Research

Geospatial patterns and models of subsistence land use in rural Interior Alaska

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ABSTRACT. Alaska Native people and rural Alaskans rely on subsistence harvesting of wild resources for their well-being. This study integrates publicly-available data from >30 Interior Alaskan communities to examine the geospatial patterns of subsistence and develop model-based maps of subsistence land use for the region. Through analysis and identification of lands important for subsistence, this study provides a tool to inform sound decision-making on land use and facilitate communication among land users. We found that most contemporary subsistence land use (approx. 70%) occurred within areas that have been traditionally used for generations. The size of subsistence use areas varied widely among communities (approx. 50–25,000 km²) and was directly related to total population. Subsistence land use varied both by resource type and by season, which reflects differences in resource availability and harvesting strategies. The spatial patterns of subsistence land use were strongly influenced by accessibility, which differed between remote and road-connected communities. Our logistic regression models showed that subsistence land use was largely predictable by distance to communities, distance to main travel corridors (roads and/or rivers), distance to lakes (for remote communities), and population size. Probability maps of subsistence use were generated and classified into used and unused areas with accuracies from 83–86%. Results suggest a large spatial extent (353,771 km²) of subsistence land use in Interior Alaska, comprising >60% of the land area of this sparsely-populated region. The outcomes of this study provide a more comprehensive view of subsistence land use patterns and spatial products that may help reduce conflict and inform decisions affecting lands and resources important for sustaining the subsistence way of life.

Key Words: *Alaska; fishing; geographic information systems; geospatial modeling; human ecology; hunting; subsistence; traditional harvest practices*

INTRODUCTION

The practice of subsistence hunting, fishing, and gathering of wild resources is integral to the well-being of Alaska Native people and rural Alaskans. Subsistence resources are used for food, fuel, shelter, clothing, tools, transportation, crafts, customary trade, barter, and sharing. Most rural households in the Interior region of Alaska (98%) report using subsistence resources (ADF&G 2020a), acquired both through direct participation in harvests and through networks of sharing (Wolfe et al. 2010, Holen et al. 2012, BurnSilver et al. 2016, Brown and Kostick 2017). Alaska Native culture and identity are tightly linked to the land, and participation in subsistence activities provides social cohesion and generational knowledge transfer (Wheeler and Thornton 2005, Loring and Gerlach 2009). Wild food harvests are also vital to the physical and nutritional well-being of rural Alaskans and are typically the preferred and healthier food source compared to store-bought alternatives (Ballew et al. 2006, Johnson et al. 2009). The annual wild food harvest in rural Alaska averages 125 kg/ person, meeting about 176% of the population's protein requirements and 25% of their caloric requirements (Fall 2018, ADF&G 2019a). The availability and accessibility of wild resources help provide food security in the mixed subsistence-market economies that characterize rural Alaska (Wolfe and Walker 1987, BurnSilver et al. 2016). Dependence on subsistence resources is particularly pronounced in the many remote communities off the road network, where opportunities for wage employment are limited and commercial goods are expensive (Wolfe and Walker 1987, Fall 2016, Magdanz et al. 2017).

The protection of traditional practices of subsistence is important to Alaskans, especially Alaska Native people, and is also a tenet of state (Alaska Statute 16.05.258) and federal law (Alaska National Interest Lands Conservation Act [ANILCA]; Public Law 96-487, Title VIII). The effects of policy, development, and climate change impact the availability and accessibility of subsistence resources. Knowledge of how and where the landscape is used for subsistence practices can help protect this traditional way of life amid rapid social, economic, and environmental changes. Accordingly, the Alaska Department of Fish and Game (ADF&G) Division of Subsistence, in partnership with tribal and local governments, works to document community-level subsistence practices. Surveys with community members provide detailed information on subsistence harvests (ADF&G 2020a) and maps of subsistence use areas (i.e., areas of land used in the search for and harvest of subsistence resources) (Neufeld et al. 2019, 2021). Reports that accompany the data provide historical, sociocultural, economic, and regulatory context for understanding local subsistence practices and concerns (Holen et al. 2012, Van Lanen et al. 2012, Brown et al. 2014, Brown and Kostick 2017).

The motivation for this study is to provide the public, researchers, and all levels of governance an understanding of subsistence land use patterns of rural Interior Alaskan communities in order to support their subsistence goals. This research provides Alaska Native communities with information and resources to advocate for their own interests. We build on research conducted at local scales and integrate the geospatial information from ADF&G for the Interior Alaska region. First, we quantify the extent of

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Fig. 1. Study area map of communities in Interior Alaska.
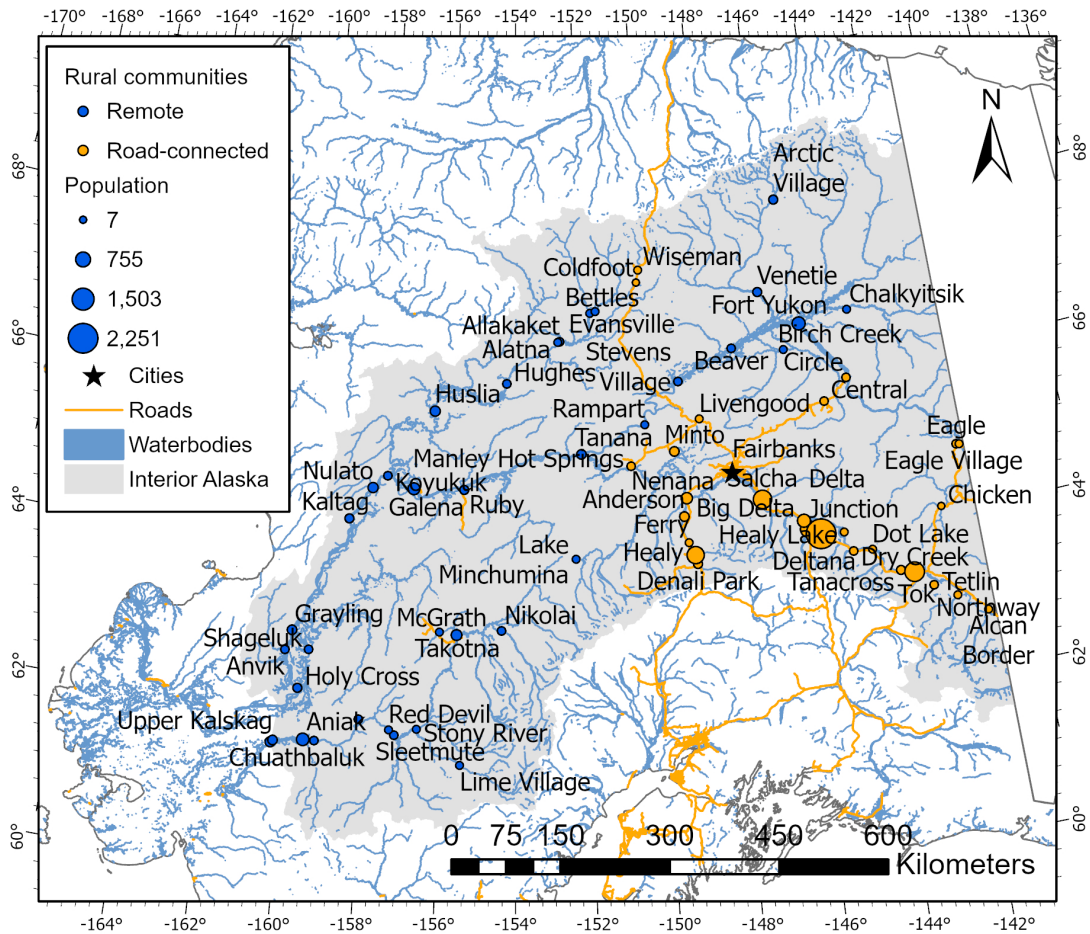
continuity and change in subsistence use areas over time, expecting to see both the continued use of traditional use areas and evidence of change. Secondly, we examine the spatial characteristics of contemporary subsistence land use and the influence of accessibility (distance to travel corridors and communities) and community characteristics (road-connected vs. remote, population size). Accessibility is known to be a key factor influencing subsistence, with most land use concentrated near communities and along travel corridors (Wolfe 2004, Brinkman et al. 2016). Because remote and road-connected communities use fundamentally different types of travel networks (rivers vs. roads), spatial patterns of land use should vary among these community types. Additionally, community population size is expected to impact the size of use areas, as residents spread out for harvesting finite resources (Hasbrouck et al. 2020a). We also investigate how subsistence land use varies by resource type (e.g., large land mammals, small game and furbearers, fish, etc.) and by season, with the expectation that the characteristics of the resource and harvesting practices (e.g., seasonality) will impact land use.

Finally, this study develops spatially-explicit models of subsistence land use that we apply to the entirety of rural Interior Alaska, providing community and regional-level maps of

predicted subsistence use probability and subsistence use areas. These geospatial products fill a critical information gap, as maps of documented subsistence use areas are not currently available for half of the rural communities in the Interior region. The model output from this study can facilitate communication of the spatial extent of subsistence activities and help inform decision-making on land use and policy to protect the subsistence way of life.

METHODS

Study Area
We conducted our research in Interior Alaska, a region extending latitudinally from the Alaska Range to the Brooks Range within the Yukon River Basin (Fig. 1). The boundaries of the study area were defined by the ADF&G western and eastern Interior subsistence regions, an area of 569,682 km², predominantly characterized by boreal forest ecosystems. This region has a continental subarctic climate. Average climate normals (1981–2010) in this region show a mean annual air temperature of -2.8° C, with minimum/maximum monthly temperatures of -25.8°C /21.3°C, and annual precipitation of 351 mm (Arguez et al. 2010). Arctic Alaska has experienced amplified effects of climate change, warming to more than double the global average over the last two decades (Meredith et al. 2019). This rapid change has impacted

subsistence practices in Interior Alaska (Brinkman et al. 2016, Cold et al. 2020).

The regional population is estimated to be 111,214, with the majority living near the population center of Fairbanks (ADL&WD 2019). This study focused on the rural communities within the Interior Alaska subsistence regions excluding the city of Fairbanks, suburban communities, military installations, and communities with a population size < 5 people (Fig. 1). The 64 Interior Alaskan rural communities considered in this study have a total population of 13,850, with 40% of the population located in 37 remote communities (not connected to the road network), and 60% in 27 road-connected communities (U.S. Census Bureau 2012). Most of the remote communities and some of the road-connected communities in the Interior have predominantly Alaska Native populations (U.S. Census Bureau 2012). Alaska Natives and non-Natives both participate in subsistence activities. For thousands of years, primarily Dene Athabascan people have inhabited Alaska's interior (De Laguna 1936, Osgood 1958, VanStone 1978). Alaska Native residents of this area primarily belong to five distinct Athabascan language groups: Deg Xinag and Holikachuk Athabascan downriver of Kaltag and in the Innoko River basin; Koyukon throughout the middle stretch centered around the Koyukuk River; Gwich'in Athabascan throughout the eastern Yukon Flats; and Han Athabascan in the easternmost portion of the drainage (Krauss 1982). Following a seasonal round that persists today, extended families or small groups followed the resources across traditional territories; for example, salmon fishing in summer, moose hunting in fall, trapping small mammals/furbearers and ice-fishing in winter, and hunting migratory birds when they leave in the fall and return in spring. Important subsistence resources for Interior Alaskan communities include: fish (salmon and non-salmon species), large land mammals (e.g., moose, caribou, bear), small land mammals and furbearers (e.g., beaver, marten, hare), birds (e.g., grouse, ducks), plants (berries and vegetation), and wood. During the ice-free season, boats and all-terrain vehicles (ATVs) are used to access resources. In winter, snow machines and dog teams (less commonly) are used to travel over frozen water bodies and trails. In areas with roads or ice roads, passenger vehicles are also used to access subsistence use areas.

Data Analysis
Analysis of documented land use patterns

The primary data for this study were publicly-available maps of community-level subsistence use areas developed by ADF&G through surveys with residents (ADF&G 2020b). ADF&G periodically conducts comprehensive surveys in subsistence-based communities to document the subsistence uses and harvest levels of all wild resources over an annual cycle, to describe sharing patterns, and to measure food security, among other objectives. Surveys are conducted only with the expressed permission of the governing bodies in communities, including tribal councils and city governments. Typically, the lead researcher will present information about potential research to the tribal council and if approved, incorporate any input from the council into the survey instrument and research design. Local Research Assistants (LRAs) from the community are hired to assist with the survey implementation. ADF&G uses different sampling methods depending on community size. A census is used to collect

subsistence harvest data in communities with approximately 100 households or less. A simple random sampling design is used for larger communities, representing anywhere from 20–80% of each community's households, depending on community size. As part of the survey, residents are asked to show on a map the locations that their household used for activities relating to the search for and harvesting of all subsistence resources over the course of the study year. The household spatial data are then compiled at the community level (Neufeld et al. 2019, 2021). Once subsistence data, including spatial data, are analyzed researchers return to the community with the data to discuss results in detail, review the analyses for accuracy and presentation, and discuss appropriate deliverables for the community in addition to a written report in many cases. Tribal entities and project respondents are provided with the draft report for review and comment. Publication of data and analyses happens only after review and approval of the draft report. Specific approval and review processes are detailed in individual reports. Other spatial data exist for subsistence uses by Interior communities, collected and held by other entities including tribes and other researchers; however, the only data included in this analysis are those publicly available through ADF&G for which the above review processes have been followed.

Our study included analyses of contemporary (2011–2017) spatial subsistence data for 32 communities in the Interior (18 remote, 14 road-connected) (Neufeld et al. 2019, 2021), and historic (approx. 1930s–1980s) data for 13 communities (Neufeld et al. 2021). By combining multiple years of subsistence activity, the data on historic subsistence may provide a more complete representation of areas used in the past (approx. 1930s–1980s) compared with the representation of currently used areas (2010s), which represent only individual years. The spatial area of overlap (km²) between the two datasets, therefore, underestimates the current use of historic use areas. For this reason, we expressed the spatial overlap as a percentage of the contemporary use area to assess continuity of subsistence land use.

For our description of the spatial characteristics of contemporary subsistence, we examined the size of subsistence use areas and relationships with community population size (U.S. Census Bureau 2012) and harvest mass (kg/community) (ADF&G 2020a) using simple linear regression. We assessed the role of accessibility on subsistence land use by community type (remote vs. road-connected) by examining how the spatial distribution of use varied by distance to home community, the nearest river (ACCS 2019), and the nearest road (Alaska DOT 2012). This analysis showed where subsistence use was concentrated in relation to communities and travel corridors (rivers and roads). Results were summarized as median percentages of community subsistence use areas within 10-km distance increments from the community and travel corridors. Trail systems are also important travel corridors but were not included since regional geospatial data were unavailable.

To understand how land use varied for different subsistence activities we compared use area by resource type and relative to harvest mass of each resource type. The resource types considered included fish, large land mammals, small game and furbearers, plants, and wood. The species included in each resource category are detailed in ADF&G (2020a) and Neufeld et al. (2021). We

also investigated how subsistence use areas varied seasonally. Snow and ice cover influence modes of travel (boat, snow machine) and accessibility of natural travel corridors. Seasonal resource availability (e.g., regulatory fishing/hunting openings, animal migratory patterns) also affects monthly activity. We broadly defined 6-month periods by the typical presence or absence of significant snow and ice cover: November–April (snow and ice present) and May–October (snow and ice absent).

Spatially-explicit predictive models of subsistence land use

Our main objective was to develop spatially-explicit models to predict subsistence land use for rural communities throughout the Interior region using publicly available data. The response variable had two possible outcomes: a location was either used or not used for subsistence purposes. To predict the probability of this binary categorical response, we used logistic regression, a widely used statistical model in the natural and social sciences (Menard 2010). Spatial applications of logistic regression have included models of human land use, in particular for agricultural systems, urban sprawl, and deforestation (Ludeke et al. 1990, Verburg et al. 2002, Etter et al. 2006, Alsharif and Pradhan 2014).

In the logistic regression model, the probability of the response can be expressed mathematically as a function of explanatory variables:

$$pr(1) = \frac{1}{1+e^{-(\beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n)}} \qquad (1)$$

For our application, $pr(1)$ is the probability of subsistence use, $x_1, \ldots, x_n$ are independent predictor variables and $\beta_0, \ldots, \beta_n$ are logistic coefficients. Parameters are estimated using the method of maximum likelihood. The joint probability function of the sample observations is developed using the Bernoulli distribution for a binary random variable, rather than a normal distribution. We used the statistical software JMP Pro 15 (SAS Institute Inc., Cary, NC) to perform this analysis.

We compared samples of areas that were used and unused for subsistence within the available area. To determine whether a location was used or unused, we used the ADF&G maps of contemporary subsistence use areas for 30 rural communities (18 remote communities, 12 road-connected communities) compiled in Neufeld et al. (2019). These maps included polygons (e.g., harvest search areas), lines (e.g., traplines), and points (e.g., harvest locations). We used all of these feature types to represent subsistence use areas after converting the line and point features to polygons with a 30-m buffer area. We defined the local available area as a 150-km radius around each community. This radius was chosen to represent an approximate maximum distance residents travel for subsistence from the community where they live (Neufeld et al. 2019).

Potential predictors were chosen through exploratory analysis of the ADF&G maps of subsistence use areas and prior knowledge. By overlaying the ADF&G maps on physical maps of Alaska in a geographic information system (GIS), it was visually evident that subsistence use areas were concentrated near communities and along travel corridors of rivers and roads (Wolfe 2004, Neufeld et al. 2019). Subsistence land use also appeared around lakes/ponds/wetland areas, which could be related to the

abundance of resources in these areas and possibly the use of these areas as travel corridors (Holen et al. 2012). Visual and statistical analysis showed that communities with relatively large populations (e.g., Tok, pop. 1258) also had larger use areas compared with smaller communities (e.g., Eagle Village, pop. 67). The potential regressors we considered in model development therefore included: community population size (U.S. Census Bureau 2012), distance to home community, distance to nearest road (Alaska DOT 2012) (for road-connected communities only), distance to nearest river (ACCS 2019), and distance to nearest lake/pond (ACCS 2019). Interaction terms between distance to home community and distance to road or river were also included. We explored the use of topographic metrics and land cover classes but ultimately decided against including these as the interpretation was confounded by multicollinearity with distance to water bodies.

We developed separate models for remote and road-connected community types. An equal number (100) of random points were cast within each of the used and unused areas by community. Seventy percent of these points were used for model training (n=2544 for remote, n=1675 for road-connected); and 30% were withheld for model validation (n=1056 for remote, n=725 for road-connected). Models were constructed with forward stepwise logistic regression using the minimum Bayesian information criterion (BIC) score to select the best-fitting and most parsimonious models with the fewest parameters and greatest explanatory power. The BIC, Akaike's information criterion difference for small samples (AICc), and McFadden R^2 (R^2_{McF}) are reported for model comparison. Predicted probabilities of subsistence use were assigned discrete classes (used or unused). To reduce bias in this classification, we balanced the trade-off between type 1 and 2 errors by choosing an optimal probability cutoff that minimized the difference between false positive and false negative rates. Rates of classification accuracy for the training datasets (used for model development) and validation datasets (withheld from model development) were used to assess model performance.

The best-fit logistic regression models were applied individually to 64 rural communities in the ADF&G Interior Alaska subsistence region (Fig. 1) within a GIS framework to generate 30-m resolution maps of predicted subsistence use probability (continuous: from 0-1.0 probability) and predicted subsistence use areas (discrete classification of used areas). A regional composite of subsistence use probability was created from community-level maps taking the maximum probability value per pixel. The total land area used for subsistence was estimated using the classified subsistence use areas. The community and regional-level spatial products from this study are available through the Arctic Data Center (https://doi.org/10.18739/A25T3G149) (Brown et al. 2021).

Our models have limitations. They were developed with subsistence use data from a single year of contemporary data for each community. Because of annual variation in use, our predictions are likely underestimates of the full extent of subsistence use areas. Further, the models did not include all variables that are known to impact subsistence practices. Human interactions with the land are complex and are influenced by many personal, social, cultural, economic, political, regulatory,

Fig. 2. Map of documented contemporary (hatched) and historic (gray) subsistence use areas combined for 13 communities (points). The historic data are from varying time periods from approx. 1930s–1980s, whereas contemporary data reflect a single year since 2010 (Table 1). The historic subsistence use area for Evansville also includes the Bettles use area. Spatial data were provided by Alaska Department of Fish and Game, Division of Subsistence (Neufeld et al. 2021).
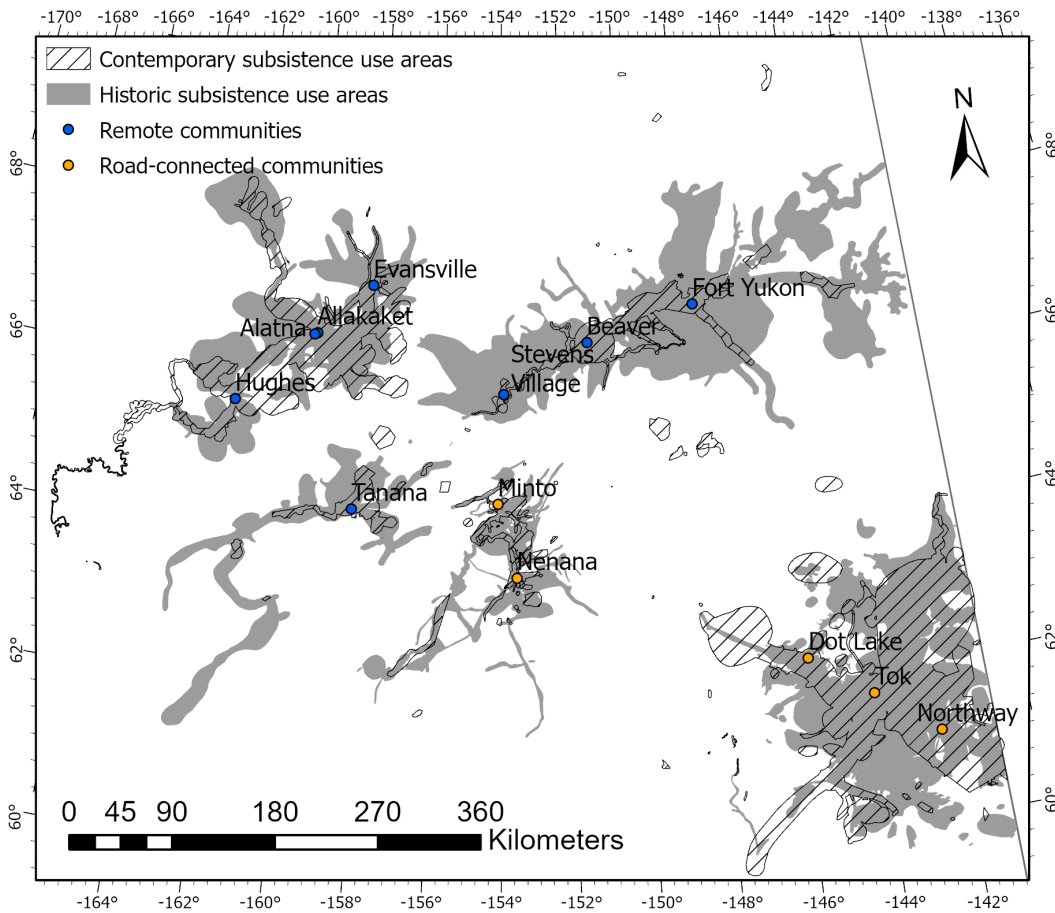
biological, and physical factors (Moerlein and Carothers 2012). Local traditions, social customs, beliefs, and values affect the choice of which subsistence resources people use, where these resources are harvested, and what practices are employed (Wolfe 2004). Resource availability significantly defines the areas of the landscape that are useful for specific subsistence activities, while land ownership and management impose important constraints on the availability of the land for subsistence use. The landscape is also dynamic, changing over time with disturbance (e.g., wildfire), succession, and climate change. Accessibility fluctuates with environmental conditions such as water levels, river ice quality, erosion and debris in rivers, and trail conditions (Brinkman et al. 2016, Brown et al. 2018, 2020, Cold et al. 2020, Hasbrouck et al. 2020b). Socioeconomic factors also affect subsistence land use patterns. For example, the distance that people can travel for subsistence is limited by the high cost of fuel (Brinkman et al. 2014) and by time constraints from wage employment (Holen et al. 2012). We could not include all of these factors because of insufficient data at the community level. Instead, our models focused on readily-available data on basic

demographics and physical predictors that remain relatively stable across time and space.

RESULTS

Spatial characteristics of documented subsistence use areas
For the 13 communities with documented historic subsistence use areas, an average of 69% (range: 41–91%) of the contemporary subsistence use area overlapped with the historic subsistence use area (Table 1). A map of the cumulative historic and contemporary use areas (combined for 13 communities) shows the spatial overlap and deviations in subsistence land use over time (Fig. 2).

Total areas of contemporary subsistence land use by community were lognormally distributed and ranged from 44–24,802 km², with a median area of 2135 km² (Fig. 3a). Nearly half (48%) of the variation in the total size of subsistence use areas was explained by community population size, which ranged from 13–1258 people (median = 95 people) (Fig. 3b). Population size was also directly related to total harvest (log(harvest)=5.17+0.90*log (population), n=28, $R^2 = 0.55$, $P < 0.0001$).

Table 1. Size and spatial overlap of historic and contemporary subsistence use areas. Historic subsistence use areas include subsistence areas over longer time periods than contemporary subsistence use areas, which represent a single year of use since 2010. Though the use areas are not directly comparable, the overlap (% contemporary area) estimates the portion of the contemporary use area that was used historically.

Community	Years of historic data	Historic use area (km²)	Contemporary use area (km²)	Overlap (km²)	Overlap (% contemporary area)
Alatna & Allakaket	1981-1983	11305	10597	6141	58.0
Beaver	1930-1986	4726	2454	1718	70.0
Dot Lake	1946-1982	1877	674	329	48.8
Evansville[†]	1981-1983	5093	371	338	91.2
Fort Yukon	lifetimes	23824	3395	2892	85.2
Hughes	1981-1983	5680	2496	1742	69.8
Minto	1960-1985	3248	1272	1104	86.8
Nenana	1981-1982	6658	2011	1313	65.3
Northway	1974-1984	4660	8268	3383	40.9
Stevens Village	1974-1984	6983	268	188	70.0
Tanana	1968-1988	9561	2052	1592	77.6
Tok	1968-1988	31747	24802	17413	70.2

[†]The historic subsistence use area for Evansville also includes Bettles.

Fig. 3. Frequency distribution of community subsistence use area sizes (km²) (a) and relationship with population size (linear regression with 95% confidence intervals) (b) .

(a)

(b)
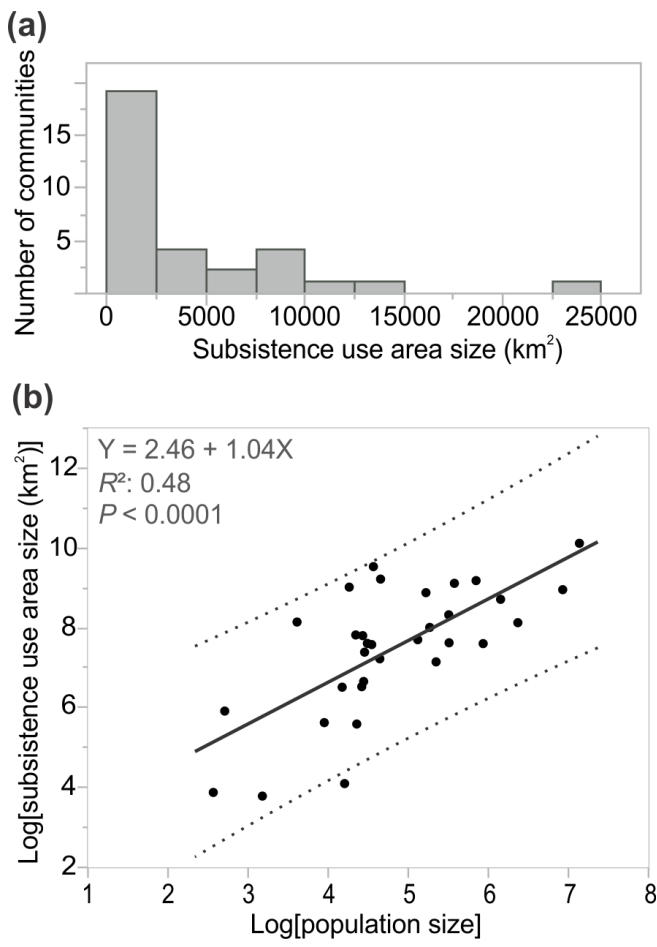
The spatial distribution of subsistence land use by distance to community, river, and road was calculated for each community and summarized as median percentages in Figure 4. The vast majority of subsistence land use occurred within 100 km of communities, with median cumulative area percentages at this distance of 100% for remote communities and 92% for road-connected communities (Fig. 4a). The road-connected communities of Anderson and Denali Park were exceptions to this pattern, where the majority of the subsistence use area was > 150 km from home communities. Among the 12 communities that reported subsistence activities > 150 km away, the majority of this land use was either for fishing (46% area, median) or hunting large land mammals (43% area, median). Some of the subsistence use >150 km from communities was just beyond this distance threshold, but use also occurred in distant regions throughout the state, including the Gulf of Alaska and north of the Brooks Range.

Subsistence land use was concentrated near travel corridors. Rivers were important travel corridors for remote communities in particular with 95% (median) of the subsistence use area within 10 km of rivers (Fig. 4b). Among the road-connected communities, the majority of subsistence land use was within 30 km of a road (75%, median) or 10 km of a river (74%, median) (Fig. 4b and c).

Figure 5 shows the variation in community-level subsistence use areas and harvest quantities by resource type. By weight, fish species and large land mammals comprised the majority of the edible harvest (96%), and wood was also harvested in large quantities. The area used for harvesting large land mammals (1694 km², median) was the greatest of all resource types, followed by the area used for harvesting small game and furbearers (661 km², median). The area used for fishing (15.7 km², median) was the smallest of all resource types. A comparison of seasonal subsistence land use showed that larger areas were used during the May–October period for the harvest of fish, large land mammals, and plants, whereas larger areas were used during the Nov–April period for the harvest of small game and furbearers (Fig. 6).
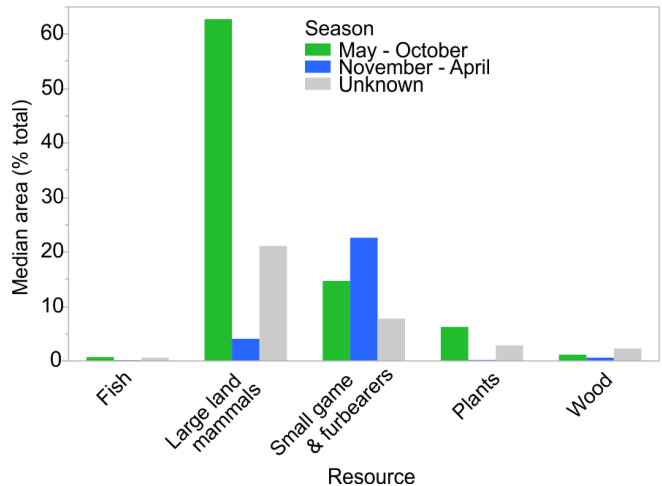
Fig. 4. Spatial distribution of subsistence land use (% total area) by distance to home community (a), nearest river (b), and nearest road (c).

(a)

(b)

(c)
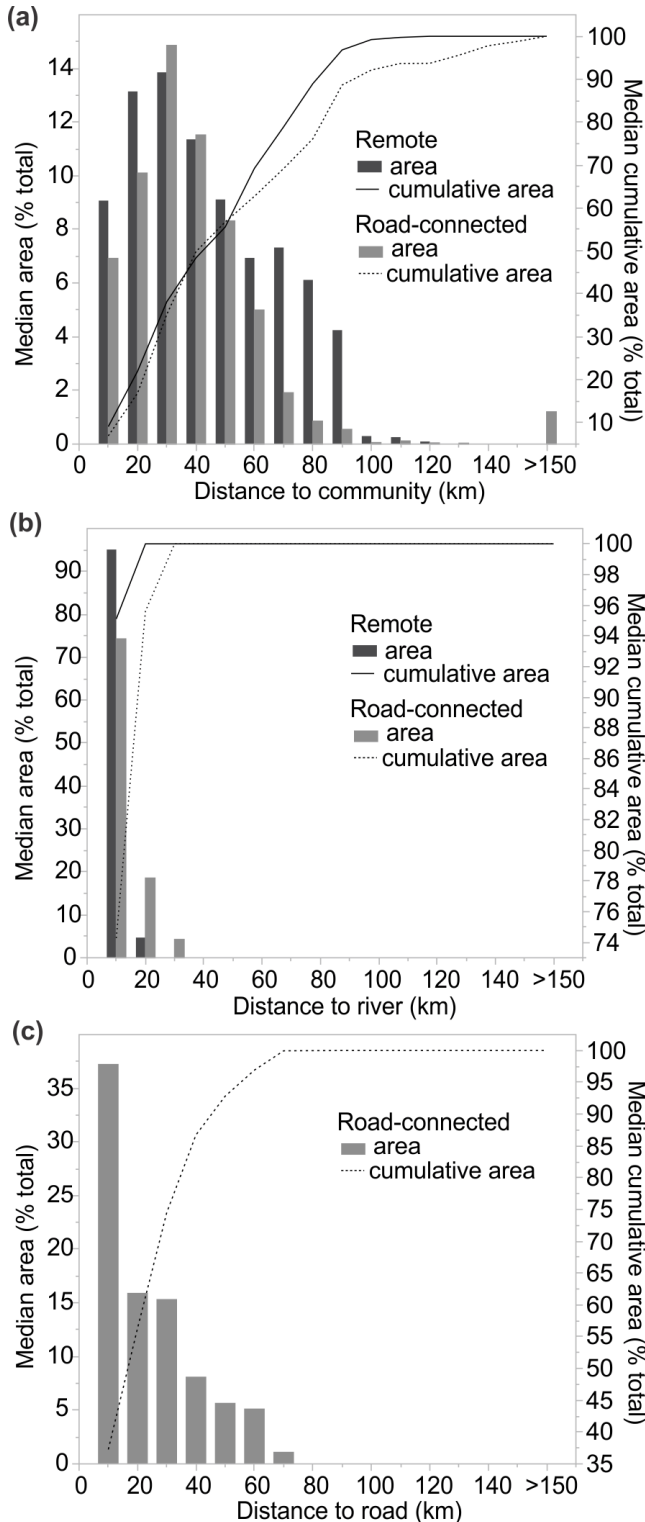
Fig. 5. Area of community subsistence land use (km²) and harvest mass (kg) for each resource type.
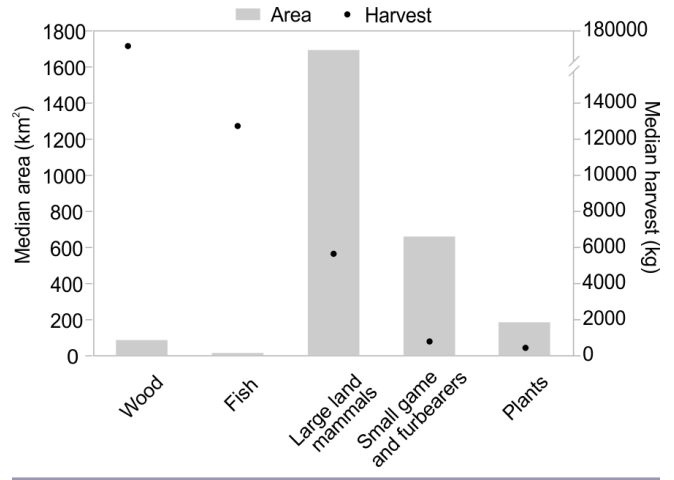
Fig. 6. Area of community subsistence land use (% total) by season and resource type.

Spatially-explicit models for predicting subsistence land use

The best-fit logistic regression models of subsistence land use each had five parameters and no interaction terms, and were statistically significant for both remote (*d.f.* = 4, χ^2 = 1752.56, *P* < 0.0001) and road-connected community types (*d.f.* = 4, χ^2 = 1073.73, *P* < 0.0001) (Table 2). The selected model for the remote community type included terms for distance to community, distance to river, distance to lake, and population size (Tables 2 and 3). The selected model for the road-connected type included terms for distance to community, distance to road, population size, and distance to river (Tables 2 and 3). Regression coefficients indicated that the probability of subsistence use decreased farther from communities (remote, road-connected), rivers (remote, road-connected), lakes (remote only), and roads (road-connected only), and increased with greater population sizes (remote, road-connected) (Table 3). Wald's χ^2 statistics showed a greater effect

Table 2. Selection of logistic models of subsistence use for remote and road-connected communities, comparing number of parameters (k), Bayesian information criterion scores (BIC), Akaike's information criterion scores (AICc), and McFaddens R² (R²McF) for training and validation datasets. The selected models with the lowest BIC scores are in bold.

Community type	Term	k	BIC	AICc	R²$_{McF}$ Training	R²$_{McF}$ Validation
Remote	comm	2	2086.1	2074.39	0.41	0.44
	comm + river	3	1832.3	1814.77	0.49	0.51
	comm + river + lake	4	1816.8	1793.42	0.49	0.51
	comm + river + lake + pop	**5**	**1813.4**	**1784.17**	**0.50**	**0.52**
	comm + river + lake + pop + (comm x river)	6	1817.1	1782.05	0.50	0.51
Road-connected	comm	2	1369.2	1358.37	0.42	0.43
	comm + road	3	1320.7	1304.46	0.44	0.45
	comm + road + pop	4	1290.7	1269.06	0.46	0.47
	comm + road + pop + river	**5**	**1285.4**	**1258.33**	**0.46**	**0.48**
	comm + road + pop + river + (comm x road)	6	1286.2	1253.7	0.47	0.48
	comm + road + pop + river + (comm x road) + lake	7	1291.2	1253.28	0.47	0.48

comm = distance to community; river = distance to river; lake = distance to lake; road = distance to road; pop = population size

of distance to communities and travel corridors for the remote communities compared with road-connected communities (Table 3).

Table 3. Selected logistic regression models of subsistence use probability for remote and road-connected communities, showing regression coefficients (β), standard errors (SE), Wald's χ2 statistics, and P-values (P).

Community type	Term	β	SE	Wald's χ2	P
Remote	Intercept	4.15	0.18	546.81	<0.0001
	Distance to community (km)	-0.0479	0.0019	608.99	<0.0001
	Distance to river (km)	-0.152	0.013	126.51	<0.0001
	Distance to lake (km)	-0.130	0.029	20.21	<0.0001
	Population size	0.00130	0.00039	11.08	<0.001
Road-connected	Intercept	3.63	0.19	355.78	<0.0001
	Distance to community (km)	-0.0462	0.0022	425.41	<0.0001
	Distance to road (km)	-0.0254	0.0040	40.12	<0.0001
	Population size	0.00104	0.00018	34.09	<0.0001
	Distance to river (km)	-0.040	0.011	12.63	<0.001

The optimal cutoffs to classify predicted subsistence use probability into binary groups (used/unused) were selected to balance false positive and false negative error rates. For both remote and road-connected communities, the optimal cutoff was 0.52; therefore, pixels with predicted subsistence use probabilities ≥ 0.52 were classified as used. Using this cutoff, the model for remote communities had a classification accuracy of 86% (for both training and validation datasets), and the model for road-connected communities had a slightly lower classification accuracy of 83% (training dataset) to 84% (validation dataset). False negatives (used areas that were misclassified as unused) tended to occur along major rivers or roads further from communities, where the models predicted lower probabilities of use. The models were used to map subsistence use probability (Fig. 7) and predicted subsistence use areas (Fig. 8) at community and regional levels (Brown et al. 2021). The regional map of subsistence use probability shows the maximum probability of subsistence land use (0 - 1.0) at each pixel among communities

(Fig. 7). Predicted subsistence use areas were defined using community-level subsistence use probabilities ≥ 0.52 (Fig. 8). Based on our model classifications, the predicted regional subsistence use area was 353,771 km², equivalent to 62% of the land area of Interior Alaska.

DISCUSSION

*Continuity and change in subsistence use areas*

Most documentation of traditional use areas is passed through generational knowledge; this study helps to translate that depth and complexity of land use through GIS analysis. Our findings demonstrate the continued importance of traditional use areas to contemporary subsistence, with approximately 70% of contemporary subsistence land use occurring within historically documented use areas. This finding was not surprising, as many traditional use areas such as hunting areas, seasonal fish camps, and trapline routes are known to be revisited for generations (Brown et al. 2014). The use of new areas is also significant, with about 30% of contemporary subsistence land use occurring outside of historically documented use areas.

Subsistence use areas can change over time for a multitude of reasons. Changes in resource availability or harvest regulations impact patterns of harvesting. For example, the severe decline in Chinook salmon stocks since 2007 has forced people to harvest greater quantities of other species (Holen et al. 2012, Hansen et al. 2013, ADF&G 2019b). Changes in land ownership and regulations frequently constrain how, when, and where subsistence activities may occur (Fall 2016). By reducing local fish and wildlife populations and altering migratory routes, industrial development can decrease subsistence harvests, cause a shift to harvesting different species, or necessitate travel further from communities (Cameron et al. 1992, Holen et al. 2012). The road-building that accompanies resource development has led to increased competition for wild resources between locals and nonlocals, resulting in more restrictive hunting and fishing regulations, and a consistently strong decrease in local subsistence harvests (Wolfe and Walker 1987, Magdanz et al. 2017). The adoption of new technologies has also had a large impact on mobility for harvesting; for example, the use of motorized boats and ATVs enabled people to travel farther and faster. Demand

Fig. 7. Predicted probability of subsistence land use by rural Interior Alaska communities derived from logistic regression models. The regional composite was constructed from community-level model output using the maximum probability value (0 – 1.0) per pixel. These models likely underestimate the probability of subsistence land use, since they were derived from maps representing a single year of subsistence activity.

for specific resources also changes over time. With the shift toward snow machine use, less fish was needed to feed sled dog teams (Anderson 1992); and as the fur trade declined so did the demand for furbearers (Holen et al. 2012). The socioeconomic change toward wage employment has also reduced the amount of time that people can allocate to traditional harvest activities (Holen et al. 2012).

Land use patterns of contemporary subsistence: accessibility and community characteristics

The overall size of contemporary subsistence use areas varied markedly among communities from under 50 km² to almost 25,000 km² and was partially explained by large differences in community population size. To avoid crowding and competition for finite resources (Hasbrouck et al. 2020a, 2020b), local residents tend to spread out across the landscape. Larger communities are therefore expected to have a larger subsistence use area. The direct relationship between population size and the probability of subsistence use held true for both remote and road-connected community types.

Subsistence use areas were concentrated around rural communities and extended outwards along the main travel corridors of river and road networks. The vast majority of subsistence activity occurred within 100 km from home, although some local residents traveled over >150 km primarily for hunting and fishing. For remote communities, most land use for subsistence occurred within 10 km of rivers, underscoring the importance of rivers as their primary travel corridors, traveled mainly by boat in summer and snow machine in winter (Johnson et al. 2016). Rural residents also commonly travel by ATV along trail networks from their home community for subsistence harvesting, although trail maps were not available to use in this study. As expected, road-connected communities used both roads and rivers as travel corridors for subsistence purposes. Subsistence use areas tended to span greater distances from roads than from rivers, which could be due to increased competition or human disturbance along roads and the use of secondary transportation means from the main travel corridors (e.g., ATV). The logistic regression statistics suggest that distance to communities and main travel corridors have a stronger influence on remote

Fig. 8. Predicted subsistence use areas for rural Interior Alaska communities derived from logistic regression models. Subsistence use areas are displayed with semi-transparency so that overlapping use areas from different communities appear darker. Predicted subsistence use areas were classified using predicted probabilities of subsistence land use ≥ 0.52, a threshold that balanced false positive and false negative error rates. The predicted subsistence use areas are likely underestimated, since the models were derived from maps representing a single year of subsistence activity.
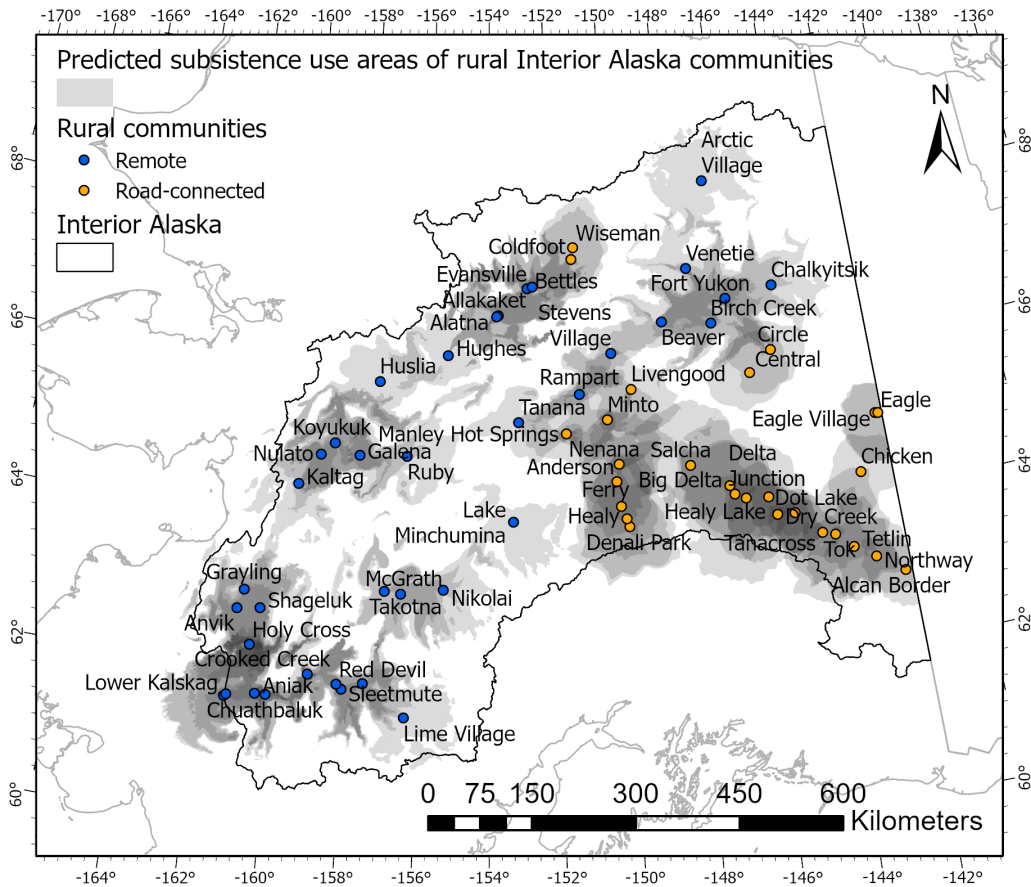
communities than road-connected communities which could reflect the use of more limited travel networks (rivers and trails) and modes of travel (boat, ATV, snow machine), the greater availability of wild resources, and less competition in remote communities.

The spatial patterns of subsistence activity quantified in this study are consistent with the *central-based use area* land use pattern described for rural Alaskan communities (Wolfe 2004), where a core area surrounding the community is used intensively for the majority of subsistence production and outlying areas are used less frequently. A central-based use area pattern is efficient, optimizing harvests per investment of effort and limited capital, such as fuel costs (Brinkman et al. 2014). Rural residents commonly use the same seasonal fishing and hunting camps for years or generations, which are generally along travel corridors that facilitate access (Johnson et al. 2016).

Variation in subsistence use areas by resource and season

Resource availability and harvesting strategies influence the land area used for different subsistence activities. For example, the

largest land area was used for harvesting large land mammals, an important resource comprising a major portion (29%) of the edible subsistence harvest. Hunting large land mammals, like moose or caribou, can require a large search area, and hunters need to spread out to reduce competition. Fish provide the largest food harvests by weight (66%); however, land use for fishing was among the smallest areas, as large volumes of migrating fish are often captured in single locations using fish wheels and nets placed in areas close to communities to foster daily trips. The harvest of plants and wood also occurred over relatively small areas.

Small game and furbearers comprised a small portion (2%) of the total non-wood harvest; yet, a disproportionately large land area was used for these resources. Though birds generally comprise small harvests by weight, they are a commonly used resource by many. Use areas for resident upland game birds (e.g., grouse, ptarmigan) sometimes encompass those of other resource types because they are often hunted opportunistically and while engaging in other harvesting activities (Holen et al. 2012). Residents travel to hunt migratory waterfowl (e.g., geese, ducks) in their habitat along river corridors, lakes, and wetlands.

Trapping strategies for the harvest of small mammals typically consist of long traplines for the harvest of few larger mammals (e.g., wolf, lynx, wolverine) and mostly small furbearers (e.g., marten). Because of a low density of furbearer populations, traplines need to traverse long distances to increase encounter rates (Van Lanen et al. 2012). Predator populations are also generally lower near human settlements, requiring trappers to travel farther away from the community (Van Lanen et al. 2012).

The spatial area used for subsistence also varied seasonally, with larger areas used for the harvest of most resources from May–October. This aligns with the seasonal round of harvesting, where most activities, such as fishing, hunting, and berry-picking, occur in spring, summer, and fall. The area used for harvesting small game and furbearers, however, was greatest from November–April. Upland game birds are hunted year-round, while trapping occurs mainly in winter when pelts are in prime condition (Holen et al. 2012). As primarily a winter activity, trappers often rely on traversing frozen water bodies to access traplines. This access has been notably compromised in recent years by changes in the seasonality of ice regimes with a warmer climate (Brown et al. 2018, Cold et al. 2020).

Model-based predictions of subsistence land use

Using maps of documented subsistence use areas (Neufeld et al. 2019), we modeled geospatial relationships that allowed us to effectively predict subsistence use areas across the Interior region, with classification accuracies of 86% for remote communities and 83–84% for road-connected communities. The models included parameters for distance to communities, distance to main travel corridors (river or road), distance to lakes (for remote communities), and population size. The spatial model output from this study supplements the maps of documented use areas to give a more complete view of land use for subsistence. These new spatial products can be used for self-advocacy by communities, to convey the spatial extent of subsistence activities to minimize conflict, and to inform researchers and decision-makers on the human impacts of development, policy, and climate change. For example, models of subsistence land use can help determine locations where development/commercial activities would directly interfere with subsistence practices, or help identify areas where competition with nonlocal hunters could be reduced through regulatory action. The models can also facilitate scientific research on how the changing environment influences access to subsistence resources and support community planning for climate adaptation (e.g., Gibson et al. 2021).

Conflicts arise when local values clash with those of outsiders (Wolfe 2004, Holen et al. 2012, Hasbrouck et al. 2020a). Some of this conflict is due to a lack of awareness of local cultural values and that much of Alaska's sparsely-populated wilderness is actively used by residents for subsistence. Our models show the vast areas used by rural residents for their subsistence activities in Interior Alaska (353,771 km²). From these models, we estimate that approximately 60% of the region's land area is used for local subsistence by rural communities. Increased awareness of these land use patterns is needed to improve outcomes of interactions with outside organizations and individuals who visit and work in rural Alaska. Outside human activities (economic development, tourism, research) continue to increase in rural Alaska. Avoiding

and mitigating disrespectful encroachment are critical for the socioeconomic and cultural well-being of rural Alaska communities.

Conclusions

This study builds upon prior research on subsistence in rural Interior Alaska and provides quantitative analyses and model-based predictions of subsistence land use throughout the region. Our study confirms the sustained importance of traditional use areas that have been used for generations, while also showing the contemporary subsistence activities in areas where historical use had not been documented. The size of contemporary subsistence use areas, influenced by community population size, exhibited wide variation. Subsistence land use varied both by resource type and by season, reflecting differences in resource availability and harvesting strategies. The spatial patterns of overall subsistence land use were strongly influenced by accessibility, which varied between remote and road-connected communities. Subsistence land use was largely explained by distance to communities, distance to main travel corridors of rivers or roads, distance to lakes (for remote communities), and population size. We used these empirical relationships to model subsistence land use for the entirety of rural Interior Alaska. The resulting maps show the vast land area that is used for subsistence by rural residents. These maps can help us assess the impacts on subsistence from changes in land use, policy, resource availability, climate, and environment. Local communities can use these maps for self-advocacy and to communicate the importance of certain areas and travel networks to their subsistence practices. A shared understanding among multiple land users may reduce conflict and inform smart, adaptive, and timely decisions. A similar approach could be applied to modeling human–environment interactions in other regions to facilitate a more comprehensive understanding of subsistence patterns and the spatial footprint of subsistence throughout the Arctic.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.
php/13256

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