ross, 2012). For many Alaska Native people, cultural transmission via subsistence and sharing is vital to a healthy and fulfilling life (McLean 1997; Loring, 2017). In this context, we suggest harvest diversity may be an important proxy for local ecological knowledge, as well as a tangible representation of the values and worldviews that are fundamental to the subsistence way of life, including the importance of sharing, particularly with those in need. These cultural dimensions of subsistence, along with the practical strategies underlying subsistence harvests and social networks, have helped Alaska Native people survive and thrive in environments with high levels of change and uncertainty for many generations, and they have also persisted despite sustained exposure to colonization, market expansion, globalization, and other forces that continue to impact Alaska Native communities. Now confronted with unprecedented social and environmental conditions arising from anthropogenic climate change, it is important to understand to what extent the practical strategies, cultural values, and worldviews underlying subsistence can continue to support well-being today and for the future. Our analysis builds on a growing body of research on subsistence that suggests a crucial link between harvest productivity and the distribution of resources through social networks, contributing new evidence that highlights how harvest diversity may enhance adaptive capacity in response to environmental change and uncertainty, in turn supporting community resilience.

ACKNOWLEDGMENTS

We would like to thank the Alaska Department of Fish and Game's Division of Subsistence for their collaboration, support, and access to these data, as well as the communities that participated in the project. We especially thank James Fall and James Magdanz for their comments on earlier drafts of the manuscript. This work was supported by the National Socio-Environmental Synthesis Center (SESYNC) under funding received from the National Science Foundation DBI-1052875. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. GRF-1840998. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors(s) and do not necessarily reflect the views of the National Science Foundation or the Alaska Department of Fish and Game.

AUTHOR CONTRIBUTIONS

Conceptualization: Shane A. Scaggs; Drew Gerkey; Data curation: Drew Gerkey, Shane A. Scaggs; Formal analysis: Shane A. Scaggs, Drew Gerkey, Katherine R. McLaughlin; Funding acquisition: Shane A. Scaggs, Drew Gerkey; Investigation: Shane A. Scaggs, Drew Gerkey; Methodology: Shane A. Scaggs, Drew Gerkey, Katherine McLaughlin; Writing—original draft: Shane A. Scaggs, Drew Gerkey; Writing—review and editing: Drew Gerkey, Shane A. Scaggs, Katherine R. McLaughlin.

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ENDNOTE

[1] These data are analyzed 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.

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How to cite this article: Scaggs SA, Gerkey D, McLaughlin KR. Linking subsistence harvest diversity and productivity to adaptive capacity in an Alaskan food sharing network. *Am J Hum Biol*. 2021;33:e23573. https://doi.org/10.1002/ajhb.23573