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Anatomy of a closing window: Vulnerability to changing seasonality in Interior Alaska

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ABSTRACT

Alaska is among the fastest warming places on Earth, and the Interior region is warming the most statewide. Significant regional-scale ecosystem services disruptions are affecting Alaska Natives' subsistence hunting and harvest success. The well-being of rural native communities is still highly dependent on access and ability to harvest wild foods such as salmon and moose (*Alces alces gigas*) among many others. Over the last decade communities in the Koyukuk-Middle Yukon (KMY) region of Interior Alaska report an inability to satisfy their needs for harvesting moose before the hunting season closes, citing warmer falls, changing precipitation and water levels, and the regulatory framework as primary causes. Through the integration of ethnographic methods to record indigenous observations and understanding of climate (IC) with analysis of meteorological data, we provide a comprehensive picture of vulnerability to recent warming trends in the Koyukuk-Middle Yukon region of Interior Alaska, one that captures more than statistical analysis of "norms" can provide. We will demonstrate how low exposure resulting in a small shift in seasonality has truly socially significant effects to people "on the ground" when community sensitivity is high because of the convergence of multiple social–ecological stressors. In this case, a seemingly small climatic exposure when combined with high social–ecological system sensitivity results in vulnerability to this climate change-related seasonality shift because of: (a) the effects on moose and the social–ecological dynamics of the system, and (b) the importance of this time of the year to meeting annual subsistence needs.

1. Introduction: seasonality shift in Interior Alaska

The northern Interior region of Alaska has experienced some of the most pronounced changes in winter and spring temperature and precipitation recorded anywhere in the state (Alaska Climate Research Center, 2008). According to indigenous observers and scientists, climate change physical manifestations include decreased thickness of river and lake ice; timing of spring break up or fall freeze up of the rivers that can make travel dangerous or impossible during key harvest times; thawing permafrost and drying of important fishing lakes; and changes in the timing, amount and intensity of rain and snowfall to name a few (ACIA, 2005; Huntington and Fox, 2005; Chambers et al., 2007; Euskirchen et al., 2007; Hinzman et al., 2005; McNeeley, 2009). All of these changes have cascading ecological effects on vegetation, fish, and wildlife, and the linkages are sometime nuanced and very complex (Wrona et al., 2005). For example, in recent decades shrubs and thickets have increased in some areas, which may benefit moose by providing increased forage,[2] but is also an indicator of lake and wetland drying, which decreases fish, waterfowl, and small water-mammal habitats (e.g., beaver, muskrats, mink). Increased shrub cover combined with the recent trend of low snowfall decreases albedo (i.e., reflectivity of solar radiation), which means more heat is absorbed by the Earth's surface, possibly contributing even more to local warming effects (Hinzman et al., 2005; Chapin III et al., 2005).

These bio-physical changes have occurred in recent years/decades as a consequence of an average of 1.9 °C warming for

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[2] Though this is debatable and depends largely on if a particular population is density-dependant forage limited. In some regions of Interior Alaska this is not the case (Tom Seaton, 2007, pers comm.).

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Alaska as a whole from 1949 to 2007, and Interior region wintertime mean temperature increases ranging from 4.2 °C to 5.3 °C for roughly the same time period (Alaska Climate Research Center, 2008). These observed changes combined with projections of continued warming and impacts on local subsistence resources and harvest practices, all point to potentially serious negative impacts and increasing vulnerability for rural Alaska villagers for decades to come (Kattsov and Kallen, 2005; McCarthy and Martello, 2005).

In recent years rural moose hunters have been reporting warmer fall seasons and lower water levels during some years, which decreases their opportunity to successfully harvest moose before the regulatory hunting season closes at the end of September (McNeeley, 2009). This, they say, results in an inability to meet their wild food subsistence needs for the year. Interestingly, "autumn" temperatures as typically measured during the three-month period of September, October, and November show a relatively weak warming trend throughout the state (+.6 °C mean change for "fall" compared to +3.5 °C for "winter") (Alaska Climate Research Center, 2008). This has left scientists and resource managers wondering how to reconcile local reports of warmer autumns in the Interior with the meteorological data that seems to show a very small magnitude of warming. The question for decision makers is – is there really a warming trend occurring during the fall moose hunt that justifies regulatory change?

> This fall it was so warm that the moose just didn't move. . .we just saw one moose track out of 70 miles because the animals were up in the hills, back in the lakes, so they just weren't moving. Western Interior Regional Advisory Council (WIRAC) transcripts October 2005.

> There is some agreement that additional data is needed before a determination could be made concerning that recent warmer-than-normal fall temperatures are part of a long-term climatic pattern. (P.D. USFWS OSM, WIRAC March 7, 2006)

These quotes illustrate a polemic debate between a number of the rural, predominantly Alaska Native, communities of Interior Alaska, and the state and federal agencies that manage wildlife and subsistence in the region. As early as 2001 the KMY-region villagers have claimed that they cannot meet their subsistence needs in years with warmer-than-normal autumns. They report that this is worse in years with minimal summer precipitation when water levels remain low and boats with outboard motors cannot access certain sloughs and rivers to reach key hunting grounds. They argue that by moving the hunting season later in the fall (i.e., late September/early October) they will have more opportunity to harvest moose before the regulatory season closes.

> We need to bump the season back into the fall a little further. . . maybe 20 years ago the seasons that we have now worked for us, but with the way the weather is changing and how warm it is this fall the moose just weren't moving around (Western Interior Regional Advisory Council (WIRAC) transcripts October 2005).

Yet, heretofore, with no official documented evidence of a warming trend for the region, federal and state game boards that make the hunting regulations continue to question whether this reported warming is really part of a long-term trend due to climate change. Confounding the issue is the state agency management position of moose population conservation measures that disallow hunting during what state biologists consider to be unchanging peak breeding dates of September 25 through October 5th in the Interior region (Alaska Department of Fish and Game, 2008; Van Ballenberghe and Miquelle, 1993). Prior to this study, there was no systematic inquiry into the patterns of climate variability and change during the autumn hunting season in the Koyukuk-Middle Yukon (KMY) region, nor was there any focused research on the vulnerability of the social–ecological system of Interior Alaska to climate variability and change. In response to this, we examined patterns of temperature and precipitation variability and change in the KMY region of Interior Alaska through the integration of indigenous observations and understanding of climate (IC) with surface station meteorological data to document and determine baseline vulnerability in the region. We will demonstrate how it is the convergence of social–ecological conditions and events along with the slight seasonality shift in terms of warmer temperatures and changes in precipitation patterns (i.e., low exposure to climate change) that result in regional vulnerability because of high system sensitivity.

2. Vulnerability to climate change

Climate change impacts, vulnerability, and sustainable adaptation are best understood in the context of changes to resource flows – especially the key resources – that are critical for sustaining livelihoods (IISD, IUCN and SEI, 2003). Resource-dependant societies (RDS) are especially vulnerable to climate shifts where alternatives to subsistence harvesting are extremely difficult or impossible to obtain on appropriate timescales, or where the quality of these alternatives is insufficient for well-being (Bebbington, 1999; Prowse and Scott, 2008). One can correctly argue that all humans are "resource-dependant societies". However, here we refer to societies that obtain a significant portion of their diet by direct harvesting of wild foods from their natural environs (Thomas and Twyman, 2005).

It is generally agreed that vulnerability to climate change is *determined* by two factors: (1) the *exposure* of the social–ecological system of interest to climate stress, combined with (2) the *sensitivity,* or ability of the system to cope with and adapt to the disturbance (Turner II et al., 2003; Smithers and Smit, 1997; Smit et al., 2000; Smit and Pilifosova, 2003; Adger, 2006; Ford et al., 2006). The exposure/sensitivity matrix includes the societal conditions that affect its own exposure (such as location in a region of rapid climate change), and adaptive capacity, i.e., the ability of the community to absorb the stress through effective responses, mitigation of damage, or adaptation (Ford et al., 2006; Smit and Pilifosova, 2003).

In the study of the human dimensions of environmental change, "sensitivity" refers to the susceptibility of a system to suffer from climatic stress, and specifically refers to the underlying socio-economic and cultural factors that structure vulnerability. Some view it as a "precondition" to vulnerability (O'Brien et al., 2004), while others include the response capacity as part of sensitivity (Luers, 2005).

A system can cope with certain deviations from average conditions, but only within limits of a range of magnitude and frequency (Smit et al., 2000). The coping range, of course, is not uniform with discrete boundaries as it is often represented schematically (see Smit and Pilifosova, 2003, p. 12). Any system is dynamic across time and space, and thus coping thresholds are non-linear and changing. Thresholds are characterized by points at which there is a change in the system to cause either increasing vulnerability and/or limited response capacity to some climate disturbance (Adger et al., 2009).

The concept of a coping range (while difficult to define boundaries that reflect a dynamic reality) provides a heuristic to conceptualize how a system is vulnerable to conditions that fall outside some range of ''normal'' or expected climatic conditions (see Smit and Pilifosova, 2001). Climate changes that cause seasonal conditions or extreme events to fall outside of the coping range challenge a systems' adaptive capacity. Any system's coping range is spatially and temporally scale-specific, though a goal in vulnerability-adaptation analysis is to understand where the thresholds might be exceeded in order to plan for serious consequences of future climate change. Events that breach a threshold are thought of as *extreme events* though they can be more subtle seasonality shifts as we will demonstrate.

Therefore, to think of coping range only in terms of extreme events is an over-simplification where more subtle seasonal shifts occur that can challenge coping capacity, or where climate impacts accumulate over time (Smithers and Smit, 1997; Smit and Wandel, 2006; Erickson, 2008). Instead of focusing only on ''hazards'' or discrete events we must also account for slow-onset, ''hazardous'' conditions, sometimes referred to as ''creeping environmental problems'' (Glantz, 1999). Much of the vulnerability to climate change literature is event-oriented, framing vulnerability and adaptive capacity in relation to specific hazards such as a drought, hurricane, and flood (Kasperson et al., 2001). However, it is the gradual, slow-onset climate stressors that can sometimes cause the most harm to communities, particularly in remote, rural natural-resource dependant societies where food security lies in a delicate balance (Bohle et al., 1994; Ford, 2009; Thomas and Twyman, 2005). In Alaska, changes in temperature, rainfall, or snowfall patterns (if occurring at key points in a season) can cause conditions such as unstable ice, changes in the habits, distribution or abundance of animal populations, or difficulties in the ability to access certain resources (Huntington and Fox, 2005). Vulnerability to slower-onset problems that affect safety when out on a landscape and success in hunting, fishing and other subsistence activities is a key factor in this case study.

In some cases, as in the one we will present here, exposure is low, and sometimes even so subtle as to be easily overlooked when conventional statistical analysis applied. Or worse, climate considerations can be viewed as relatively unimportant in a larger context when competing interests, agendas, concerns or scientific or cultural paradigms prevail. Where climate exposure is small and/or subtle, but the exposed system is highly sensitive to seasonal shifts it is especially important to look at the range of stressors affecting the system, though this is one of the biggest challenges in vulnerability assessment (Eakin and Luers, 2006). It requires incorporating and understanding the multiple socio-economic, environmental, political stressors that underpin, exacerbate or drive the vulnerability of any social–ecological system of interest is required (McCarthy and Martello, 2005). Seasonal cycles are characterized by the timing of weather variables with ecological dynamics and social behaviors. When climate shifts affect the timing of weather phenomena this can create ''windows of vulnerability'' causing added stress to the system (Dow, 1992). The purpose of this paper is to discuss such a case that demonstrates a *low exposure* to climate change combined with a *high social–ecological sensitivity* during a particular window of vulnerability. This window catalyzes a convergence between multiple social–ecological stressors to result in food system vulnerability via changes in moose behavior and more difficult conditions affecting harvest success.

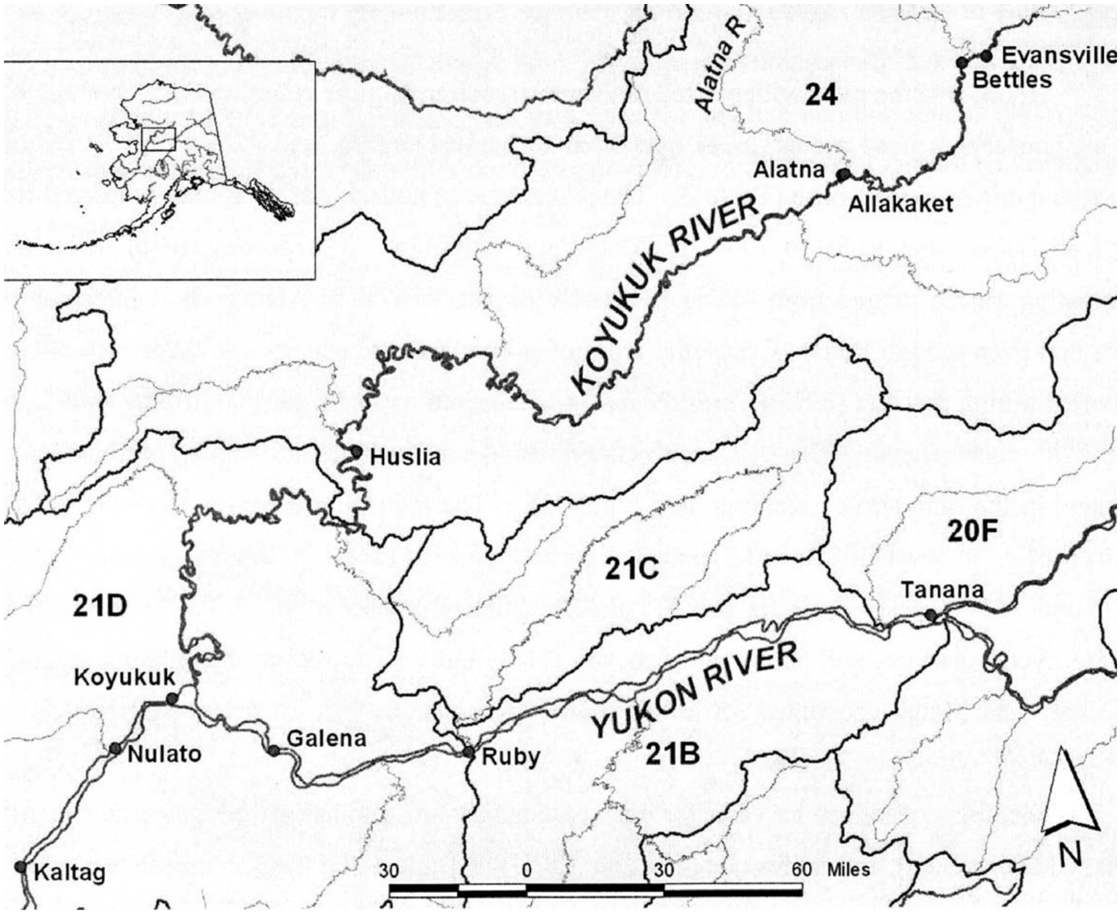
3. Assessing vulnerability and adaptive capacity

We implemented an interdisciplinary, participatory approach through collaborations and partnerships with various indigenous experts, scientists, and wildlife agency staff. This necessarily required the involvement of stakeholders and collaborators in the work to be able to have both the breadth and depth needed to answer the research questions outlined below (Drew and Henne, 2006). The analytical framework used was an in-community, place-based, participatory vulnerability and adaptive capacity assessment (VA). This approach employs historical data to establish baseline vulnerability and adaptive capacity and contributes to practical adaptation initiatives (Smit and Wandel, 2006). VA entails understanding the phenomena and main processes involved in the social–ecological system and identifying relationships and key resources susceptible to harm (e.g., food, financial, or energy resources) across scales from the local to global (Turner II et al., 2003; Adger et al., 2004). We followed the model set forth by Smit and Wandel (2006) where problems and determinants of vulnerability are not determined *a priori*, but rather are determined with the stakeholders themselves.

From the years 2003 to 2008 social science methods included key informant interviews, participant observation, an Elder focus group, observation of multiple community and regulatory meetings ($N = 10$), and document content analysis of subsistence regulatory meeting transcripts from 2000 to 2008 (http://alaska.fws.gov/asm/racdetail.cfml?rac=06). These multiple methods provided the broader context to situate and guide the analysis of the instrumental weather data, connecting the human needs, well-being, and responses to the ecosystem and bio-physical system into a comprehensive whole. Formal, semi-directed interviews were conducted in three KMY villages (Koyukuk, Hughes, and Huslia, see Map 1) from 2004 to 2005; interviewees were chosen by age (Elders and so-called ''younger Elders'', i.e., 55+), long-term residency in the region, participating in subsistence activities, availability, and willingness to participate ($N = 25$). Participant observation took place in all but two (Kaltag and Allakaket) villages in the region.

Local and indigenous insights, knowledge, and observations about climatic changes combined with instrumental observations of meteorological data are used in this study. Multiple studies have documented indigenous observations of climate variability and change (Cruikshank, 2001; Huntington and Fox, 2005; Krupnik and Jolly, 2002; Ford and Smit, 2004; Orlove et al., 2010; Green and Raygorodetsky, 2010; Ford and Martinez, 2000), and several have tried with varying success to utilize both indigenous observations and understanding of climate with western scientific data (Huntington, 2000; Huntington et al., 2004; Weatherhead et al., 2010). When properly treated as complementary (not correlating) forms of observation and knowledge this method can provide discoveries and additional insights than either individually (Gearheard et al., 2010) and by working directly with communities this can guide vulnerability and adaptive capacity analysis (Ford and Smit, 2004; Berkes and Jolly, 2001; Riedlinger and Berkes, 2001). For ease of understanding when working with climate scientists and multiple indigenous and non-indigenous stakeholders, we use the term indigenous observations and understanding of climate (IC) for talking specifically about observations of weather and climate (McNeeley, 2009). IC can encompass traditional and non-traditional, local and regional, native and non-native and describes observations about changing weather and climate of a ''place-based'' people (that have lived in an area for many decades), and who have the knowledge and wisdom to be able to detect conditions that are outside the expected or normal range of climatic variables (for a more detailed discussion see McNeeley, 2009).

One important aspect of IC is that it is predicated on traditional phenological knowledge (TPK), defined as an



Map 1. Map of the Koyukuk-Middle Yukon Region with numbered state game management units (GMUs) courtesy of the Alaska Department of Fish and Game.

understanding of the expected timing of weather variables with ecological variables (Lantz and Turner, 2003). Locals indicated to us that the timing of climatic conditions is critically important for fall subsistence hunting, i.e., the relationships between when it rains, when it cools down, starts to freeze, when the leaves fall, and when the moose go into "rut" (the time period of breeding behaviors and copulation). The observations gleaned from qualitative analyses directed us to specific time periods in the instrumental record for analysis. The analysis was iterative between IC and instrumental data to understand regional weather and climate patterns and anomalies. This included multiple presentations to the various stakeholders in both Koyukon communities and government agencies to validate our findings.

Koyukon "seasons" as they are experienced in the region, are not the same as the typical breakdown of 3-month seasons that climatologists use. For example, March is considered "spring" in the conventional 3-month seasonal breakdown (March, April, May), but spring in the villages is characterized by the arrival of migratory birds, melting and crusting of the snow, and breakup of the river ice, all of which do not begin until April and May. "Winter" in its entirety to a villager might mean mid-October through mid-May (as this is the time period that the rivers are frozen. "Fall" (or more accurately, "early fall") can mean the last two weeks in August and the first few weeks of September, but this varies year to year making the season designation somewhat fluid across time. "Late fall" is characteristically different than early fall as it is the time when the river ice completely freezes and the transition to early winter. All of these designations depend on what is going on across the landscape physically and ecologically, as well as what human activities are happening in the context of subsistence practices, and they can vary from year to year and are more fluid across temporal and spatial scales.

Therefore, there is a poor correspondence between the climatologically defined seasons and the seasonal changes that impact people in the KMY region. Superimposing the 3-month seasonal breakdown over a much more intricate and nuanced seasonality does not capture the level of detail required to understand seasonal shifts. This understanding is also the key to communicating about climate change with Koyukon Elders and community members for research and resource management as it aligns more with their understanding of and experience of "seasons" thereby making cross-cultural communication and research more successful.

We looked specifically for changes taking place during the late summer and early autumn, and in particular, during the designated hunting season, which varies depending on the game management unit (GMU) or sub-unit as determined by the Alaska Department of Fish and Game designations (Alaska Department of Fish and Game, 2007). Generally, in this region (GMU 24 and 21D), the hunt begins from between August 27th and September 5th depending on the location and stays open to subsistence hunters until generally around September 25th.

Surface station meteorological data were analyzed for the four weeks starting between August 25th and September 25th.[3] A time series trend analysis of mean annual and seasonal temperature and precipitation was performed. The four weeks during the hunting season (25 August–25 September) were analyzed separately, as well as the season on the whole, to check for patterns of change or shifts in temperature and precipitation.[4]

4. Results and discussion – climate variability and change in early fall

4.1. Importance of the fall moose hunt for winter food security

Early fall time in the Koyukuk-Middle Yukon region is the most important time of the year for conducting the activities that maintain winter food security and thus is met with great anticipation and hopes for good seasonal conditions, a healthy moose population, and harvest success. Of the wild foods harvested in the KMY region, moose (*Alces alces gigas*) is the most important big game animal (Nelson, 1983; Brown et al., 2004; Watson and Huntington, 2008) weighing 360–770 kg (Emanuel, 1997). Overall, 92% of the households use moose (Brown et al., 2004). Even in communities where no moose are reported as harvested, almost all households report using moose, confirming not only the vital importance of moose but also that intra- and inter-village sharing and food distribution continues to be an important trait of these subsistence communities (Brown et al., 2004). Despite the relatively recent arrival of moose to the Koyukuk River valley within the last 70 years or so when the landscape transitioned from predominantly tundra to boreal forest, moose have become something the people are economically and psychologically attached to and that are deeply ingrained into the social and cultural fabric (Nelson et al., 1982; Watson and Huntington, 2008). Moose are also the most efficient wild food to harvest in terms of pounds of meat harvested per unit of time, energy, and money put into the harvest effort (Feit, 1987).

Maintaining a healthy moose population and hunting access and opportunity is a top priority in the region. A deficit in moose harvest means having to rely on more labor-intensive wild foods (e.g., salmon and other fish species, caribou, bear, beaver) and on nutritionally inferior and expensive store bought food flown long distances from the urban hubs to the rural villages. Recent poor salmon runs during the late 2000s on the Yukon River and its tributaries make salmon a less reliable substitute putting more pressure on a successful fall moose harvest. The population of moose in the KMY reached a peak in the early-1990s but has since declined as a result of increased hunting pressure during the mid- to late-1990s (Alaska Department of Fish and Game, 2001). The moose population decrease combined with the effects of warmer falls has resulted in less opportunity to: (a) access prime hunting areas, and (b) encounter moose for successful harvest. This convergence of biological factors with seasonality shift impacts harvest success.

4.2. Social–ecological system dynamics of the fall moose hunt and climate change effects on moose and hunter behavior

During the summer months, the moose tend to spend their time in the higher grounds and wetland areas, thermoregulating from the summer heat, replenishing lost body reserves from the previous winter, and fattening up for the upcoming fall breeding season and winter (Renecker and Schwartz, 1997; Schwartz and Renecker, 1997). In the fall they move out of those areas into open areas of valleys and riparian corridors where they perform the annual mating ritual known as "the rut" (Bubenik, 1997).

The timing of climatic conditions affects the social–ecological system dynamics of the fall moose hunt, and an intimate understanding of this transition time is central to the success of subsistence hunters. It is widely accepted among moose biologists that fall breeding dates are determined by the photoperiod (i.e., hours of daylight) (Schwartz, 1997). However, rutting *behavior* begins when the temperatures are cool enough that the bulls begin to start moving around, searching for cows to breed (Bubenik, 1997). The exact process and temperature threshold that triggers bull movement is not well understood, however, it is widely known that warm weather affects the ability for the moose to thermoregulate without overheating or expending too much energy to do so (Vucetich and Peterson, 2008). If the temperatures are not cool enough for the moose to begin rutting activities, they become inactive and do not move around looking for cows to breed until later in the season when temperatures cool.

Hunters rely on the bulls moving, making mating noises, and on entering riverine or open areas for visibility and encounters. The ability to travel overland is limited this time of year, so when moose stay away from the rivers and lakes, they are inaccessible to most hunters in areas off the road system. The best conditions for moose hunting are when temperatures are around freezing at night, around 5–9 °C by day, and before it remains cold enough for a long enough period of time that the rivers begin to freeze. It is a window of about a month between the end of summer and the fall freeze up during which moose hunting conditions are ideal for successful harvest.

In past decades and in cooler than normal years, rutting behavior typically began around the end of August/beginning of September (Nelson, 1983). Research during the 1960s and 1970s suggested that hunting season was mid-August to mid-Sept (Bane, 1982; Nelson et al., 1982). Local hunters now report that in some warm years the season has shifted later by 2–4 weeks, depending on the year, with prime conditions now typically beginning in early- to mid-September during cool years, but mid- to late-September in warm years – a period that is out of sync with the regulated hunting season.

Locals observe that preparing for hunting trips is very difficult when the weather is increasingly unpredictable. The understanding of seasonal cycles and environmental cues allows hunters to accommodate inter-annual variability without wasting time,

[3] We used August 25th as the starting date to have four 7-day weeks that included the time period between August 27th and September 25th. Weather stations used for this analysis are the three stations that sit within the KMY region – i.e., Bettles (66°55′N/151°31′W, 196 m a.s.l.), Tanana (65°10′N/152°06′W, 69 m a.s.l.), and Galena (64°44′N/156°56′W, 37 m a.s.l.). The Bettles site is a National Weather Service first-class observing station and has been in operation since April of 1944. It is located on the Koyukuk River south of the Brooks Range. The longest-running of these stations is Tanana, which began operation in 1902 and is located at the confluence of the Yukon and Tanana Rivers in central Alaska. In Galena, on the north bank of the Yukon River downstream of Tanana, the observing station has been in operation since 1941. Daily climatological data for Bettles, Galena, and Tanana were obtained from the National Climatic Data Center (NCDC) from the Daily Surface Data (TD3200 and 3210) datasets. Missing observations were filled in where available from NCDC Serial Publications; Climatological Data and Local Climatological Data reports (http://www7.ncdc.noaa.gov/IPS/). Daily maximum and minimum temperatures were averaged for all stations to obtain monthly average temperatures, and then further averaged for each season and year. Precipitation and snowfall were summed to obtain a total for each month, season, and year. Calendar years were used to generate annual average temperature and precipitation (January–December). Winter seasons were identified using data from July through the following June. The best-fit linear trend and 5-year running mean were determined for the time series of monthly, seasonal, and annual totals/averages. The total change over the period of record was calculated for each parameter-station. Long-term averages were computed; periods of record for each station and the departures from average for each year were determined; and time-series plots were constructed.

[4] Linear regression analysis was performed on all the time series data, and statistical significance of the trends were determined at the $P = 0.05$ level.

money, and energy through premature travel to distant harvesting sites (Turner and Clifton, 2009). However, with seasonal shifts and lack of persistence (i.e., less predictability) of weather conditions compared to the past, the accurate assessment of when and where to hunt is further complicated.

> Because of the high cost of fuel people have to be able to take the precise opportunity to harvest... this is getting down to the fine lines of the economics of subsistence, the economy of time, effort, and expense. (J.R. WIRAC Meeting October 4, 2005)

Changes in precipitation patterns can result in low water levels at the beginning of the hunting season, which makes getting into key hunting areas very difficult or impossible when sloughs or rivers are too low to access by boat. Also, warmer temperatures mean the moose will move around at night when it is too dark for hunters to see them, or they will stay in higher ground away from the bugs that linger during warmer falls. All of these factors reduce opportunity for hunters to harvest moose under optimal conditions. As a result, hunters must adapt their hunting practices to try and increase both access to and encounters with moose. This includes higher risk methods such as traveling longer distances, hunting at night when it is cool enough for the moose to move around, and/or using canoes to get into shallow waters where outboard motors cannot. Each adaptation measure comes with a cost, usually in terms of time, labor, and money for gas, food, supplies.

With unseasonably warm temperatures meat spoilage is also a significant problem. This is because from the time of harvesting the animal the entire process requires many hours of butchering, packing, and transporting long distances from the kill site to the camp site, and then to the residential location in the village and into the freezer, and blow flies that are still active destroy meat. Meat spoilage is a key indicator for hunters as to whether or not temperatures are favorable, as this was not the problem for them in past decades that it is now.

> The amount of time we hunted in the fall didn't change, we'd go out for a week or so but we didn't have the freezers then so we'd wait until it started getting cold and then we'd go out, that's the appropriate time. Now, we can't do it because we've got such a short window that when that window's there everybody's got to go out and the other thing that happened is it would be staggered. If we knew somebody had been up the Northfork next week then, well, we'll wait a few days before we go up so we weren't all hunting at the same time. And the seasons are really putting a crimp on traditional subsistence activities of going out when it's appropriate, when the weather, you can take care of the meat and so on (Mr. C. WIRAC meeting October 4, 2005).

An important question of the agency and scientist stakeholders in this case study is – what constitutes a trend? Agency decision makers require statistical evidence to back up their decisions. Climate scientists need time scales of several decades to determine a trend. However, villagers relate climate variables such as temperature, precipitation, snow quantity and quality, wind direction and speed relative to a whole range of variables in the system and ultimately consider how these combine to either hinder or help harvest success. Examples in autumn include air temperature, freezing ice on waterways, vegetation changes, moose behavior, and water levels that all are interconnected and relative as opposed to absolutes. When integrating indigenous observations and understanding of climate (IC) with instrumental weather data we had to reconcile these different, but complementary, ways of knowing and understanding. Criteria for statistical significance can downplay social significance if viewed only by those criteria. In other words, just because something is not statistically significant at the 95% confidence level does not mean it is not a real phenomenon such as subtle, yet important, changes in seasonality observed by hunters on the landscape. Yet, management decisions are often made based on this criterion (Morrow and Hensel, 1992; Nadasdy, 1999; Nadasdy, 2003). The strength of our analysis is in the integration of instrumental weather observations with indigenous observations of climate to identify key time periods of vulnerability that are critical to subsistence livelihoods.

5. IC and instrumental observations on hunting season trends

5.1. Temperature

Koyukon Elders have indicated that September weather is often what August conditions used to be, i.e., warmer and wetter. In recent years the average temperature during the hunting season has shown a predominance of positive anomalies indicating a warming trend. From 1995 to 2007, eight of thirteen years (61%) have had warmer-than-normal temperatures, particularly in the three autumn seasons of 2005–2007. These years combined have mean anomalies of 2.2 °C, which is greater than one standard deviation above average (>1.6 °C) for this time period, which makes these years warmer than the normal range of expected variability. Combined, these three years represent the warmest consecutive three-year period of all hunting seasons in the historical records.

The total change in temperature over the period of record (1944–2007) for the hunting season (August 25–September 25) is a range from 0.7 °C for Galena to 1.6 °C for Tanana. Each individual week within this month shows an increase on the order of 0.4–2.3 °C. Calculation of Heating Degree Days (HDD) provides an additional measure of the relative warmth or coolness of a season by looking at how often temperatures were low enough to require the heating of homes (assuming a heating temperature of 18 °C).[5] HDD totals for the months of August and September are on average 604 for Bettles, 531 for Tanana, and 533 for Galena. Each of these stations shows a decrease in the two month (August and September) HDD total since 1944, indicative of a warming for this two month time period. The trend is statistically significant for Tanana at the 95% confidence level with a total change of 76 units, but is not for Bettles and Galena with a total change of 73 and 42 units, respectively, though the trend for all stations is of similar magnitude.

As indicated by indigenous observers, the time when temperatures start to oscillate around freezing is a key time period for the moose rut. In a community meeting with villagers in Hughes, one Elder told us:

> Moose don't move until it starts to freeze and you get that crunch in the ground. (Field Notes in Hughes, Spring 2007)

Similarly, during the fall of 2007 an Elder hunter in the village of Koyukuk was asked what temperature it needs to be for the bulls to start mating in the fall. He said somewhere around freezing (0 °C) because they (the moose) need to wait for the right temperature to mate.

[5] The mean daily temperature is subtracted from 18 °C and all the resulting daily values are added together for each month. This measure is often used for determining energy consumption required to warm a home to 18TC inside. Therefore, if the mean daily temperature is less than 18 °C then it is a heating degree day because energy is needed to maintain the home's internal temperature.

> The moose need the ground to freeze a little bit to get a good foothold for mating. Right now the younger bulls have it okay but it is still not frozen enough for the more mature (heavier) bulls. (Field notes in Koyukuk September 27, 2007)

IC such as the statements above indicates that an important threshold temperature for climate-dependant moose and hunter behavior is 0 °C. As such, we determined the first date when the minimum temperature was at or below 0 °C at the end of summer. The end of this freeze/thaw period was identified as the date when the minimum temperature went below freezing and remained so for the duration of the winter. This time period is of biological importance because it signifies when the deciduous tree leaves that moose browse undergo senescence, which also triggers the bull moose to stop eating and go into rut as well as provide visibility for hunters.

We found the date of first freeze in late summer/early autumn, to occur earliest at Galena relative to Tanana and Bettles. Over the entire period of record, dates for the occurrence of first freeze range from August 3rd to October 2nd with an average date of September 1st. Galena showed a trend toward earlier occurrence of the first freeze with a change over the period of record of 8 days, which is statistically significant at the 95% level. The length of the freeze/thaw period ranged from almost 80 days to 0 indicative of high variability (a long season for the former and a short season for the latter), in which the temperature went below freezing and remained so for the duration of the winter. Galena and Tanana both show a trend toward lengthening of this time period by one week since 1944. Bettles shows only a slight change of one day. In addition, the inter-annual variability of this time period is high, yielding inconsistencies from year to year, which could mean less predictability as the Elders have indicated from their observations. The occurrence of earlier first freeze dates seems to contradict the findings that interpret an overall warming trend for this season. However, the longer time period until persistence of temperatures below freezing indicates a longer freeze/thaw season. Local IC of early killing frosts impacting gardens concurs with this finding.

Our analyses of the temperature data for the time period during moose hunting suggests that the season in general is warmer, however, the initiation of the freeze/thaw period is occurring earlier. The warming trend is pushing the fall season later, but there can be short but significant intrusions of cold air resulting in these early freezes. Perhaps the most important trend from the moose hunter's perspective is an increase in inter-annual variability resulting in less seasonal predictability, and more frequent temperature extremes, both of which can impede successful harvest of moose. Falls that are too warm are simply a detriment to hunters, so relatively rigid regulations that do not allow for in-season adjustment to these conditions are problematic for subsistence livelihoods.

5.2. Precipitation

Koyukon Elders and hunters note that fall precipitation patterns are shifting from the expected historic conditions. "August rains" were typically when precipitation was at its peak, and would recharge the river and slough water levels. September was typically cooler and drier than July and August. Local reports indicate that this is beginning to shift in time and "August rain" is coming more frequently in September.

> Well, it's unpredictable [rainfall] this season moose hunting season it was really good, it was dry, but the year before that it rained, rained, rained in September. It usually rained in August. ∼Benedict Jones, Koyukuk (Jones, 2004)

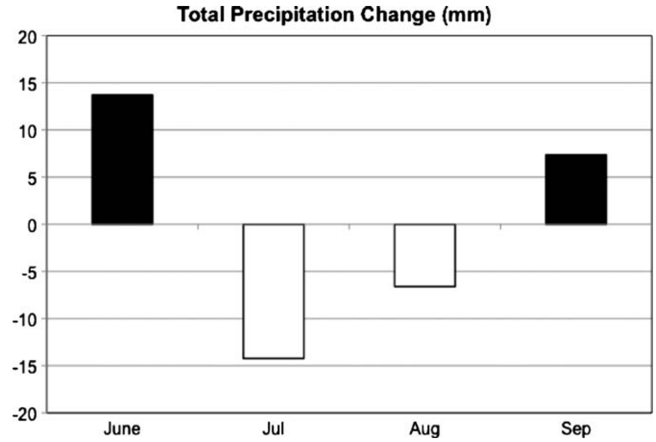


Fig. 1. Changes in Galena average rainfall for June through September calculated over the full time period from 1944 to 2007 indicating a slight decrease in July and August and a slight increase in September.

Analysis of Galena data shows that precipitation has decreased overall in July and August but has increased in September (Fig. 1). By investigating the four weeks individually during moose hunting season, the first two weeks, August 25th to August 31st and September 1st through September 8th, show a slight decrease in precipitation, while the latter two weeks, September 9th through September 16th and September 17th to September 25th, show a slight increase. Therefore, within the hunting season at Galena, the first half is trending toward warmer and drier and the second half toward warmer and wetter, with the weather data analysis agreeing with local reports of change. The analysis for Bettles shows the same trend, although Tanana shows an overall drying for each of the four weeks. Although these weekly and monthly temperature and precipitation trends are not always statistically significant at the 95% confidence level, the results do concur with local reports in the KMY region.

6. Anatomy of a "closing window" of harvest opportunity

Subtle shifts are occurring during the transition season when bio-physical changes of importance to people are taking place on the landscape. High inter-annual and inter-regional variability is such that an overall trend in the data is hard to detect when looking

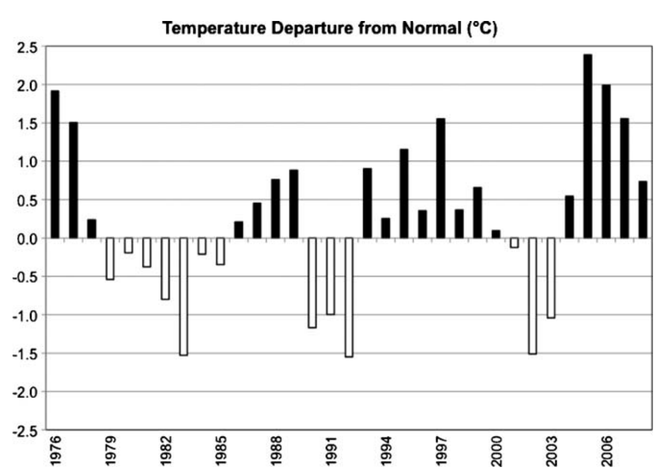


Fig. 2. September temperature departure from normal (°C) for the combined temperature record from the Bettles, Galena, and Tanana stations 1976–2008. The standard deviation for the years 2005–2007 are at or over one standard deviation from the long-term normal.

only at three-month seasonal averages, which is why indigenous observations and understanding of climate help identify nuances that are difficult to detect in conventional statistical analyses of the data. One factor that stands out in the temperature record is high variability, which confounds decision makers when balancing a variety of factors to manage wildlife in a way that satisfies all the stakeholders involved. The high variability also leads people to question whether this is a trend to be concerned about (i.e., climate change), or just the ''weather doing what it does'' (i.e., natural variability). In this case, climate variability and change are both key factors; therefore stakeholders need to be prepared for both.

The linear regression trend lines for the three stations we analyzed appear as if there is only a slight and sometimes even statistically insignificant warming trend. Upon closer examination of the departure from the mean temperatures we gain a better understanding of individual years in relation to others (Fig. 2). With respect to climate, it is this relativity that matters most because it is what conditions hunters' expectations each year. A string of warm years in a row, which local residents perceive as a warming trend over the last two to three decades, can result in conditions that shift the coping range of the hunters as the cumulative effects of multiple, successive warm years affect the overall coping capacity of communities. When multiple stressors and regulations accumulate and/or converge to constrain the ability to move through time and space accordingly, social vulnerability increases.

The falls of 2005–2007 were three years in a row with significant temperature departure at or over one standard deviation, which for this time period is 1.6 °C. Does seasonal warming beyond a standard deviation above average temperature provide a threshold for local or regional harvest success or failure? It is not enough to just look at average temperatures. We need to look closely to understand how all the variables in the system are interacting; and the cross-section of time and space of the analysis matters.

Combining this with qualitative sources of data we have a better picture of the ''window of vulnerability''. Windows of vulnerability are created when timing of events or periods in which hazards become more severe because of the combination of circumstances (Dow, 1992). This case demonstrates a closing window of opportunity for the successful harvest of moose under circumstances of shifting seasonality. When combined with the other socio-economic and biological stressors, specifically decreased moose populations, and increased gas and food prices, along with the decreased hunting opportunity through regulatory restrictions, this ''closing window'' of opportunity creates the window of vulnerability for the rural communities of the Koyukon-Middle Yukon region.

When restricted by a small window of opportunity, the environmental conditions matter much more than they did

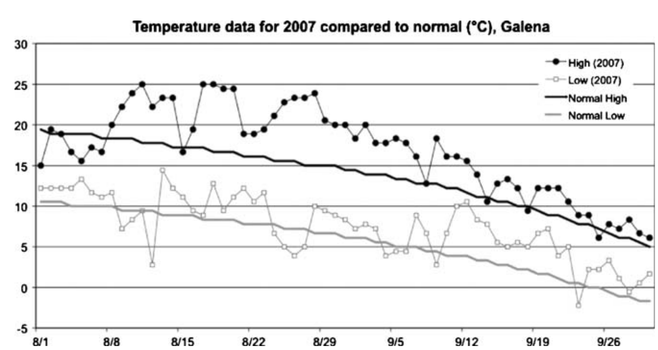


Fig. 3. High and low temperatures for August and September 2007 compared to the 1999 decadal mean.

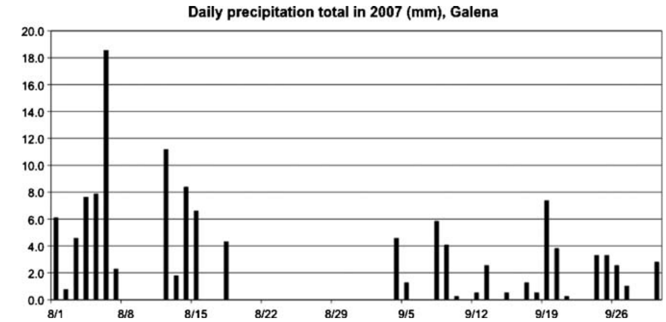


Fig. 4. Daily precipitation total (mm) for Galena August and September, 2007. This shows no rain during the last week of August, which resulted in low water levels in sloughs and rivers. It rained through September, which helps with water levels, but is not good for caring for meat or for moose mating.

historically when flexibility across time and space facilitated adaptive practices. An examination of the fall season in 2007 gives us a better understanding of how the convergence of a very warm season with other factors creates this ''closing window'' and so 2007 is exemplar for understanding baseline vulnerability to fall seasonality changes. The season was unseasonably warm, as it had also been for the previous two years. Hunters in several villages with surrounding low density moose populations (e.g., Hughes, Koyukuk, and Nulato) had difficulty harvesting moose before the season closed on September 25th. Water levels were low in many places because of lower than normal precipitation in late August, and hunters were unsuccessful for the first few weeks of the hunting season. In September the conditions changed and precipitation was higher than normal. Elders in Koyukuk village reported that this had been the wettest September they had ever seen and that the weather they were having at the end of September was ''August weather'' described as wet and cool but not freezing and with no frost on the ground.

Fig. 3 shows August and September high and low temperatures compared to normal during the 2007 moose hunting season. The temperatures were above average for most of the season. Most importantly, temperatures did not decrease until September 19th and the first freezing temperature was on September 24th – one day before the close of the season. Additionally, the precipitation record shows the last week of August until September 3rd was dry (Fig. 4). This resulted in low water levels in many places at the start of the season. Later in the season it was quite wet, and very wet late in the hunting season for several days at exactly the time temperatures were opportune. Consequently, for many hunters in the region, there were very few days where conditions were suitable for hunting success.

If an overall warming trend on the order of 0.5–1.0 °C since the mid-1970s has pushed the hunting season back by weeks to a month during warm years, the continued fall-time warming projected by climate models could eventually result in an even later seasonality shift (Walsh, 2009). The long-term ecological effects of this are unknown, but in terms of moose behavior and hunting success, this could eliminate the fall hunting opportunity altogether in some years if the current regulatory window is not allowed to expand. Local individual and group adaptations notwithstanding, as long as the moose population numbers are of concern and peak breeding dates are rigidly adhered to that prevent the legal hunt in this region from going later than September 25th, this will mean continued conflict between the goals of protecting the moose populations for future generations, and the ability to harvest moose successfully in the present.

7. Conclusion: fall seasonality and vulnerability to climate change

In conclusion, indigenous observers throughout the northern Interior region of Alaska report that warmer temperatures during early fall (i.e., late August/September) are affecting the fall moose hunt and instrumental weather records support these observations. Even though the climate change exposure is relatively low, changing seasonality results in difficulty harvesting moose before the regulatory moose-hunting season ends on September 25th. This "window of vulnerability" created in warmer-than-normal fall years decreases the opportunity to meet annual harvest needs for the winter. Inability to access moose and/or harvest failures can cause hardship for families, households, and even entire communities. It means having to rely on more labor-intensive wild foods (e.g., salmon and other fish species, caribou, bear, beaver), and, on nutritionally inferior and expensive store bought food flown long distances from the urban hubs to the rural villages. Recent poor salmon runs during the late 2000s on the Yukon River and its tributaries make salmon a less reliable substitute.

The fall seasonality shift in combination with multiple stressors are affecting moose harvest and threatening food security. The difficulty in fall harvest is also caused or worsened by many social, biological, economic, and political stressors. Therefore, there are socio-economic variables and biological variables underlying the problem, and now climate change is added to the complexity of all of these multiple driving variables/stressors. This is happening within the context of a subsistence and wildlife regulatory system that constrains movement across time and space for a local hunting society whose adaptability has long depended on great flexibility to respond to environmental change. Because of mandated state regulations, certain practices are limited in time to a specific window of opportunity, making seemingly small or insignificant climate trends or shifts quite critical for those dependent on the direct harvest of natural resources. Timing of temperature and precipitation, moose behavior, and the regulatory window all combine to result in a system where a slight shift in climate (i.e., small exposure) challenges the coping range and capacity of these hunting communities. This research also demonstrates the importance of indigenous observations and understanding of climate in helping to identify these important nuances that might be missed in conventional scientific analysis.

Given the context of the larger warming trend across temporal and spatial scales in Alaska over the last 60 years, and especially over the last 30 years, we conclude that this is likely part of a long-term warming trend. Yet, when considering issues of social–ecological system vulnerability and adaptation, whether or not this is part of a longer-term trend is, in a sense, the wrong question. A more appropriate question is perhaps that given the relative certainty that the global climate will continue to warm, and predictions of how this will affect Alaska, how can we plan for the future? We suggest that examining historical and current vulnerability and adaptive capacity provides good analogues and a baseline understanding upon which to make planning decisions.

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