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Source: Wildlife Biology, 2020(2)

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/wlb.00631

Wildlife Biology 2020: wlb.00631
doi: 10.2981/wlb.00631

Subject Editor: Christophe Bonenfant. Editor-in-Chief: Ilse Storch. Accepted 23 March 2020

Quantifying effects of environmental factors on moose harvest in Interior Alaska

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Alaska moose (*Alces alces*) hunters have expressed concern that harvest has been challenged by warmer temperatures altering moose behavior and low water levels limiting boat access to hunting areas. The environmental impacts of these changes on moose harvest have not been quantified and are not well understood. Our objective was to assess how environmental conditions impact hunter harvest in Interior Alaska from 2000-2016. We split hunters into categories (local or non-local) and analyzed relationships during 5-day blocks that spanned the moose hunting season. The local harvest model associated high water level with increased harvest during block 4 (peak-harvest) of the hunting season ($p = 0.006$). A water level increase of 1 m increased daily harvest by 1.5 ($p = 0.003$). Non-local harvest was significantly different than null models for block 2 ($p = 0.001$), 3 ($p = 0.048$), and 4 ($p = 0.001$), and nearly in block 5 ($p = 0.063$). The non-local harvest model associated an increase in mean high temperature with reduced harvest in block 2 ($p = 0.004$) and block 5 ($p = 0.037$), and an increase in water level with increased harvest in block 3 ($p = 0.083$), 4 ($p = 0.017$), and block 5 ($p = 0.092$). These results reveal that local and non-local hunters are impacted differently by environmental conditions throughout the hunting season. We provided quantitative information on previously untested hypotheses regarding the impacts of dynamic environmental conditions on moose hunter harvest. Our findings provide wildlife managers with new insight on causes of variation in harvest among different user groups.

Keywords: *Alces alces*, big game, hunting, temperature, water level, weather, wildlife management

Hunter harvest of ungulates can be impacted by numerous factors. Previous research on ungulate harvest focused primarily on the impacts of access (Gratson and Whitman 2000), wildlife density (Reardon et al. 1978), wildlife behavior during hunting season (Grau and Grau 1980, Ciuti et al. 2012, Lone et al. 2015), hunting habitat (Mockrin et al. 2011) or hunter motivation (Bhandari et al. 2006). A few studies have explored temporal characteristics of hunter behavior and effort. For example, Mysterud et al. (2006) found non-local hunters of roe deer selected earlier hunting dates and better hunting locations, and Rivrud et al. (2014) noted that moon phase and day of week were strong predictors of hunter effort. However, the effects of temporal changes in environmental conditions on harvest are understudied, but timely considering climate-related shifts in local environmental conditions and trends. This topic is particularly relevant at high northern latitudes where changes in weather patterns have been amplified (Overland et al. 2014, Dai et al. 2019).

Changing environmental conditions are impacting the availability of wildlife that northern communities rely on for nutrition and culture (Brinkman et al. 2016, Cold et al. 2020). Communities in Interior Alaska documented a 3.7–4.8°C increase in mean annual temperatures and a 1.1–2.7°C increase in mean autumn temperatures from 1949 to 2015 (Alaska Climate Research Center 2018). These environmental variables are changing habitat characteristics and seasonality which may be altering hunter–wildlife interactions and challenging access to subsistence resources (Cold et al. 2020). Subsistence resources are wild resources used for customary and traditional purposes, meaning they have been economically, culturally, socially and nutritionally important for generations. In Interior Alaska, moose *Alces alces* is one of the most important subsistence species (Brown et al. 2010, 2018a).

During recent decades, rural communities who rely on moose meat have expressed concern about the effects of a changing climate on moose harvest opportunities (Brinkman et al. 2016). Specifically, communities have reported changes in autumn water levels (Wilson et al. 2015) and air temperature that are challenging their moose hunting opportunities (McNeeley 2009, McNeeley and Shulski 2011). The majority of moose hunting occurs along the major rivers and tributaries because riparian zones are suitable moose habitat and hunters primarily use watercraft to locate and transport moose (Johnson et al. 2016). Lower-than-normal river levels may hinder or block watercraft access to popular moose hunting areas such as sloughs, lakes and shallow tributaries of the major rivers (Brown et al. 2010). Therefore, low water may reduce the area and number of moose available to hunters. Further, changes in ambient temperature may influence moose and hunter behavior. Moose behavioral research shows that moose may respond to warmer temperatures by decreasing activity (McCann et al. 2016), switching to nocturnal behavior (Dussault et al. 2004), selecting shrubbier habitats (Melin et al. 2014), or avoiding open-spaces (van Beest et al. 2012). These shifts in behavior may decrease the likelihood of hunters locating moose. Additionally, warmer temperatures cause harvested moose meat to spoil more rapidly. It is common for hunters to voluntarily reduce their effort during warmer days to decrease opportunities for spoilage (Ball et al. 1999). Larger hunting groups may need to end their hunt earlier than anticipated to take care of the meat, which may restrict the opportunity for some members of the group to harvest. Communities have submitted proposals to the Alaska Board of Game requesting changes in regulations due to these weather-related factors.

However, the associations between moose harvest and changes in temperature and water levels during the hunting season have not been quantified. Therefore, our objective was to estimate impacts of these variables on moose harvest in Interior Alaska to inform moose management. We compared differences in the effects of environmental conditions between local and non-local hunters because hunting strategies and regulations are different between these user groups and concerns were mainly expressed by local hunters. We hypothesized that warmer temperatures would reduce daily harvest (i.e. reduce moose activity and encounters) and higher water levels would increase daily harvest (i.e. improve hunter access). To our knowledge, this study represents the first quantitative estimate of the association between moose harvest and environmental change and represents one of the few assessments of the effects of environmental factors on game harvest. Since climate change is a global threat it may be important for other regions to assess the impacts of local environmental factors on big game harvest and hunter satisfaction.

Study area

Our study was conducted in Interior Alaska near the Native (primarily Koyukon Athabascan) communities of Nulato, Koyukuk, Kaltag, Galena, Ruby, Huslia and Hughes (Fig. 1). These communities are located on the Yukon and Koyukuk Rivers about 400–500 km west from Fairbanks. The communities are isolated and disconnected from the road system. Due to high costs of living, as well as cultural preferences, residents rely on a mixed cash-subsistence economy (BurnSilver et al. 2016). In this type of economy, wild harvest and income are important parameters for livelihoods. For example, in Nulato, a typical rural community in Interior Alaska, 90% of households report using moose meat during the year (Brown et al. 2010). In 2010, Nulato residents reported that access to preferred hunting areas was limited in recent years due to low water levels (Brown et al. 2010). Moose hunting is regulated by both state and federal agencies. These regulations are complex, occasionally confusing and differ by region of the state and sometimes year (ADF&G 2016). Hunting season length, timing and quotas

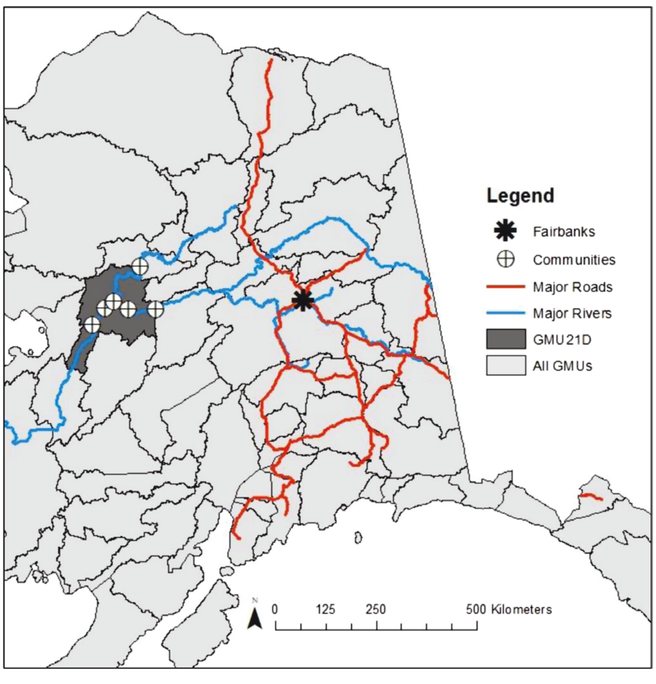

Figure 1. Map depicting the study area (Game Management Unit 21D) in relation to Fairbanks, Alaska.

are based on the timing of biological events (e.g. rut, calving, antler drop) and estimated moose populations. Moose hunting season is typically 1–25 September with some variation depending on location and hunt type.

The study area is in Game Management Unit (GMU) subunit 21D and is adjacent to the northern unit of the Innoko National Wildlife Refuge. For this study we assessed harvest within GMU21D. GMUs are subregions (n = 26) in the state that are designated and managed individually (or in clusters) by Alaska Department of Fish and Game (ADF&G) to maintain sustainable wildlife populations while providing hunting opportunities. The GMU is located in a boreal forest ecosystem at the juxtaposition of two ecoregions: Interior bottomlands, and Interior forested lowlands and Uplands. The area supports typical boreal species: white spruce *Picea glauca*, black spruce *P. mariana*, birch *Betula neoalaskana*, aspen *Populus* spp. forests, low to tall willows *Salix* spp., and wetlands mottled with oxbow lakes and thaw lakes comprised of low scrub bogs, herbaceous meadows and forb herbaceous marshes. The area experiences short, warm summers and long, cold winters with annual temperatures ranging from −40°C to 22°C (Brabets et al. 2000).

The Koyukuk controlled use area (KCUA) was established in 1978 due to the accelerating demand by hunters for a high moose density with large bulls and relatively easy boat access. The KCUA typically has more moose and more hunters than other parts of GMU21D and therefore ADF&G created the Koyukuk moose checkpoint station, a mandatory stop for all people hunting in the KCUA. Wildlife agencies manage the KCUA and the remainder of GMU21D and 24D with different regulations. Hunting season length and timing are often based on biological events (e.g. rut, calving) and accessibility (e.g. dangerous ice conditions) for local hunters (Glenn Stout pers. comm.) (Supplementary material Appendix 1). A geo-spatial population estimate (GSPE) conducted in 2011 in the KCUA estimated the population at 6379 ± 957 moose (Stout 2018). In 2014, GMU21D had an estimated 8749 ± 1300 total moose. In 2015, the checkpoint station documented 211 local residents, 205 non-local Alaska residents and 10 nonresident hunters attempting to harvest moose in the KCUA. A total of 237 bull moose were harvested by 111 local residents, and 126 non-locals (119 non-local residents, and 7 nonresidents), with success rates (no. harvested/no. permits) of 53, 59 and 70%, respectively (Stout 2018). The annual number of non-local hunters decreased in the early 2000s as a result in regulation change that was created to stabilize the harvest (Fig. 2). The number of local hunters apparently increased over time but this was likely a result of increased reporting rates rather than increased harvest rates. 'Failure to report' regulations were implemented statewide in 2004 and harsh consequences (e.g. loss of hunting permit the following year) helped increase reporting rates (Stout 2016).

Methods

We quantitatively assessed the local concerns about environmental conditions (temperature and water levels) on moose hunting by estimating the effects of those variables on moose harvest. We used daily data collected within our study area on temperature, water levels and moose harvest. We used daily high temperature data from the National Oceanic and Atmospheric Association (NOAA 2018) collected in Galena, Alaska (60 km east of Nulato), the only community within the GMU with a long-term weather station. We used data from the United States Geological Survey water gauge station on the Yukon River in Galena, Alaska to assess water level (m a.s.l.). We assumed that increase or decrease in water level caused a similar shift in tributaries and we acknowledge that these day may not account for other factors (e.g. riverbank erosion, sedimentation) that could affect access into sloughs adjacent to main river channels.

We used daily ADF&G moose harvest data collected from 2000 to 2016. We split hunters into two categories: local hunters (those who reside within GMU21D) and non-local hunters (those who reside outside GMU21D but come in to hunt). We assessed these hunter groups independently because regulations and hunt strategies are different for these hunter groups. We conducted analyses within the hunting season by breaking harvest into 5-day blocks to account for heterogeneity in timing of harvest prior to modeling. We examined harvest, water level (m elevation), and daily high temperature (°C) during block 1 (1–5 Sep), block 2 (6–10 Sep), block 3 (11–15 Sep), block 4 (16–20 Sep) and block 5 (21–25 Sep). The 5-day block analysis maintained an

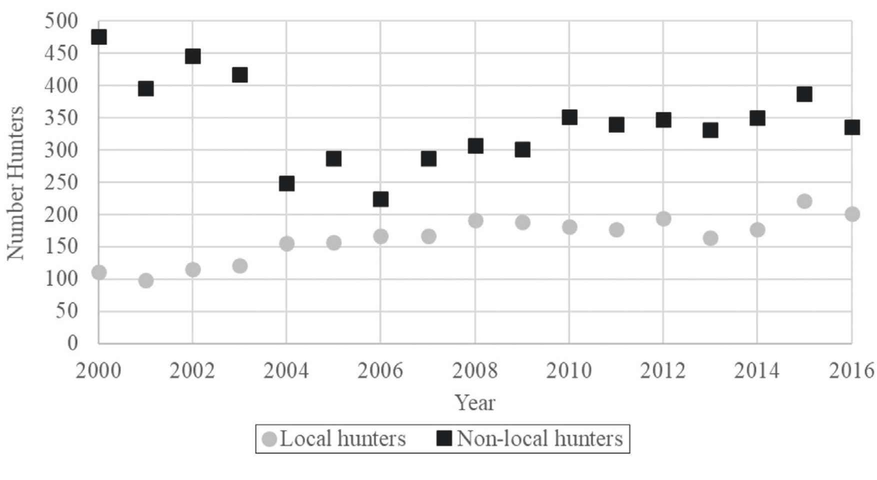

Figure 2. Annual number of local and non-local moose hunters in GMU21D from 2000 to 2016.

Table 1. Minimum (min), maximum (max), mean and standard deviation (SD) for dependent variables (local harvest and non-local harvest) and covariates (maximum temperature (°C), and water level (m above sea level)) from 2000 to 2016 in Interior Alaska.

Block	Parameter	n*	Min	Max	Mean	SD
1 (1–5 Sep)	Local harvest	61	0.0	7.0	2	1.9
	Non-local harvest	61	0.0	4.0	1	1.1
	Max temp	61	7.8	21.1	15	3.5
	Water level	61	30.4	33.7	32	0.8
2 (6–10 Sep)	Local harvest	68	0.0	7.0	3	1.8
	Non-local harvest	68	0.0	14.0	5	3.3
	Max temp	68	7.8	22.8	14	3.4
	Water level	68	31.3	33.7	32	0.7
3 (11–15 Sep)	Local harvest	65	0.0	11.0	4	2.6
	Non-local harvest	65	0.0	13.0	6	3.0
	Max temp	65	5.6	21.1	13	4.1
	Water level	65	31.0	33.6	32	0.6
4 (16–20 Sep)	Local harvest	64	1.0	18.0	6	3.2
	Non-local harvest	64	3.0	21.0	10	3.9
	Max temp	64	1.7	20.0	11	4.5
	Water level	64	31.0	33.2	32	0.6
5 (21–25 Sep)	Local harvest	68	0.0	14.0	6	2.9
	Non-local harvest	68	0.0	17.0	6	4.3
	Max temp	68	2.2	15.6	8	3.5
	Water level	68	30.8	33.0	32	0.6

* The number of days within the block that had harvest, water level and temperature data from 2000 to 2016.

adequate sample size during block assessment (Table 1). The majority of harvest (78% for local hunters and 81% for non-local hunters) occurred from 11 to 25 Sep. We used Pearson's r to assess correlation, and potential for collinearity, between our predictor variables. Correlation coefficients above 0.6 are assumed collinear.

We used a generalized linear model (Nelder and Wedderburn 1972) to predict the main effects of environmental variables on harvest during moose hunting season. Our model used a Poisson distribution with a log-link function because our response variable (moose harvest) was count data with a non-normal distribution. We used the omnibus test to perform a likelihood-ratio chi-square test to estimate if the model that included our environmental predictors outperformed the null model (i.e. intercept only model). We used the F statistic to assess significant effects of model variables. Model parameter estimates were used to assess the relationship and direction of influence between environmental variables and daily harvest count. We used exponentiated beta coefficients (Exp(B)) of model output to estimate how harvest changes with a one unit change in statistically significant environmental variables. We used SPSS (IBM SPSS statistics ver. 24) to generate all descriptive and model statistics and parameters.

Results

We used descriptive statistics to record the mean, minimum and maximum harvest, water level and temperature during our time period (Table 1). One year (2002) did not have water level data and other years had some days missing.

Table 2. Results from omnibus test of model performance. A significance value indicates that the model including environmental predictors outperformed the null model (intercept only).

	Block	Likelihood ratio χ^2	df	Sig.
Local harvest	1 (1–5 Sep)	0.55	2	0.759
	2 (6–10 Sep)	0.26	2	0.878
	3 (11–15 Sep)	1.97	2	0.374
	4 (16–20 Sep)	10.27	2	0.006***
	5 (21–25 Sep)	0.81	2	0.668
Non-local harvest	1 (1–5 Sep)	3.16	2	0.206
	2 (6–10 Sep)	14.23	2	0.001***
	3 (11–15 Sep)	6.09	2	0.048**
	4 (16–20 Sep)	13.70	2	0.001***
	5 (21–25 Sep)	5.53	2	0.063*

Significance levels: *** 0.01, ** 0.05, * 0.1.

Year 2002 was excluded from analysis and so were days within other years that had missing water level data. Our sample sizes within each block remained sufficient for analysis (Table 1). Environmental variables were not collinear for any time block (block 1, Pearson's $r = 0.13$; block 2, Pearson's $r = -0.28$; block 3, Pearson's $r = -0.44$; block 4, Pearson's $r = -0.51$; block 5, Pearson's $r = -0.34$).

Local and non-local hunters were impacted differently by environmental factors. For local hunters, only block 4 (16–20 Sep) was significantly different than the null model ($\chi^2 = 10.3$, $p = 0.006$) (Table 2). The local block 4 model estimated that water level was significant ($F = 9.35$, $p = 0.002$) (Table 3). For every one-meter increase in water level during block 4, we expect a 52% increase in moose harvest by locals per day (Table 4). For non-local hunters, blocks 2 (6–10 Sep), 3 (11–15 Sep) and 4 (16–20 Sep) were all significantly different than the null model ($\chi^2 = 14.2$, $p = 0.001$; $\chi^2 = 6.1$, $p = 0.048$; and $\chi^2 = 13.7$, $p = 0.001$, respectively) (Table 2). The block 5 model nearly outperformed the null model ($\chi^2 = 5.5$, $p = 0.06$) (Table 2). The non-local block 2 model found high temperature to negatively impact harvest ($F = 8.7$, $p = 0.004$) (Table 3). For every one-degree increase in temperature, we expect a 7% decrease of moose harvested per day by non-local hunters (Table 5). The non-local block 3 model found water level to be nearly significant ($F = 3.1$, $p = 0.083$) (Table 3), with higher water levels associated with increased harvest, but confidence intervals crossed 1.0 (Table 5). The non-local block 4 model found water level to be significant ($F = 6.1$, $p = 0.017$) (Table 3). For every one-meter increase in water level, we expect 25% increase in harvest per day by non-local hunters (Table 5). The non-local block 5 model identified temperature ($F = 4.55$, $p = 0.037$; $F = 2.92$) and water level ($F = 2.92$, $p = 0.092$) as significant (Table 3), respectively. During non-local block 5, for every one-degree increase in temperature, we expect a 6% increase in moose harvested per day by non-local hunters. For every one-meter increase in water level, we expect a 33% increase in moose harvested per day (Table 5).

Discussion

We accepted both of our hypotheses based on our findings. Higher temperatures and water levels decreased and increased harvest, respectively. Local hunters differed from

Table 3. Model effects of covariates (Temp = temperature (°C) and WL = water level (m a.s.l.)) on local and non-local moose harvest during moose hunting season in Interior Alaska from 2000 to 2016. Hunting season was broken into 5-day blocks.

	Block	Covariates	F	df1	df2	Sig.
Local harvest	1 (1–5 Sep)	Intercept	6.35	1	58	0.015**
		Temp	0.00	1	58	0.951
		WL	0.53	1	58	0.47
	2 (6–10 Sep)	Intercept	153.23	1	65	0
		Temp	0.02	1	65	0.886
		WL	0.26	1	65	0.612
	3 (11–15 Sep)	Intercept	209.07	1	62	0
		Temp	0.01	1	62	0.943
		WL	1.62	1	62	0.208
	4 (16–20 Sep)	Intercept	376.92	1	61	0
		Temp	0.65	1	61	0.423
		WL	9.35	1	61	0.003***
	5 (21–25 Sep)	Intercept	551.17	1	65	0
		Temp	0.06	1	65	0.811
		WL	0.53	1	65	0.468
Non-local harvest	1 (1–5 Sep)	Intercept	0.48	1	58	0.491
		Temp	2.83	1	58	0.098*
		WL	0.18	1	58	0.676
	2 (6–10 Sep)	Intercept	172.57	1	65	0
		Temp	8.67	1	65	0.004***
		WL	1.84	1	65	0.18
	3 (11–15 Sep)	Intercept	559.56	1	62	0
		Temp	0.47	1	62	0.497
		WL	3.10	1	62	0.083*
	4 (16–20 Sep)	Intercept	1361.87	1	61	0
		Temp	1.13	1	61	0.293
		WL	6.06	1	61	0.017**
	5 (21–25 Sep)	Intercept	224.62	1	65	0
		Temp	4.55	1	65	0.037**
		WL	2.92	1	65	0.092*

Significance levels: *** 0.01, ** 0.05, * 0.1.

non-local hunters in regard to the impacts of environmental conditions on moose harvest. Non-local harvest was more effected than local harvest by weather conditions throughout more of the hunting season. The relationship between non-local harvest and temperature may be related to fundamental moose biology. Moose are a cold-climate species and exhibit thermoregulation stress or decreased health at higher ambient temperatures. Renecker and Hudson (1986) found that winter temperatures exceeding 5°C and summer temperatures exceeding 14°C increased metabolism, heart rate and respiration rate in moose. Wind speed, habitat and an individual animal's physical health also contribute to heat stress (McCann et al. 2013). Moose respond to warm temperatures by selecting more densely vegetated

Table 4. Model parameter estimates of the effects of environmental factors on daily moose harvest within the moose hunting season for local hunters in Interior Alaska from 2000 to 2016. Temp is maximum temperature (°C) during the block and WL is average water level (m a.s.l.) during the block. Hunting season was broken into 5-day blocks.

				95% Wald CI		Hypothesis test				95% Wald CI (Exp(B))	
Block	Covariates	B	SE	Lower	Upper	χ^2	df	Sig.	Exp(B)	Lower	Upper
1 (1–5 Sep)	Intercept	−4.53	6.79	−17.8	8.8	0.45	1	0.51	0.01	0.00	6503.63
	Temp	0.00	0.05	−0.1	0.1	0.00	1	0.95	1.00	0.92	1.10
	WL	0.15	0.21	−0.3	0.6	0.52	1	0.47	1.17	0.77	1.76
2 (6–10 Sep)	Intercept	−0.93	3.95	−8.7	6.8	0.06	1	0.81	0.40	0.00	906.89
	Temp	0.00	0.02	0.0	0.0	0.02	1	0.89	1.00	0.96	1.05
	WL	0.06	0.12	−0.2	0.3	0.26	1	0.61	1.06	0.84	1.34
3 (11–15 Sep)	Intercept	−4.68	4.92	−14.3	5.0	0.91	1	0.34	0.01	0.00	142.53
	Temp	0.00	0.02	0.0	0.0	0.01	1	0.94	1.00	0.96	1.05
	WL	0.19	0.15	−0.1	0.5	1.62	1	0.20	1.21	0.90	1.62
4 (16–20 Sep)	Intercept	−11.87	4.52	−20.7	−3.0	6.90	1	0.009***	0.00	0.00	0.05
	Temp	0.01	0.02	0.0	0.0	0.65	1	0.42	1.01	0.98	1.05
	WL	0.42	0.14	0.2	0.7	9.31	1	0.002***	1.52	1.16	1.99
5 (21–25 Sep)	Intercept	−0.68	3.50	−7.5	6.2	0.04	1	0.85	0.50	0.00	481.88
	Temp	0.00	0.02	0.0	0.0	0.06	1	0.81	1.00	0.96	1.03
	WL	0.08	0.11	−0.1	0.3	0.53	1	0.47	1.08	0.88	1.34

Significance levels for environmental variables: *** 0.01, ** 0.05, * 0.1.

Table 5. Model parameter estimates of the effects of environmental factors on daily moose harvest within the moose hunting season for non-local hunters in Interior Alaska from 2000 to 2016. Max temp is maximum temperature (°C) during block and water level is the average water level (m a.s.l.) during the block. Hunting season was broken into 5-day blocks.

				95% Wald CI		Hypothesis test				95% Wald CI (Exp(B))	
Block		B	SE	Lower	Upper	χ^2	df	Sig.	Exp(B)	Lower	Upper
1 (1–5 Sep)	Intercept	3.54	6.06	−8.3	15.4	0.34	1	0.56	34.58	0.00	4936082.4
	Temp	−0.08	0.05	−0.2	0.0	2.71	1	0.10	0.93	0.85	1.01
	WL	−0.08	0.19	−0.4	0.3	0.18	1	0.67	0.92	0.64	1.34
2 (6–10 Sep)	Intercept	−3.33	4.51	−12.2	5.5	0.54	1	0.46	0.04	0.00	248.99
	Temp	−0.08	0.03	−0.1	0.0	8.46	1	0.004***	0.93	0.88	0.98
	WL	0.18	0.14	−0.1	0.4	1.84	1	0.18	1.20	0.92	1.57
3 (11–15 Sep)	Intercept	−4.24	3.64	−11.4	2.9	1.36	1	0.24	0.01	0.00	17.95
	Temp	−0.01	0.02	0.0	0.0	0.46	1	0.50	0.99	0.96	1.02
	WL	0.19	0.11	0.0	0.4	3.09	1	0.079**	1.21	0.98	1.50
4 (16–20 Sep)	Intercept	−4.74	3.00	−10.6	1.1	2.50	1	0.11	0.01	0.00	3.10
	Temp	−0.01	0.01	0.0	0.0	1.13	1	0.29	0.99	0.97	1.01
	WL	0.23	0.09	0.0	0.4	6.07	1	0.014**	1.25	1.05	1.50
5 (21–25 Sep)	Intercept	−7.86	5.48	−18.6	2.9	2.06	1	0.15	0.00	0.00	17.76
	Temp	0.06	0.03	0.0	0.1	4.52	1	0.033**	1.06	1.01	1.12
	WL	0.29	0.17	0.0	0.6	2.89	1	0.089*	1.33	0.96	1.86

Significance levels: *** 0.01, ** 0.05, * 0.1.

areas (Melin et al. 2014). Moose also ‘bed down’ in thermal refuges during warmer temperatures, therefore decreasing movement (McCann et al. 2016). In some parts of their geographic range, moose respond to warm temperatures by decreasing diurnal activity and increasing nocturnal activity (Dussault et al. 2004). In Interior Alaska, bull moose begin to increase movement from 19 to 25 Sep (Joly et al. 2015) and peak their movement during rut, around 1–7 Oct (Brown et al. 2018a). Additionally, warmer temperatures cause meat to spoil more rapidly. In Alaska, data are absent on how concerns about meat spoilage affect hunter behavior. However, other research on moose hunting suggests it does alter hunter effort (Ball et al. 1999).

The importance of water level for local and non-local hunters was most likely related to access and not moose biology. Climate-related changes in access to hunt areas have been found to be more important than game abundance or distribution of wildlife populations (Brinkman et al. 2016) and therefore, reduced access to hunting grounds may negatively influence harvest. Key tributaries and sloughs may become inaccessible for boat-based hunters, which is the primary hunting strategy in rural, Interior Alaska. Rural Alaska communities are known for being resilient to changes in the climate (Kofinas et al. 2010) and this resilience may explain why harvest within the season was not significantly associated with environmental factors for more than one week for local hunters. During 16–20 Sep, low water level may shut down harvest by reducing access or very high water may open up access to new areas creating better access to more moose. We are uncertain why local hunters were less effected by temperature and water level (excluding 16–20 Sep). We speculate that locals residing close to the hunting area may have more day-to-day opportunities to hunt and may be able to select ‘better weather’ days opportunistically during the season. Local hunters may be able to switch hunting locations easier than non-local hunters. Non-local hunters travel great distances to access the hunting area and are committed in advance to hunting during the time they allocated to the hunt.

Our results both partially support and contradict similar qualitative research (McNeeley 2009) and Board of Game Proposals written by rural entities. McNeeley (2009) raised concerns regarding the impacts of environment on moose hunters and suggested that recent environmental trends decrease harvest. Our results suggest that local harvest is impacted by environmental factors, but mainly during the peak season. Our results indicate that non-local hunters are more limited by challenging environmental conditions than local hunters. However, it is the local, rural hunters that were hypothesized to be negatively influenced by environmental factors. Our study suggests local hunters may be more adaptive to intra-annual variation. BOG proposals requested shifting season dates because inferior environmental conditions at the beginning of the season negatively impacted hunting opportunity. Added flexibility in harvest regulations may be warranted if trends in warming temperatures and later leaf drop continue. Local hunters may be challenged by these environmental factors but it does not appear that it directly impacted their harvest, yet. Continued monitoring of the association between environmental variables and harvest is necessary to determine when challenges may be too difficult to overcome and harvest is impacted.

Temperature and water level are not the only environmental variables that can impact harvest. Leaf drop, or the timing of when trees lose their leaves, has also been cited as a factor limiting moose harvest (McNeeley 2009). Extended growing seasons and delayed leaf drop dates are causing challenges for hunters because trees with leaves provide cover for game and obstruct hunter sightability (BOG Proposal 94 2017). Forest type has been shown to affect a person’s visibility of Sitka black-tailed deer *Odocoileus hemionus sitkensis* (Brinkman et al. 2009) and white-tailed deer *O. virginianus* (Sage et al. 1983) and logically extends to other forest ungulates such as moose. Leaf drop typically occurs during hunting season but if leaf drop is delayed, there may be fewer days within hunting season with good visibility. If the timing of senescence is changing in Interior Alaska then wildlife managers may need to consider potential impacts on hunting opportunities. We attempted to assess leaf drop in GMU21D, but the spatial and temporal resolution of the remote sensing data was insufficient to capture heterogeneity within the study area. Future research may be able to use remote-sensing technology (e.g. Sentinel satellite imagery) to assess this factor as higher spatial resolution imagery becomes increasingly available. At the time of this research, higher spatial resolution imagery was only just becoming available form Planet Labs. Further, techniques need to overcome cloud-cover limitations, a common issue with remote sensing in northern regions.

Although, this project was relatively short term and could not address climate change, it did show important relationships between environmental variables and harvest. As the climate continues to change these relationships may become exaggerated. In regard to water level, research in subarctic Alaska reveals shrinking ponds are linked to melting permafrost and increased evapotranspiration rates (Riordan et al. 2006) and research in south-central Alaska concluded 80% of field sites across the Kenai Peninsula are undergoing drying events (Klein et al. 2005). Lakes that are not undergoing terrestrialization (the process of changing from water to land) in boreal ecosystems in Alaska are influenced by permafrost presence and steeper banks with low surface to volume ratios, whereas disappearing lakes are characterized by encroaching vegetation, increased water temperature and shallow depths (Roach et al. 2011). If the landscape near ideal hunting grounds dries, hunters relying on boat access will likely be negatively impacted.

We acknowledge several limitations regarding our harvest data and environmental covariates. River depth was not measured for most Yukon River tributaries used by hunters within the study region. There may be differences in water levels in some secondary stream systems. The effects of fluctuating water levels and permafrost thaw may accelerate riverbank erosion and sedimentation, which also may inhibit access (Brown et al. 2018b). These changes were not addressed in this study but warrant additional exploration. We only assessed the impacts of environment on successful hunters, but we acknowledge that non-successful hunters are an important group to evaluate. It would be useful to assess the number of days people spent hunting to understand if effort changed over time or was associated with environmental parameters, but these data are possibly unreliable due to changes in reporting rates as well as hunter memory recall. Our ability to assess the impacts of changes in reporting rates were limited, which continues to be a difficult in rural Alaska (Schmidt et al. 2014). We recommend that wildlife agencies both explore strategies that enhance consistent harvest reporting and improve records on the activities of unsuccessful hunters in order to accurately gauge the impacts of environment on success and to enhance hunt satisfaction.

In Alaska, prior to this research, most information compiled on the association between climate and the availability of fish and game has been qualitative or anecdotal (Brinkman et al. 2016). This paper is among the first research attempts to quantify the effects of environmental variables on hunter harvest. We quantified impacts of environmental conditions on moose harvest in Interior Alaska and therefore addressed previously untested hypotheses regarding weather and harvest. The relationship between weather and harvest is complicated (Rivrud et al. 2014). Managers now have a better understanding on how unseasonable and extreme weather may affect moose harvest. Reduced moose harvest may cause decreased hunt satisfaction or may decrease food security in some locations. This research can be used as a stepping stone for future research in the area or for other regions where hunter satisfaction may be challenged by a changing climate. Further, hunters may be able to use this information to help decide hunt dates, select hunt locations or shift hunt strategies and can help managers form regulations that may assist hunters to adapt to changing environments. Our research identified that relationships between environmental conditions and harvest exist but we did not explore the specific mechanism linking these parameters. Changing environmental conditions (e.g. temperature) are impacting moose biology (Montgomery et al. 2019, Thompson et al. 2019, Weiskopf et al. 2019), but the specific effects of weather on moose behavior and physiology was beyond the scope of this study. Now that a relationship between moose harvest and environmental conditions has been identified, a logical next step is to assess how moose biology interacts with hunter–environment relationships. Future research could explore possible mechanisms (e.g. changes in moose and human behavior, habitat loss, access, etc.) linking these parameters through moose behavioral studies, human interviews and remote sensing of habitat characteristics and change. Although our research was focused on a case study in Alaska, accelerated trends in climate change are global. Wildlife management in other regions may benefit from investigations on the impacts of environmental conditions on local hunting opportunities.

Acknowledgements – This research was made possible through our partnerships with Nulato Tribal Council (especially A. Demoski), Koyukuk Traditional Council, Council of Athabascan Tribal Governments, and Tanana Chiefs Conference, as well as guidance from K. Heeringa and the Community Research Partnerships for Supporting Sustainable Traditional Harvest Practices crew.

Funding – Our research was funded by the National Science Foundation (award 1518563) and NASA (award NNX15AT72A).

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Supplementary material (available online as Appendix wlb-00631 at <www.wildlifebiology.org/appendix/wlb-00631>). Appendix 1.