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## Quantifying Rural Hunter Access in Alaska

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### ABSTRACT

Despite hunter access influencing harvest success, few studies have quantified characteristics of hunter access. Based on spatially explicit interview data, we used geographic information system (GIS) analyses to calculate access pathways and distances that rural hunters traveled to moose (*Alces alces*) harvest locations in Interior Alaska. Using Jenks Natural Breaks classification, approximately 53%, 21%, 5%, and 21% of harvest locations occurred along navigable rivers within 0 to 24, 25 to 52, 53 to 86, and >86 km (0 to 14, 15 to 32, 33 to 53, and >53 mi), respectively, from the hunter's community of residence. We used moose density estimates in the area being accessed by hunters to calculate annual moose harvest. Our results were similar to estimates from independent sources that used more standardized methods (e.g., agency household surveys). This suggests that our access-based approach has potential to provide an alternative method for estimating harvest intensity in areas where harvest report data are considered unreliable. Also, our findings demonstrated how insight on hunter access may help prioritize areas for active management.

### KEYWORDS

Arctic; GIS; hunter access; subsistence; wildlife management

## Introduction

Along with game population size and seasonal distribution, a hunter's ability to access land controls the availability of the resource for harvest (Brinkman, Kofinas, Hansen, Chapin, & Rupp, 2013; Gratson & Whitman, 2000a; Millspaugh, Brundige, Gitzen, & Raedeke, 2000). An increase in the amount of spatial and temporal data on hunter interactions with wildlife and wildlife habitat has increased the understanding and ability for researchers to quantify how hunters use the landscape. Overall, these data have demonstrated that hunters predominantly use easily accessible areas (Gratson & Whitman, 2000b). For example, white-tailed deer (*Odocoileus virginianus*) hunters concentrated effort within .8 km (.5 mi) of a road 98% of the time in Minnesota, disproportionately harvesting deer in those areas (Fuller, 1990). Increased hunter access decreased moose (*Alces alces*) density in Ontario, and increased the probability of mortality of elk (*Cervus canadensis*) in Idaho, whereas closing roads significantly decreased the number of elk hunters in a given area (Gratson & Whitman, 2000a; Rempel, Elkie, Rodgers, & Gluck, 1997; Unsworth, Kuck, Scott, & Garton, 1993). The

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development of access may quickly change the amount of hunting pressure in a region. In African communities, new logging roads facilitated access and increased legal and illegal harvest of game for personal use and commercial markets (Bowen-Jones, Brown, & Robinson, 2003). Given there is a strong link among hunter pressure, harvest, and access, game managers can benefit from estimating, monitoring, and incorporating the extent of hunter access into management plans.

Qualitative evidence suggests that access to subsistence resources in the Arctic may be as important to harvest success as abundance of subsistence resources (Brinkman et al., 2014; Chapin et al., 2010; Kofinas et al., 2010). However, limited data are available to quantitatively assess this statement. We define subsistence as non-commercial “customary and traditional use” of wildlife and fish as legally defined by the state of Alaska (Fall & Wolfe, 2012). To date, few published studies have quantified characteristics related to rural hunter access to subsistence resources. Brinkman et al. (2014) examined the effect of fuel costs on access to subsistence resources and found that rising fuel costs have reduced subsistence activity (e.g., travel distance) by 60% in the last 10 years. Spatially explicit data on how and where game populations are accessed may aid game managers by providing insights into relative pressure on habitat and the resource, and the importance of certain corridors and habitat types that facilitate or hinder hunter access.

Our research quantified access of subsistence hunters from several communities in the interior of Alaska. Specifically, we quantified access to moose by five communities in the Yukon Flats using decades of spatially explicit documentation (e.g., traditional ecological knowledge [TEK]) of hunting patterns of subsistence users. TEK provides a tool for researchers to gain insight from area residents that are most familiar with the land, and can be defined as the insight gained from an individual or community based on their long-time, in-depth, and broad interaction with a species or use of an area (Huntington, 2000). TEK research has been shown to be an effective component of sustainable management and monitoring of local wild resources (Huntington, 2000; Polfus, Heinemeyer, & Hebblewhite, 2013). Moose are an ideal resource to quantify access in the Yukon Flats because they are a primary subsistence resource pursued by most hunters in the area on an annual basis. Predominant access for moose occurs in September using boats, which allows us to infer an access path with confidence (Van Lanen, Stevens, Brown, & Koster, 2012).

Game management goals usually include population level and harvest targets (Crichton, 1993). Within Alaska, hunters are required to report information from their hunt (e.g., harvest success, location), and those compiled reports inform game managers if harvest targets were met. This information also helps when setting future management goals. Andersen and Alexander (1992) demonstrated that harvest reporting via harvest tickets is low in rural communities because harvest tickets and a one-moose limit are not in line with traditional group hunting and sharing practices. McCorquodale (1997) reported a similar sentiment in other subsistence hunting regions of the United States. Traditionally in indigenous communities, a single hunter may harvest several moose in a season and share the harvest with several households. Andersen et al. (1992), citing a personal communication, suggested that only 40 to 50% of moose harvest was being reported in some rural communities. Schmidt and Chapin (2014) reported that levels of under-reporting were correlated with percentage of community that was indigenous, amount of moose-meat sharing among

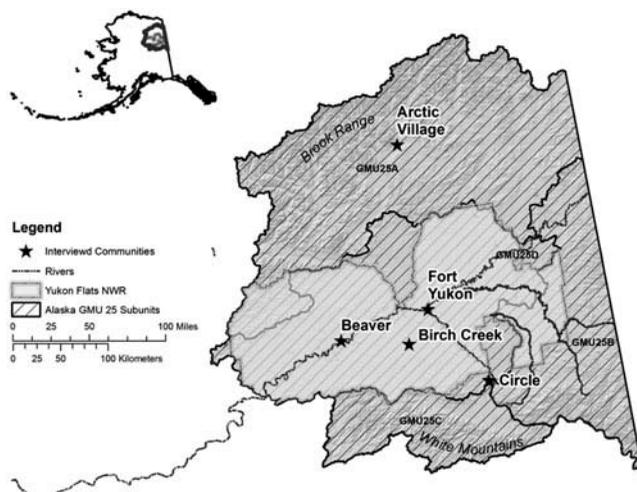
households within a community, and the absence of an agency wildlife biologist in and road access to the community. In rural areas with under-reporting, wildlife managers are unable to effectively use harvest data to guide management (Klein, Moorehead, Kruse, & Braund, 1999).

We propose an alternative approach to estimating moose harvest that may circumvent these under-reporting problems. Our research used spatially explicit information on moose hunter access, estimates of moose density, and the best-available data on moose harvest rates to answer the following questions: (1) where are local communities concentrating their moose hunting activity, (2) how many moose are available for harvest in areas accessible to moose hunters, and (3) how many moose are harvested by communities on an annual basis from these areas? We addressed these research questions in remote areas of the interior of Alaska where few communities are connected to the road network and high levels of under-reporting of moose harvest are thought to occur. Given that communities are disconnected from the road network, travel may be limited by fuel cost (Brinkman et al., 2014), and qualitative data suggest that subsistence activity focuses on navigable rivers in the interior of Alaska (Caulfield, 1984), we hypothesized that our quantitative investigation would reveal that moose hunter access concentrated around communities and near primary rivers. We quantified access based on TEK interviews and estimated harvest using game densities and access likelihood. This approach represents a novel way to inform wildlife managers of spatially explicit levels of harvest. More broadly, our research proposes that quantifying access to wildlife resources within a spatially explicit framework may provide insight on how to monitor and manage hunter access to achieve harvest goals in the Arctic and elsewhere. Also, our approach may provide a model for other systems where hunting pressure and success are strongly correlated to access.

## Methods

### *Study area*

The Yukon Flats is located in the eastern interior of Alaska and is bounded by the Brooks Range to the north and the White Mountains to the south (Figure 1). The Yukon River bisects the region, and at its center is the confluence of the Yukon, Porcupine, and Chandalar rivers. The Yukon Flats National Wildlife Refuge (NWR) covers approximately 34,000 km<sup>2</sup> (8.6 million acres) and a majority of the Yukon Flats (~90%). It stretches approximately 350 km (220 miles) from east to west and 190 km (120 miles) north to south. Land ownership of the Yukon Flats is a complicated checkerboard pattern of private, state, and federal lands. Subsistence moose harvest is regulated under a “dual management system.” Harvest of moose on state lands is regulated by the Alaska Department of Fish and Game (ADF&G) and moose harvest on federal lands is regulated by the federal government under a Memorandum of Understanding (Fall & Wolfe, 2012). Most of the Yukon Flats is within Game Management Unit (GMU) subunit 25D, but the Yukon Flats does bisect 25B to the east and 25A to the west (Figure 1). Within the GMU subunits, moose hunting occurs between August 25 and February 28. Hunters are allowed to harvest one Bull Moose per regulatory season. However, 89% of moose hunting often occurs in September before freeze-up and is predominantly conducted by boat (Van



**Figure 1.** Study area including the boundary of the Yukon Flats National Wildlife Refuge and interviewed communities.

Lanen et al., 2012). In general, qualitative data suggest that moose are killed near rivers (Caulfield, 1984; Van Lanen et al., 2012). Moose populations within the Yukon Flats are at some of the lowest densities in the world (Gasaway et al., 1992; Lake, Bertram, Guldager, Caikoski, & Stephenson, 2013). Aerial estimates during November 2010 indicated .08 moose/ km<sup>2</sup> (.20/ mi<sup>2</sup>) in the western Yukon Flats (Lake, 2013). Based on the National Land Cover Dataset (Homer et al., 2007), the Yukon Flats is 67% boreal forest and 33% riparian areas. Boreal forests and riparian species include white spruce and black spruce (*Picea glauca*, *P. mariana*), white birch (*Betula papyrifera*), aspen and poplar (*Populus tremuloides*, *P. balsamifera*), alder (*Alnus spp.*), and willow (*Salix spp.*) (Caulfield, 1984; Homer et al., 2007).

We analyzed moose hunting patterns for five communities within the Yukon Flats: Beaver, Birch Creek, Circle, Fort Yukon, and Arctic Village. The community of Arctic Village lies just beyond the northern border of the Yukon Flats NWR in the foothills of the Brooks Range and Circle lies just south of the Yukon Flats NWR border. With the exception of Circle, these communities are disconnected from the road network. Some communities off the road network are accessible by barge during the summer and snow machine during winter, and all communities are accessible by plane year-round. Fort Yukon has the largest population ( $N = 583$  (U.S. Census Bureau, 2010) of all the communities in the Yukon Flats. Populations in the other communities range from 33 to 104 people (U.S. Census Bureau, 2010) and residents of the communities are mostly Athabaskan Indian (U.S. Census Bureau, 2010). Previous studies in the Yukon Flats have outlined areas used for subsistence (Caulfield, 1984; Sumida, 1988, 1989; Sumida & Andersen, 1990), but these studies have not quantified access within those areas.

Communities within the Yukon Flats have a mixed cash-subsistence economy. Wage employment is low and subsistence harvest provides a significant source of nutrition for community residents (Wolfe & Walker, 1987). Subsistence resources also are critical to the cultural well-being of the region (e.g., potlatches) (Brinkman et al., 2014; Kofinas et al., 2010; Van Lanen et al., 2012). Primary subsistence resources

include moose, caribou (*Rangifer tarandus*), fish (e.g., *Oncorhynchus tshawytscha*, *O. keta*, *O. kisutch*), berries, and firewood (Van Lanen et al., 2012).

Communities within the Yukon Flats have similar harvest patterns (e.g., timing, methods) (Caulfield, 1984). During 2009–2010, 78% of households in the Yukon Flats reporting using moose, and 26% of households harvested a moose (Van Lanen et al., 2012). Sharing of hunting equipment and harvest is common (Holen, Hazell, & Koster, 2012). It is common for families who move to a different community to continue using the same fishing and hunting areas (e.g., traditional use areas) they used when residing in their previous community (Kofinas et al., 2010). Therefore, multigenerational subsistence areas are maintained despite family relocations. When a moose is harvested, sharing often occurs among households within a community. Reporting of harvest to management agencies is considered low in these study communities (Andersen & Alexander, 1992; Schmidt & Chapin, 2014). Therefore, game managers view harvest numbers as unreliable and an alternative method of determining harvestable moose is sought by game managers.

### **Hunter interview process**

We used moose hunting data generated from a traditional land-use mapping project conducted by the Council of Athabaskan Tribal Governments (CATG). CATG's objective was to develop a "rigorous and legally defensible database" by systematically interviewing subsistence users in communities of the Yukon Flats to document knowledge of areas important for traditional and cultural activities such as subsistence (Thomas, 2005, p. 6). Each community's Tribal Council drafted a comprehensive list of interviewees including hunters, elders, berry pickers, traditional medicine practitioners, tribal historians, and those (if any) currently living away from the community who had traditional knowledge of local harvest activities. CATG conducted structured interviews in 2005 and 2007 using a one-on-one format. During the interview, the interviewer asked the interviewee to identify the local resources they have harvested (e.g., moose, ducks, berries, house logs). The interviewee was then encouraged to spatially document where and when the resource was used. If the interviewee was unable to clarify an exact location, the location was not mapped. Harvest locations were mapped on a transparent, mylar sheet overlaid on a topographic map. Metadata were recorded for each use location in a separate data table. During the interview, interviewers collected use points (e.g., harvest location), use line (e.g., trap line, access corridor), or use polygon (e.g., waterfowl hunting areas) depending on the feature type that fit the activity best. CATG also collected metadata on access method, years of use, and the cultural name of harvest location. We digitized the data from CATG interviews in ArcGIS to a File Geodatabase and projected the spatial data in NAD Zone 6 N.

For the purpose of this study, we explored moose harvest data because moose are a critical subsistence resource harvested on an annual basis, hunting corridors (i.e., rivers) could be inferred, and there was a sufficient sample size ( $n = 247$ ). Within the database, moose points were both described as "moose hunting" and "moose harvest" (hereafter, jointly referred to as harvest points). Interview participants reported moose harvest points over their lifetime and include data from 1941 to 2005. Some harvest points represented moose hunting areas used over consecutive years (e.g., 1960 to present). In these instances,

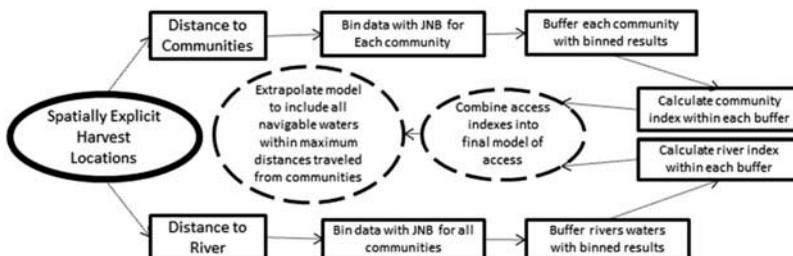
no extra weight was given to these points in our analysis because multiple stacked points from one interview participant were not considered independent.

### **Spatial analysis of interview data**

We evaluated hunter access by identifying the river route and distance that hunters traveled from their respective communities to their moose hunting/harvest area, and the distance they traveled from rivers. For this analysis, we pooled harvest points for all years due to strong spatial overlap in reported harvest locations across all years. We calculated the Euclidean distance of the harvest points from nearest navigable river at 1:1,000,000 scale and the Euclidean distances of each harvest point to the hunter's community of residence. We calculated the actual river distance to the point, and ran a linear regression of the Euclidean distance and the actual river distance travel to the harvest point. The regression showed a strong relationship ( $p < .001$ ,  $F = 454.6$ ,  $df = 216$ ,  $r^2 = .68$ ). This correlation was important because it demonstrated that using Euclidean distance in our model translated into real distance traveled, making our model applicable to subsistence users.

To distinguish levels of access, we grouped Euclidean distances from rivers and each of the five communities into five groups using Jenks Natural Breaks (JNB). The JNB method is often used in ArcGIS as a method for grouping data. In the method, the user selects the attribute to be classified and specifies the number of classes. A set of  $k-1$  random or uniform values are generated in the range and utilized as initial class boundaries. The mean values for each initial class are computed and the sum of squared deviations of class members from the mean values is computed. The values for each class are systematically assigned to adjacent classes with the goal of reducing the total sum of squared deviations. The procedure ends when within class variance is as small as possible and between class variance is as large as possible (De Smith, Goodchild, & Longley, 2007). We chose the JNB method to help draw out moose hunting patterns due to irregular groupings in the distances traveled in each community. Given this analysis relies on visual interpretations of the data, it is important that the trends of each community are emphasized. Alternative methods such as equal interval or quartiles may have hidden visual data trends.

To translate the JNB distances into GIS layers representing spatially explicit routes and distances traveled, we created a multiring buffer around river access routes to harvest points (Figure 2). We calculated the access routes in ArcGIS 10.2 Network Analysis and



**Figure 2.** Conceptual model of data analysis. The input data are contained within the bold oval. GIS processes are within rectangles, and the final model is within dashed ovals.

buffered them based on the JNB grouped values to create a layer of access distance from rivers. We calculated multiring buffers around each community based on their unique JNB grouped values to create a layer of access distance from communities. Within each buffer ring of the access routes and communities, we calculated the “access index” representing the number of harvest points contained in the buffer divided by the total harvest points up to that buffer ring edge (i.e., first buffer ring equals 100%). In the model, the access index represents the percentage of moose hunters accessing up to the edge of the buffer distance; a higher index represents an area that is accessed by a relatively higher percentage of moose hunters.

Our goal was to create an access index that combined the reported distance from community and river. To accomplish this, we rasterized the access distance from rivers layer and access distance from each community layer (cell size = 100 m), and we used ArcGIS raster math to add the six layers together into a final probability raster. We reclassified the final probability raster surface using JNB and three classes of high (1.39 to 2.52), medium (.80 to 1.38), or low (.12 to .79) access indices.

To extend the model of access to the entire study area (i.e., beyond rivers with reported harvest points), we used our access distance from community and river layers to identify other rivers and areas within our study area likely being accessed by moose hunters who did not participate in CATG’s traditional land-use mapping project (Figure 2). These areas did not have reported harvest locations, but were likely accessed by moose hunters given the areas were within reported travel distances. We determined navigable river size by averaging the Strahler stream order value (SSO) (Strahler, 1954) along travel routes to see what stream order was utilized. The average SSO was  $4.33 \pm 1.47$  SD. Based on that, we selected all streams within travel distances reported by communities that did not have reported harvest points along them, and had a SSO attribute value greater than 4. We buffered each of those rivers using the JNB values calculated from the travel routes. By extrapolating our model to rivers with characteristics similar to those of known travel routes, we encompassed rivers that did not have reported harvest locations. This was necessary, as our sample sizes varied by community in both the number of interviews and the number of points reported by the interviews (Table 1). Sample sizes in the smallest communities may adequately represent the variability in behavior of moose hunters from that community. However, in Fort Yukon, the population of which exceeds 500, the small sample size likely underrepresents the number of rivers used by hunters to access moose hunting areas. Extending our model to the entire area also enhances the model’s relevance to game managers of moose who are evaluating population dynamics at a GMU scale.

**Table 1.** Summary of JNB of the Euclidean distance of harvest points from community of residence. The number of points in parentheses is the number of moose harvest points falling inside of that break area.

Community	n (Number interviews)	Break distance km					Mean km $\pm$ SE
		(# pts)					
Fort Yukon	11	25.9 (13)	47.6 (14)	86.0 (5)	134.8 (16)	165.0 (36)	100.3 $\pm$ 53.4
Arctic Village	4	12.6 (5)	21.3 (3)	30.0 (3)	43.8 (3)	85.4 (1)	25.8 $\pm$ 20.7
Beaver	9	4.1 (4)	14.2 (9)	19.7 (11)	29.2 (3)	41.2 (1)	15.5 $\pm$ 8.2
Circle	8	11.4 (12)	26.7 (9)	52.6 (12)	62.6 (3)	82.7 (3)	32.4 $\pm$ 24.0
Birch Creek	11	6.6 (16)	13.4 (28)	23.2 (22)	32.7 (6)	40.8 (8)	15.0 $\pm$ 10.5
All	43	–	–	–	–	–	47.0 $\pm$ 32.0

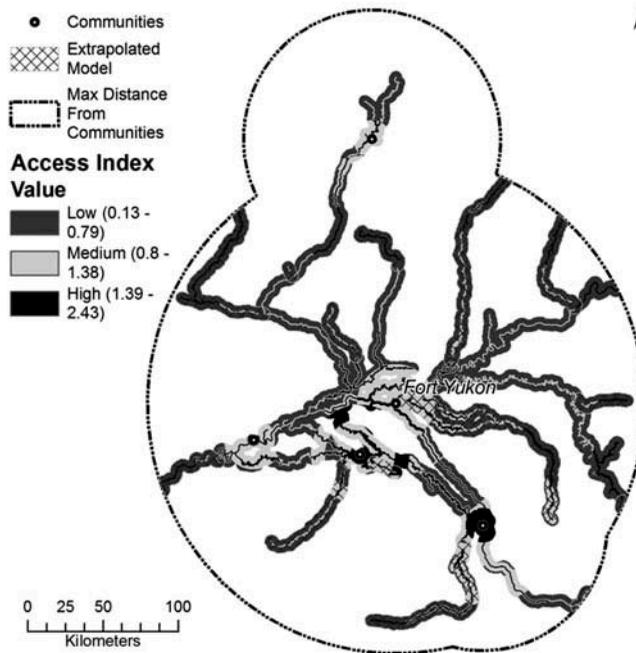
We demonstrated wildlife management applications of the final model in three ways. First, to demonstrate the area of hunter access relative to the areas of GMU 25, we calculated the total area of access (e.g., maximum distance buffer around rivers and from community) as the number of cells multiplied by cell size of  $.1 \text{ km}^2$ . We divided this area by the entire GMU to estimate the percentage of the GMU actually being accessed by hunters. Second, to demonstrate the number of bull moose available (legally harvestable demographic) in areas being accessed, we calculated the total area of each probability class by multiplying  $.1 \text{ km}^2$  by the number of cells in each access index class (i.e., high, medium, low). We then multiplied the result by  $.016 \text{ bull moose/km}^2$  ( $.04/\text{mi}^2$ ) (Lake, 2010). Important to interpretation of the number of accessible Bull Moose was that the density estimate ( $.016 \text{ bull moose/km}^2$ ;  $.04/\text{mi}^2$ ) was based on post-peak hunt (e.g., September) surveys. The survey time coupled with several other factors (e.g., non-uniform distribution) contributed to a conservative estimate of numbers of accessible moose. The moose surveys do not take into account the transient nature of rutting bulls that make them more susceptible to hunters (Jason Caikoski, ADFG, pers. comm.) because they are easier to see, and moose counts on the Yukon Flats tend to be greater closer to rivers (Lake, 2010). Although moose density post-peak hunt is not ideal, surveys are not conducted prior to hunting season because they are not socially acceptable, as data collection activities are perceived to disturb moose and impact hunter success.

## Results

Based on 43 interviews in five communities, we identified 247 moose harvest points along or near rivers between 1941 and 2005 (Table 1). On average, hunters traveled  $.9 \text{ km}$  ( $.6 \text{ mi}$ ) (SE =  $.6 \text{ km}$ ;  $.4 \text{ mi}$ ) from river corridors. Using JNB, 53%, 21%, 5%, and 21% of harvest locations occurred along navigable rivers between 0 to 24 km, 25 to 52 km, 53 to 86 km, and  $>86$  (0 to 14, 15 to 32, 33 to 53, and,  $>53 \text{ mi}$ ), respectively, from the hunter's respective community. The average travel distance from communities was  $47 \text{ km}$  ( $29 \text{ mi}$ ) (SE =  $32 \text{ km}$ ;  $7 \text{ mi}$ ).

The composite surface resulted in an access index (Figure 3) that ranged from  $.12$  to  $2.52$ . Areas with the highest composite access index value are accessed by the highest proportion of moose hunters. When we extrapolated distance findings to rivers around communities without reported harvest locations, we identified an access index of  $.13$ – $2.43$ , similar to the areas with harvest points.

We applied the models of combined access index around rivers with and without reported harvest to create a final access index (Figure 3) and estimate the number of legally harvestable moose available in each access index level (i.e., low, medium, high) based on regional moose density estimates. The reclassified combined access index surfaces (Figure 3) contained  $3,751 \text{ km}^2$  ( $1,448 \text{ mi}^2$ ) (17% of total) classified as high combined access index,  $5,645 \text{ km}^2$  ( $2,179 \text{ mi}^2$ ) (25% of total) classified as a medium access index, and  $13,300 \text{ km}^2$  ( $5,135 \text{ mi}^2$ ) (59% of total) classified as a low access index. The total access area is  $22,697 \text{ km}^2$  ( $8,763 \text{ mi}^2$ ) (16% of GMU25). By applying a general and uniform assumption of density of  $.016$  (95% CI  $\pm .007$ ) bull moose/ $\text{km}^2$  ( $.04/\text{mi}^2 \pm .02$ ) (i.e., legally harvestable) to the high probability area, we estimated conservatively that 60 (95% CI  $\pm 26$ ) legal moose are highly accessible to hunters from five communities. In medium access index areas, 90 (95% CI  $\pm 39$ ) legal moose are accessible, and 212 (95% CI  $\pm 93$ ) legal moose are accessible in the low index area. Within the total access area, we estimate 363 (95% CI  $\pm 159$ ) legal moose are available for harvest. Accounting for all



**Figure 3.** Combined access index surface of rivers with a Strahler stream order value  $>4$ , and which are within reported travel distances of communities, but that do not have reported harvest locations. Surface is based on raster math addition of access index values of distance from rivers and community. In the model, blue areas indicate lower probability of access, and red indicates a higher probability of access.

households that report using moose ( $N = 270$ ) within our study communities, we approximate that .22 (95% CI  $\pm .09$ ), .33 (95% CI  $\pm .14$ ), and .79 (95% CI  $\pm .34$ ) moose are available per household in the high, medium, and low access index areas, respectively. In the total access area, we estimate conservatively that 1.34 (95% CI  $\pm .59$ ) moose are available per household.

## Discussion

Our study quantified moose hunter access in rural Alaska. Similar to qualitative descriptions (Sumida, 1989; Sumida & Andersen, 1990; Van Lanen et al., 2012), we determined that hunters are using rivers. The traditional ecological knowledge dataset used in this analysis demonstrates the richness of data that can be collected through an interview process. For example, these data provided fine-resolution information that has not been captured well under the traditional harvest reporting systems that are reported at the broader scale of GMU sub-units or watersheds. The fine resolution of these TEK data provided practical insight into critical hunting areas. The accessed river corridors represent a small percentage (16%) of the total area (i.e., GMU) managed for a specific moose population goal and harvest number. During times with budget shortfalls, game managers may consider managing for and improving areas most accessed by users. Focusing management on this 16% of land may improve moose harvest opportunities, and alleviate conflict with non-local hunters by directing them to areas less utilized local communities.

Alternatively, if the goal of managers is to maintain moose numbers, rather than estimate harvest amount, they may consider liberalizing harvest in areas with less access and restricting harvest in high access areas.

Conflict between rural communities and non-local hunters continues to be an important issue in rural Alaska (Kofinas et al., 2010). Within the total access area, 40% of land is owned by native corporations and 44% is managed by the U.S. Fish and Wildlife Service (USFWS). The remaining 16% of land is managed by the State of Alaska, Bureau of Land Management, National Park Service, and Department of Defense. These different entities may implement measures that increase apparent local moose densities in the access corridors through moose habitat improvement or through manipulation of habitat to increase moose sight-ability. They may increase hunter access area through establishment of terrestrial trails (e.g., all-terrain vehicle [ATV]) trails away from navigable rivers, which may be difficult to access ordinarily because of impenetrable characteristics (e.g., shrub vegetation) of the upland landscape. Currently, the few established ATV trails around communities are used by moose hunters, but only offer day-hunt opportunities (Van Lanen et al., 2012). All of these management strategies have direct benefit to subsistence users and may also benefit the non-local hunting experience.

We linked our access model to estimates of Bull Moose density (.016 moose/ km<sup>2</sup>; .04/ mi<sup>2</sup>; Lake, 2010) to estimate the number of harvestable moose (363 moose) in the area accessed by hunters on an annual basis. If we multiply this estimate with the mean harvest success rate across Yukon Flats communities (27 to 46%; Alaska Department of Fish and Game, 2015; Van Lanen et al., 2012), we calculate that somewhere between 98 to 167 moose may be harvested annually. Using door-to-door household surveys, Van Lanen et al. (2012) estimated that Fort Yukon, Beaver, Birch Creek, and Circle harvested 88 moose in 2010. Although Van Lanen et al.'s (2012) estimate is 24% of our modeled estimate of 363 available moose, that study does not account for moose harvest in other communities (Arctic Village, Venetie, Chalkyitsik, Stevens Village) along the access pathways within our final model (Figure 3). Estimated annual moose harvest in those communities is roughly 26 moose (Stevens & Maracle, 2012) bringing the total community harvest of moose to around 114 moose. This estimate may be conservative considering the potential for underreporting in rural communities in Alaska (Andersen & Alexander, 1992; Schmidt & Chapin, 2014). Our estimates derived from an evaluation of access (98 to 167) are firmly within the plausible range of estimates from independent sources using other methods.

The similarities in estimates suggests that fine-scale information on access characteristics may provide an alternative method to estimating harvest and may be a more acceptable approach in communities that are reluctant to report harvest through agency channels (Andersen & Alexander, 1992; Schmidt & Chapin, 2014). Rather than rely solely on reported harvest of moose or GMU-wide bull moose densities to inform decision making, evaluation of moose densities in accessible areas and how that changes over time could provide a useful criteria for management. This would require development of smaller-scale population survey areas termed "analysis areas" by Kellie and Delong (2006), in combination with the larger areas that are already surveyed (Lake et al., 2013).

Our results indicated that hunters from Fort Yukon travel farther than any of the other communities (Table 1). Fort Yukon hunters may be traveling to traditional use areas or moving to areas with less hunting pressure and bypassing areas where moose could be

found (Van Lanen et al., 2012). We define traditional use as factual knowledge of both past and present uses of the land, and may include social and historical factors that influence the traditional land use of a population of people (Usher, 2000). Given that Fort Yukon is a regional hub with a larger population that includes residents with family in neighboring communities, it is a reasonable assumption that traditional use areas are outside Fort Yukon and closer to other communities. The best example of this is the high access of moose hunting in the Chalkyitsik region and Draanjik River (Black River). These data originate from Fort Yukon interviewees and demonstrate high access to an area up to 165 km (103 mi) (Euclidean distance) from Fort Yukon. Our results are in-line with qualitative work by Caulfield (1984) who found Fort Yukon moose hunters used hunting areas in Beaver, Chalkyitsik, Birch Creek, and Circle.

Our study represents an innovative way to model and quantify access for subsistence users in an arctic or sub-arctic system. This hunting system is dynamic and may be strongly affected by changing climate, river conditions, and social and economic factors in the future. For instance, the ability to access resources by boat or snow machine may be directly impacted by rising fuel costs (Brinkman et al., 2014) or changes in hydrology (Kofinas et al., 2010). Responding to fuel prices and risk to equipment subsistence from low river flow, hunters already report taking fewer, but longer hunting trips (Brinkman et al., 2014; Kofinas et al., 2010). This may reduce hunter effort (e.g., time and distance traveled) and success during each moose hunting season. Based on this, future studies may examine changes in access distance and effort over time with changing socio-economic costs, and could include how unique hunter demographics or user groups may access hunting areas differently. Of particular interest, hunter demographics and access could differ between private and public land hunting, and provide managers with estimates of harvest on private lands. Researchers may refine results by including a dynamic of hunter preference using popular resource selection functions (Boyce & McDonald, 1999; Manly, McDonald, Thomas, McDonald, & Erickson, 2002).

River access within our study area is analogous to road or trail access within many hunting systems, and enables our model to be applied to hunting systems where hunter access is driven by landscape characteristics or regulations. Along with access characteristics, game managers may consider changes in hunter demographics to forecast hunter pressure or harvested game based on a growing or retracting human population. Within North America, ungulate hunting success is strongly associated with road density (Fuller, 1990; Hayes, Leptich, & Zager, 2002; Rempel et al., 1997) and road closures on federal lands are a method of decreasing harvest. Spatial modeling of hunter access from the roads may inform game managers of the total area impacted by road closures, and with known ungulate densities, allow them to access the number of animals impacted by the closure. If the goal of management is not to create greater harvest opportunities, but instead maintain population levels, modeling future access may give managers a tool to proactively restrict quotas in a region, instead of waiting for hunter harvest information to inform their decision making. With a prior understanding of the game harvest as a response to hunter access, game managers could model the effect of newly established roads or trails on harvest. In Africa, applying access distance to newly established remote roads could identify areas where game harvest is not happening intensely, thus identifying conservation regions (Bowen-Jones et al., 2003).

Our model and methodology quantified moose hunter travel pathways and distances in rural Alaska, and used those metrics to estimate hunter harvest. Researchers and managers may find our approach useful when studying the influence of access in other hunting systems. As suggested, our approach may be used in regions where managers seek alternative ways to estimate or model harvest with varying scenarios of hunter access.

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