

A reindeer herder's perspective on caribou, weather and socio-economic change on the Seward Peninsula, Alaska

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Keywords

Alaska; climate change; *Rangifer tarandus*; reindeer; reindeer herding; weather.

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doi:10.1111/j.1751-8369.2009.00102.x

Abstract

Non-climate variables shape vulnerability and adaptive capacity to climate change. Here, we describe how recent environmental and socio-economic developments have transformed reindeer herding and perceptions of weather on the Seward Peninsula, Alaska. The reindeer industry has shrunk considerably since the early 1990s, when the winter range of the Western Arctic Caribou Herd expanded, and over 17 000 reindeer mixed with migrating caribou and left the region. Socio-economic and environmental repercussions make the continuation of herding tenuous, and erode the ability of herders to cope with weather variability, among other perturbations. We present a case study of one herder's annual cycle, and juxtapose physical drivers of herding activities, including weather-station and herder observations of local weather variability, with socio-economic factors. There is an increased urgency to access and monitor reindeer with caribou present, but herding plans are constrained by lower economic returns and the need to spend more time in non-herding jobs. Although weather is a greater concern now for immediate herd access, standard weather data are largely irrelevant to the mechanics of herding, whereas variables pertaining to the timing of biotic events (e.g., synchrony of spring break-up and calving) and visibility are attributed to lost herding opportunities. Short-term responses to weather conditions stem from more long-term vulnerability associated with caribou presence, reduced herd size, difficulties affording snowmobile maintenance or crew assistance, and dwindling market opportunities. We emphasize the environmental and socio-economic interactions that affect vulnerability and adaptive capacity for modern herding.

Reindeer herding has been an integral part of the identity of many Inupiat and Yupik communities on the Seward Peninsula, Alaska, since the introduction of reindeer (*Rangifer tarandus tarandus*) in 1891 (Stern et al. 1980; Simon 1998; Hillanna & Sherrod 2004). However, reindeer numbers are currently in decline. Between 1992 and 2005, over 17000 reindeer (approximately 80% of peak herd numbers) were lost as the Western Arctic Caribou Herd (WAH) grew to 490000 and expanded its winter range onto the Seward Peninsula (Fig. 1; Dau 2005; Finstad et al. 2006). The reindeer readily mixed with the caribou (*ranger tarandus tarandus qranti*), and left the region with caribou migrating to their spring calving grounds (Finstad

et al. 2002; Oleson 2005). Most reindeer never returned and could not be recovered. Eleven of 15 herds lost 90-100% of their reindeer, or are now too small to be economically viable (Fig. 1; Finstad et al. 2006). The estimated loss to the regional economy is more than 1.4 million USD per year, at year 2000 values (Carlson 2005).

The current downturn for the reindeer industry is exceptional in that a major ecological event (range expansion of caribou) resulted in depleted reindeer numbers and the near folding of an important cash economy on the Seward Peninsula. Several factors make the system vulnerable to further decline. Most herders cannot currently maintain reindeer with the perennial

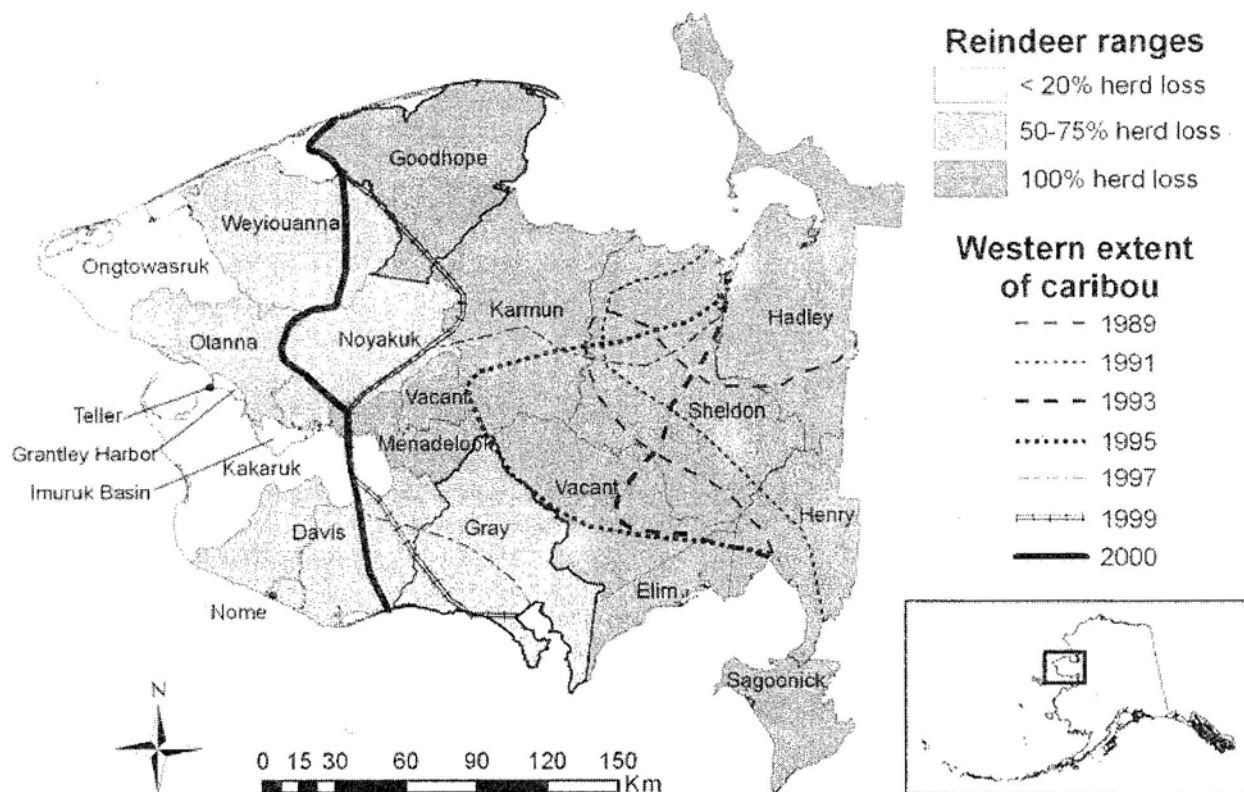


Fig. 1 Map of reindeer ranges and observed western extent of caribou on the Seward Peninsula, Alaska. The shading of the ranges shows the percentage of herd loss by 2005. (Figure from Finstad et al. 2006.)

presence of caribou on their ranges (Finstad et al. 2006). Herders on the western Seward Peninsula have experienced less impact, but they are compelled to spend more time on the land to retain their remaining reindeer (Finstad et al. 2006). At the same time, dwindling economic returns resulting from smaller herds and weak markets for velvet antler (following the 19905 recession in East Asia, where antler is imported) have made it necessary for herders to increase their time spent in non-herding jobs (Carlson 2005; Schneider et al. 2005). Non-herding incomes have become crucial to finance herding activities, particularly to pay for snowmobile maintenance and fuel; snowmobiles, or snowmachines as they are called in Alaska, are the primary means of moving reindeer in winter, when most herding activity occurs (Schneider 2002; Schneider et al. 2005). Mitigation measures include the use of satellite collars to track both reindeer and caribou, and the establishment of refugia (designated "safe areas") and fenced enclosures, where reindeer can be isolated from migrating caribou (Finstad et al. 2006).

Current stresses resulting from caribou and low economic returns make other aspects of the herding system

more critical at this time. Winter weather conditions have become especially important with caribou present (Schneider et al. 2005). Delayed freeze-up (the build-up of snow and ice in early winter) restricts herd access, and may thereby compound losses of reindeer to caribou, as occurred in the autumn of 1996 and 2001 (Gray 2002; Finstad et al. 2006). Rain and thaw-freeze events in mid-winter hinder travel and create an icy surface, making it difficult for reindeer to dig for forage (Davis 2001). Early break-up (the spring melt or snow and ice) may leave herds inaccessible during the calving season (Sagoonick 2003), when predation by bears and wolves can be high (Paine 1988; Chetkiewicz 1993). Although the herders have always known unpredictable freeze-ups, variable snow conditions, winter rain, and icing, and these conditions have been devastating in the past, ... the present adaptation or herding (village centered, motorized access), and the overwhelming rush of caribou makes the timing of freeze-up and adequate snow cover even more critical.

(Schneider (et al. 2005)

In order to examine the relative role of weather variability among the many factors affecting the vulnerability

of herding to environmental and socio-economic change, we conducted a case study with one herder to contextualize weather among those factors (including individual perception and choice) that determine seasonal herding decisions, and the capacity to maintain and manage reindeer. The specific study objectives were to (1) describe specific weather conditions that affect winter herding for herder James Noyakuk, (2) document seasonal weather variability on Noyakuk's range, based on his observations and data from weather stations, and (3) describe other ecological and socio-economic factors that influence Noyakuk's adaptability to weather variability and range expansion by caribou. We considered the current situation within a vulnerability framework (Turner, Kasperson et al. 2003) that emphasizes the interactions among key environmental and socio-economic factors, and the dynamic nature of these factors and linkages.

Vulnerability and changing arctic livelihoods

Land- and natural resource-based livelihoods in the Arctic, such as reindeer herding, have always been in flux-adapting to various environmental, social, economic and political changes over time. There have been profound changes in the last 50 years (Pelto 1987; Caulfield 2000; Myers et al. 2005; Symon et al. 2005), and complex emerging vulnerabilities associated with these changes (Ford, Smit & Wandel 2006). Vulnerability as a concept for analysing impacts to communities typically indicates susceptibility to negative impacts or degradation from change (Adger 2006), and can be defined as "the conditions, determined by environmental, social, economic and political factors and processes in a system, which make the system more susceptible to harm" (UNISDR 2004).

Vulnerability arises from the interlinked characteristics of "social-ecological systems" (SESs), where an SES is the relationship between humans and their environment, including all components, linkages and processes within the scope of the analysis, be it at the individual, community or regional level (Robards & Alessa 2004). This includes linkages extending beyond immediate geographic boundaries (Turner, Matson et al. 2003). Vulnerability is a function of the exposure and sensitivity of an SES to various hazards, and the adaptive capacity of the human actors in the SES to respond to or prevent impacts from those hazards (Adger 2006). Thus, the means to reduce vulnerability are to reduce exposure and sensitivity, and increase adaptive capacity (Chapin et al. 2006). Exposure, sensitivity and adaptive capacity vary both spatially and temporally. What represents a hazard, affects exposure-sensitivity, or contributes to adaptive

capacity in a village, may not do so for the individual or the region, or at all times (Turner, Kasperson et al. 2003).

Critical to the vulnerability framework is a systems approach, where key social, economic, political and environmental components, linkages and processes are examined together to assess exposure-sensitivity and adaptive capacity (Turner, Kasperson et al. 2003). Additionally, these components, linkages and processes are recognized as being dynamic (Turner, Kasperson et al. 2003). Some components may become more or less decisive in increasing exposure-sensitivity and adaptive capacity, and new vulnerabilities, adaptations, behaviours or perceptions may arise. For example, perceptions of safe travel conditions in Igloodik, Nunavut, have changed, such that hunting takes place now in what was traditionally considered unsafe visibility conditions, as a result of less hunting time being available, new GPS technology and different perceptions of risk by younger or less-experienced hunters (Ford, Smit, Wandel & MacDonald 2006).

We look at the impacts of caribou range expansion, which has already negatively affected the social-ecological system of reindeer herding on the Seward Peninsula, Alaska. The nature of herding has been altered, and weather variability has become a more critical determinant for future loss, via its effects on flexible herd access whenever caribou or predators are present. We apply the vulnerability framework to our work with one herder, and his perspective on weather, vis-a-vis other constraints and opportunities within his herding SES.

A case study of weather and herding

This study was part of a larger project that investigated the ways in which the reindeer industry has been transformed by caribou range expansion. Previous papers place the current situation within the historical context of herding adaptation through oral history interviews (Schneider 2002; Schneider et al. 2005), and an examination of changes in *Rangier-human* relationships in the region (Oleson 2005; Finstad et al. 2006). Finstad et al. (2006) and Oleson (2005) discuss key mitigation measures, particularly refugia, satellite collars and online mapping of collar locations, as well as potential repercussions such as the overgrazing of slow-growing lichen in refugia (Oleson 2005). Carlson (2005) used an input-output model - and impact scenarios to assess the economic role of reindeer in the region before and after the arrival of caribou, and the direct and indirect impacts of a diminished reindeer industry on the regional economy. These papers identify various environmental

and socio-economic factors that affect modern herding. In particular, Schneider et al. (2005) conducted a series of oral history interviews with 13 herders, who could best couch caribou range expansion within the context of past and present adaptations of herding. One common theme that herders brought up was the impact of weather variability and concerns about climate change, which became the stimulus for the current study.

There is a growing body of literature about the impacts of climate change on Arctic indigenous communities, and indigenous observations are an active part of climate change documentation and research (Krupnik & Jolly 2002; Helander & Mustorien 2004; Symon et al. 2005; Parry et al. 2007). Several studies have been initiated in response to concerns about increased weather variability. Some empirical analyses concur with local observations (e.g., an increase in autumn freezing rain events in northern Canada [Hanesiak & Wang 2005]; increased wind speed since 1979 in Barrow [Hinzman et al. 2005]), but others are less conclusive about the variability of other weather parameters (e.g., storm frequency, Atkinson 2005; seasonal temperature variability, Walsh et al. 2005). This dichotomy stems from geographic and temporal gaps in station and satellite data (Serreze et al. 2000; Krupnik & Jolly 2002), the difficulty in defining or quantifying many climate variables critical to land-based livelihoods (Atkinson 2005; Walsh et al. 2005), and the influence of technological and social changes on perceptions of weather, climate and other environmental conditions (Walsh et al. 2005; Ford, Smit & Wandel 2006; Gearheard et al. 2006). The Arctic climate is changing (Serreze et al. 2000; Hinzman et al. 2005; Symon et al. 2005), but the implications for Arctic residents stem from the local conditions that affect their communities and livelihoods (Gearheard et al. 2006).

There has been a strong focus on the impacts of environmental change on communities, but SESs also exist at the individual level and adaptive capacity varies among individuals within the same community (Huntington 2002; Kassam and the Wainwright Traditional Council 2001). An individual may be more or less affected by various forces of the local or regional SES, depending upon his or her social network, economic means and involvement in a natural resource-based livelihood (Chance 1968). Case studies of individual SESs offer relevant pictures of the similarities and the variation within a community, without neglecting the role that individual choice plays in adaptation (Kruse 1991).

Each herder on the Seward Peninsula has been able to, or has been forced to, make a variety of technological, socio-economic and management adaptations in response to caribou use of the region. These adaptations are influenced by weather, herd size, caribou presence, season,

distance between village and range, economic means, family experience, oral tradition and available technology, among other factors (Schneider et al. 2005). The interplay between these factors is different for each herder, and each herder perceives his or her situation in a unique way such that responses to caribou, weather and other ecological, social or economic change cannot be easily generalized (Schneider et al. 2005). A case study with one herder allowed us to contextually document the many factors that shape modern herd management, with an emphasis on the effects of weather.

Herder James Noyakuk of Teller, Alaska

James Noyakuk of Teller, Alaska, was the primary consultant for this project, because he was actively herding at the start of this study in 2003, and caribou have been a major challenge in herd management during this time. He agreed to work with us on this project, and has a 20-year working relationship with the University of Alaska Fairbanks Reindeer Research Program (RRP), which conducts range management, reindeer health, meat science and applied telemetry research in Fairbanks, and on the Seward Peninsula.

Noyakuk resides in the coastal village of Teller, but his 3100-km² range is 30 km east of Teller, in the interior of the Seward Peninsula (Fig. 1). Noyakuk boats to his range in summer via Gramley Harbor, Tuksuk Channel and Imuruk Basin (Fig. 1). In winter, he travels by snowmobile across the ice on Grantley Harbor, and then on overland trails. His corral and cabin are on the north shore of Imuruk Basin. The land surrounding the corral is flat, with numerous sloughs and ponds and treeless, wet tussock tundra, except where tall thickets of willows (*Salix* spp.) dominate in riparian areas. The hills north of the corral rise to 875 m a.s.l. at Kougarok Mountain, and are vegetated with tussock tundra and dry heath species. Gramley Harbor, Imuruk Basin and inland rivers are usually frozen between late November and May. The effective snow season is slightly shorter, but snow depth is variable across the range.

Noyakuk started herding in 1971 when he was 16, and worked for his uncle Larry Davis, who had a large herd in Nome. He established a herd with another uncle, Arthur Tocktoo, in 1985, on his current range. Initially, 580 reindeer were loaned from the Davis herd via a Bureau of Indian Affairs (ETA) programme. He monitored the herd intensely in the early years to prevent the loaned reindeer from returning to the Davis range during the calving season. By 1996, Noyakuk had as many as 1500 reindeer, which had developed fidelity to his range, and required less frequent monitoring. During the early 1990s, profits from antler and meat sales funded helicopter use for

herding and new snowmobiles each year. Noyakuk could also afford to hire large crews to assist with the winter and summer handlings - multi - day events when the reindeer are gathered and moved through the corral to earmark calves and other unmarked reindeer, administer veterinary care, harvest velvet antler (summer only), and record the age and sex composition of the herd.

Large influxes of caribou in 1996 and 2000, and the consequent emigration of hundreds of reindeer, reduced Noyakuk's herd to less than 150 reindeer. His herd has averaged 200 reindeer at summer handlings since 2002, with emigration and predation seemingly negating any gains from the survival of new calves. Since caribou began wintering on the central Seward Peninsula, Noyakuk constrains his herd to the area just north of his

corral. This area is his self-designated "comfort zone" (Fig. 2), where he is familiar with the landscape, and the flat terrain allows for travel even in poor visibility. Noyakuk also keeps his herd on the south-eastern portion of Leonard Olanna's range, which is one half of a refugia shared with Olanna (Oleson 2005; Schneider et al. 2005). Either herder can keep his reindeer on the refugia to prevent losses to migrating caribou. Satellite collars were first deployed on Noyakuk's reindeer in 2000, and maps showing updated reindeer locations are available through a website managed by the Reindeer Research Program. Maps of collared caribou locations are available to herders from the Alaska Department of Fish and Game.

Noyakuk spends more time on his range now that caribou are present. Some of the current costs of herding

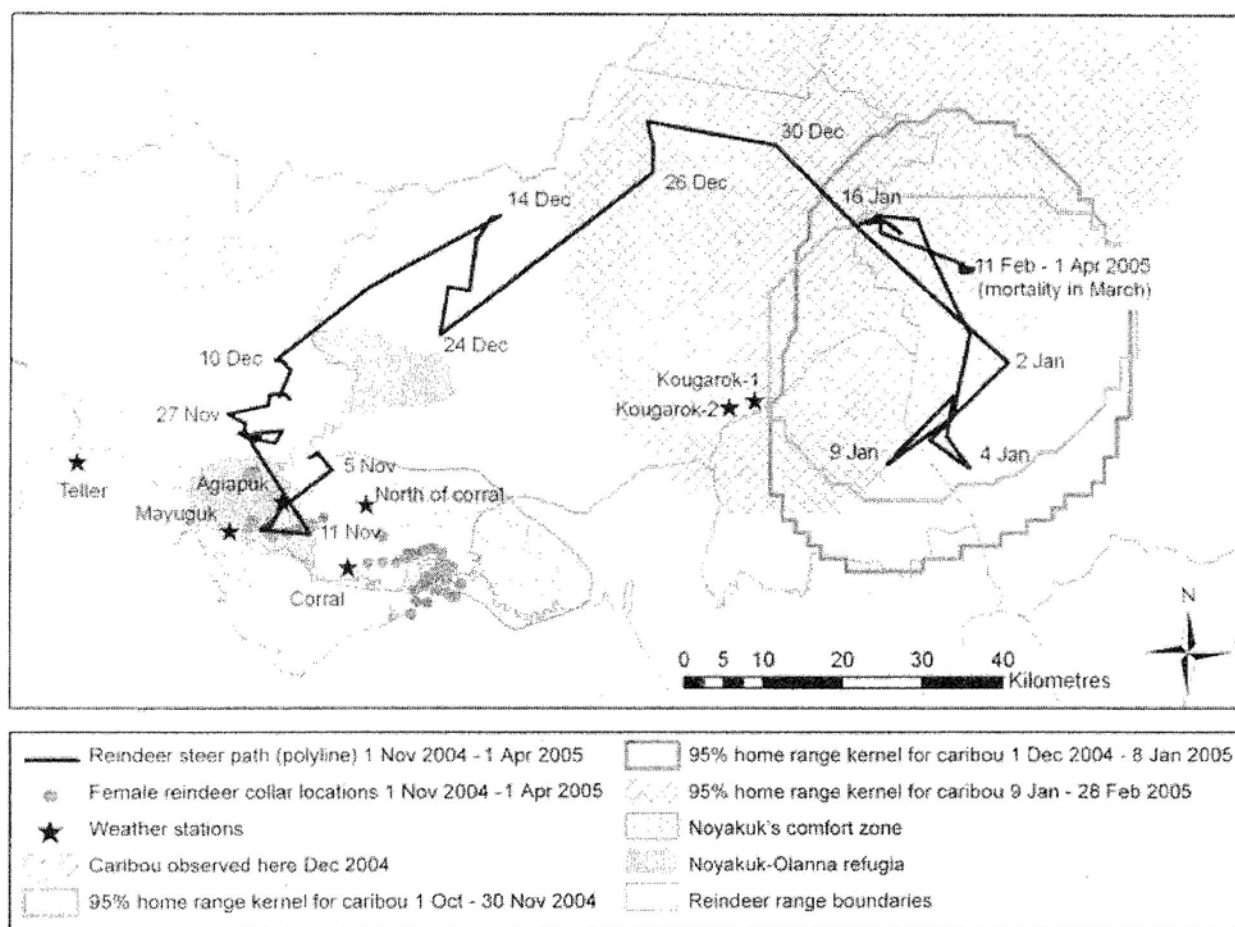


Fig. 2 Map of James Noyakuk's range, weather stations, and satellite-collared reindeer and caribou (1 November 2004–1 April 2005). A satellite-collared steer in Noyakuk's herd left the range in December 2004, presumably with caribou. Locations of satellite-collared female reindeer show greater fidelity to Noyakuk's comfort zone during the same period. There were at least two satellite-collared caribou within the 95% home range kernels on this map, but the kernels were produced from a total of 15–19 collared caribou, spread across the Seward Peninsula ($n = 110$ –118 locations per season). (Collar locations for reindeer were provided by the University of Alaska Fairbanks Reindeer Research Program. Collar locations for caribou were provided by the Alaska Department of Fish and Game through 28 February 2005.)

are offset with seasonal construction jobs, although this limits the time available for herding. He assists his extended family in various ways in exchange for their help with some herding activities, such as handlings, but the community of Teller is currently less involved with herding events than it once was. Many local residents miss the employment opportunities and communal experience of the larger handlings of the past, but most appreciate the opportunity to hunt caribou that have been largely absent from the Seward Peninsula since the late 1800s (Skoog 1968; Burch (1972).

Methods

Interviews

Interviews with James Noyakuk and fieldwork on his range took place between February 2004 and June 2005. Interview methods included semi-directed discussions about herd management, participatory mapping sessions to document herd use areas and travel routes, and field interviews on the range, where Noyakuk described weather, snow and ice conditions in relationship to various herding activities. We spoke with Noyakuk by telephone on a weekly or biweekly basis to ask about recent herding activities and weather conditions, including his rating of weather and trail conditions ("good", when it was possible to travel by snowmobile at preferred speeds; "minimal", when conditions had deteriorated enough to slow but not prevent safe travel; and "poor", when travel was impossible or unsafe). We also participated in activities such as winter slaughter and summer handlings. A group interview was held with four herders on 25 March 2004, and structured surveys were conducted in person or on the telephone with Noyakuk and 12 other reindeer herders, or members of herding families, in March 2005.

Weather stations and snow transects

We deployed weather stations (HOBO Microstations; Onset Computer Corporation, Bourne, MA, USA) at Noyakuk's corral, and along navel routes on his range, to record hourly air temperature, wind speed and wind direction from 15 February to 29 May 2004 (four stations: Mayuguk, Agiapuk, Corral and North of Corral), and from 15 March to 31 May 2005 (three stations: Mayuguk, Corral and Teller) (Fig. 2). We also obtained hourly data for air temperature, wind speed, wind direction and visibility (Nome only) from 15 February to 29 May 2004 and 1 October 2004 to 31 May 2005 from the National Weather Service (NWS) station in Nome, and from stations established by the University of Alaska Fairbanks

Water and Environmental Research Center on the eastern side of Noyakuk's range (Kougarok-1 and -2) and in Teller (from 15 February to 29 May 2004 only). The wind-chill equivalent temperature (WCT) was calculated using the current National Weather Service conversion (NWS 2006):

$$WCT(^{\circ}F) = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16}),$$

where T is the workday average air temperature (in $^{\circ}F$) and V is the workday average wind speed (in mph).

Temperature, wind speed, WCT and visibility data between 09:00 and 20:00 h were averaged for each day to cover the time when Noyakuk was most likely to conduct herding activities. We compared these workday averages among Noyakuk's "good", "minimal" and "poor" rated days at each station for three periods: 15 February–29 May 2004, 1 December 2004–14 March 2005, and 15 March–31 May 2005, based on when the HOBO stations were deployed and seasonal herding events. We used Wilcoxon ranked sum tests ($P < 0.05$, SAS 9.1; SAS, Cary, NC, USA) to compare "good" and "poor" rated days for 15 February–29 May 2004 data, because there were only two "minimal" rated days. We used Kruskal-Wallis tests ($P < 0.05$, SAS 9.1) to compare "good", "minimal" and "poor" rated days for the 1 December 2004–14 March 2005 data. We did not compare rating categories for 15 March–31 May 2005 data because of the lack of "poor" and "minimal" rated days. The wind direction data were analysed visually with wind roses (WRPLOT View; Lakes Environmental, Waterloo, Ontario).

Transects were conducted to measure snow depth at each station (20 measurements per station) on 15 February 2004, 19 and 20 March 2004, and 29 and 30 March 2005. We compared the average snow depth among transect dates at each station, and among stations for each transect date (ANOVA with Scheffe's multiple comparisons tests, $P < 0.05$, SAS 9.1).

Spatial data

Information from the mapping interviews and satellite collar locations of reindeer and caribou were mapped using ARCVIEW 3.3 (ESRI Redlands, CA, USA) and the ANIMAL MOVEMENT SA 2.04 beta extension (Hooge & Eichenlaub 1997). Location data for satellite-collared reindeer were processed and provided by the Reindeer Research Program (Oleson 2005). During the study period, there were two female reindeer and one steer (male reindeer castrated for meat production) that were equipped with satellite collars in Noyakuk's herd. Additionally, two collared reindeer from Leonard Olanna's herd occasionally mixed with Noyakuk's herd. The loca-

tion data of satellite-collared caribou were provided by the Alaska Department of Fish and Game for the Seward Peninsula from 15 February 2004 to 28 February 2005. The Alaska Department of Fish and Game collaring procedures are described by Dau (2005).

The reindeer collars were scheduled by the RRP to transmit a location every five days, and the caribou collars were scheduled by the Alaska Department of Fish and Game to transmit a location every six days. We selected locations with Argos accuracy classes 2 and 3 (± 400 and 283 m, respectively; Oleson 2005). For illustrative purposes, we produced 95% home range (use area) kernels from seasonal caribou location data using the fixed kernel and least squares cross validation methods of ANIMAL MOVEMENT (Seaman et al. 1999) (fig. 2).

Results and discussion

The original goals for this study were to investigate the role of weather within the larger social-ecological system of herder James Noyakuk of Teller, Alaska. We found that short-term responses to weather variability occur within more long-term vulnerability (exposure, sensitivity and adaptive capacity) to the stresses associated with caribou range expansion, reduced herd size, difficulties maintaining snowmobiles and dwindling market opportunities. This section is structured along the lines of the study objectives. First, we present information about the seasonal round of herding activities and the daily decision processes that serve as a backdrop for understanding weather as a system variable. Next, we compare the weather station data with Noyakuk's rating of weather conditions. We then describe the ways that weather events directly and indirectly impacted herding during the winters of 2003/04 and 2004/05, as well as implications for examining local effects of climate change. Finally, we discuss other ecological and socio-economic factors that have been altered by the presence of caribou, and the consequent effects on exposure-sensitivity, and adaptive capacity, in Noyakuk's herding system.

Seasonal herding activities, daily decisions and the effects of weather

Noyakuk divides the year into seven herding seasons, although the season length varies annually depending on planned herding activities and herd accessibility (Table 1). During the late summer and early autumn, herding is infrequent because access is difficult across the marshy tundra. Moreover, the reindeer may be scattered in groups of 20–30 animals from mid-August through September for the rut (mating season). During freeze-up (October–November), Grantley Harbor and Imuruk Basin are not navigable by boat or snowmobile, and the reindeer are inaccessible. Following freeze-up, Noyakuk moves his herd to a specific winter range, although herding in December and January is limited by the short day length. The preferred time to slaughter is early winter, because of the higher fat content and quality of the meat. In the past, Noyakuk held winter handlings in January and February, but winter handlings are less common now because of the lower economic returns with fewer reindeer.

In late winter (March–early April) Noyakuk moves his reindeer to specific calving sites near his corral, where there is adequate lichen for forage, and he can easily monitor and protect the reindeer from predators. Calving begins in mid-April and continues through May. Break-up typically occurs in May, and the herd is again inaccessible because of the melting harbor and river ice. Noyakuk usually conducts one or two handlings in June and July, but the reindeer are otherwise unattended during the summer months. Winter is thus the primary season when Noyakuk can actively keep the reindeer in specific grazing areas. Caribou may be present on the Seward Peninsula from October to May, although the caribou use of the central Seward Peninsula has varied annually (Dau 2005).

Noyakuk bases daily herding decisions on a number of factors. First Grantley Harbor, Imuruk Basin and rivers and streams on the range must be passable either by boat or snowmobile (i.e., they must be either completely open or completely frozen). Second, the status of the herd (i.e.,

Table 1 Typical annual herding seasons between 1996 and 2005 for herder James Noyakuk of Teller, Alaska.

Season	Typical year	2003/04	2004/05	Reindeer herding activity
Late summer/autumn	mid-Jul.–mid-Oct.	10 Jul.–14 Oct.	1 Jul.–14 Oct.	Limited herding. Reindeer rut. Caribou arrive.
Freeze-up	mid-Oct.–mid-Nov.	15 Oct.–30 Nov.	1 Oct.–30 Nov.	Reindeer inaccessible.
Early winter	late Nov.–Dec.	1 Dec.–31 Dec. Handling 19 Dec.	1 Dec.–8 Jan.	Round-up. Slaughter.
Mid-winter	Jan.–Feb.	1 Jan.–7 Apr.	9 Jan.–14 Mar. Handling 13 Mar.	Slaughter, winter handlings.
Late winter	Mar.–early May	—	15 Mar.–1 May	Reindeer moved to calving site. Calving begins mid-April.
Break-up	May–early Jun.	8 Apr.–29 May	2 May–31 May	Reindeer inaccessible. Calving ends. Caribou migrate north.
Summer	early Jun.–mid-Jul.	30 May–30 Jun.	1 Jun.–14 Jul.	Summer handlings.

caribou or predator threat, herd size and herd location) determines the travel and herding plans for the day. Sudden, pronounced movements of satellite-collared reindeer and/or reports about caribou or predators usually initiate travel to the range. Third, reliable, mechanized transport, affordable fuel and an experienced crew (for some tasks) are crucial. Noyakuk usually travels alone to monitor or drive the herd short distances, but requires assistance for longer reindeer drives, or when travelling to less familiar territory. He will borrow a snowmobile or fuel when necessary. Finally, poor weather and trail conditions may impede herding plans, even when the above conditions are met. However, Noyakuk often travels to his herd in inclement weather, when there is imminent caribou or predator threat, and the herd is within his comfort zone.

The interviews also focused on the effects of specific weather and environmental conditions (Table 2; see also Rattenbury 2006). The most limiting factor for Noyakuk is ice conditions on Grantley Harbor, Imuruk Basin, and

the rivers and streams on his range. Freeze-up and break-up amount to 2-3 months per year when it is unsafe to travel to the range. Between freeze-up and break-up, the largest concern is visibility. Blizzards, blowing snow and fog often prevent travel, and have been the cause for missing person incidents, accidents and fatalities in the region. Poor visibility, including flat light conditions, is particularly problematic in the more rugged terrain outside of Novakuk's comfort zone. Inadequate, very hard or very deep soft snow, or sastrugi-wind-hardened snow drifts and ridges to 2 m in height, aligned parallel with the prevailing wind direction (Ryan & Crissman 1990) - may slow travel, damage the snowmobile and/or compound the process of moving the herd. Wind speed, direction and air temperature have less of an effect on winter herding, except in combination with other conditions (e.g., wind speed is critical when there is loose snow on the ground, blizzard conditions and/or low air temperatures). Blizzard and wind-chill warning, are critical because temperatures tend to be colder on Noy-

Table 2 Weather and snow conditions affecting Noyakuk's herding decisions.

Weather variable	Index for "good" conditions	Factors creating "minimal" and "poor" conditions	Seasonal considerations
Freezing of waterways (Grantley Harbor, Imuruk Basin, inland rivers)	Completely frozen; no open water or water over ice (overflow); no "hollow ice"; snow covering ice where moving reindeer	Unstable ice during freeze-up and break-up. Overflow >30 cm—hides cracks and holes in ice. "Hollow ice" forms when warm spells raise water levels below river ice, and an air pocket remains when the water recedes. Reindeer balk when crossing glare ice.	Ice usually safe for travel from late Nov. (early Dec. since 2000) to May. Poor ice conditions are typical during freeze-up, early winter and break-up.
Visibility	Visibility >5 km, although Noyakuk will travel with <0.5 km visibility if travelling in comfort zone (flat, familiar terrain near corral) and/or caribou or predators are near reindeer.	Blizzard conditions. Blowing snow (ground blizzards). Flat light conditions when cloud cover/lighting distorts contrast and vertical relief on the landscape. Fog. Short day length in Dec./Jan. "Poor" conditions require a GPS for navigation. Reindeer more wary of snowmobile when visibility is poor.	Storms expected in Jan. but there has been a higher than normal storm frequency during the winters of 2003/04 and 2004/05. Fog is common in autumn and in spring.
Snow pack/snow cover	Well-packed snow covering cottongrass tussocks (>30 cm total) and smooth, soft surface	Inadequate snow cover—exposed tussocks and rocks, especially in early winter, on hills. Sun- or wind-hardened surface (glazing). Sastrugi (hard snow drifts). Soft snow >1 m that immobilizes the snowmobile and increases fuel consumption.	Adequate snow depth usually not well-established until mid Dec. Wind-hardened drifts may be common throughout the winter.
Wind	Effects of wind depend on the presence of loose snow on ground and/or windchill.	High winds (>30 km h ⁻¹) are a concern, with loose snow and low air temperature. Winds strongest in Teller, and in hills west and north of corral. Reindeer tend to move upwind in poor visibility.	Cold, north winds typical in winter; warm, south winds in Mar./Apr. Reindeer move upwind to avoid summer insects.
Air temperature/windchill equivalent temperature (WCT)	Ideal winter herding conditions from -10°C to -30°C	Temperature/WCT threshold -35°C, but Noyakuk frequently travels at lower temperatures/WCTs. Above-freezing temperatures in winter create open ice, overflow and thaw-freeze events (which creates an icy snow surface and hinders reindeer digging for forage).	Winters are colder and summers are hotter on Noyakuk's range than in Teller. Reindeer overheating is a concern for summer handlings.

akuk's range than in Teller. Above-freezing temperatures in mid-winter can result in icy snow surfaces, overflow, open water and early snowmelt,

Weather station data and the rating system

Reduced visibility was the main reason for most of Noyakuk's "poor" and "minimal" weather ratings during the study. However, workday average visibility in Nome was not significantly different among the rating categories (Table 3), and Novakuk's observations often differed from Nome data, except during major storm events. Nome is the nearest location where visibility is recorded, but it is approximately 95 km south-east of Teller, and 75 km south of Noyakuk's corral. The coastal and topographical features of Nome influence storms and fog differently

than at Teller, or in the interior Seward Peninsula. Additionally, visibility data from Nome, which is an ocular observation of up to 16 km across the airport runway, cannot account for flat light conditions, when cloud cover and low light distorts contrast and vertical relief on the landscape. Although a key weather variable for herding, local visibility is difficult to quantify for empirical analyses of trends and variability.

There were also little or no difference for workday average temperature, wind speed and WCT among Noyakuk's "good", "minimal" or "poor" rated days for any of the stations or periods ($P < 0.05$, Tables 4–6). Likewise, there were few trends for wind direction among rating categories or seasons, although the analyses were limited (Rattenbury 2006). The rating system is problematic because Noyakuk usually rated weather conditions

Table 3 Workday average visibility (km) registered by the Nome National Weather Service (NWS), by rating category.

Station	Date	Good days ^a	Minimal days ^a	Poor days ^a	Mixed rating ^a	Unrated days ^a	Days not discussed ^a
Nome (NWS)	15/2/04–7/4/04	14.1 ± 3.3 (5)	15.6 ± 0.4 (2)	14.6 ± 1.1 (5)	n.d.	12.6 ± 4.2 (2)	14 ± 3.6 (39)
Nome (NWS)	1/12/04–14/3/05	14.3 ± 2.9 (11)	12.4 ± 2.1 (4)	12.2 ± 4.2 (10)	10.1 ± 1.8 (4)	15.4 ± 0.7 (2)	12.8 ± 4.2 (73)
Nome (NWS)	15/3/05–1/5/05	16 ± 0.3 (8)	n.d.	16.1 (1)	n.d.	15.4 ± 1.9 (19)	12.8 ± 2.7 (19)

^aMean data ± SD (n); n.d., no data.

Table 4 Workday average temperature (°C) by rating category.

Station	Date	Good days ^a	Minimal days ^a	Poor days ^a	Mixed rating ^a	Unrated days ^a	Days not discussed ^a
Teller (WERC ^b)	15/2/04–7/4/04	−16.3 ± 8.1 (5)	−19.3 ± 0.9 (2)	−18.2 ± 1.9 (5)	n.d.	−11.8 ± 7.6 (2)	−14.6 ± 7.9 (39)
Teller (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Teller (HOBO ^c)	15/3/05–1/5/05	−12.9 ± 7.6 (8)	n.d.	−19.9 (1)	n.d.	−7.9 ± 9.4 (19)	−12.6 ± 8 (19)
Mayuguk (HOBO)	15/2/04–7/4/04	−18.2 ± 8.3 (5)	−19.7 ± 0.9 (2)	−19.2 ± 1.7 (5)	n.d.	−13.1 ± 8 (2)	−15.7 ± 8 (39)
Mayuguk (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Mayuguk (HOBO)	15/3/05–1/5/05	−14.1 ± 7.8 (8)	n.d.	−20.6 (1)	n.d.	−9.3 ± 9.8 (19)	−13.8 ± 8 (19)
Agiapuk (HOBO)	15/2/04–7/4/04	−18.8 ± 7.8 (5)	−18.4 ± 1.6 (2)	−18.1 ± 1.7 (5)	n.d.	−13.8 ± 10.3 (2)	−15 ± 8 (39)
Agiapuk (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Agiapuk (no station)	15/3/05–1/5/05	—	—	—	—	—	—
Corral (HOBO)	15/2/04–7/4/04	−19.2 ± 8.1 (5)	−17.9 ± 1.1 (2)	−17.6 ± 2.7 (5)	n.d.	−15.4 ± 10 (2)	−15.4 ± 7.8 (39)
Corral (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Corral (HOBO)	15/3/05–1/5/05	−13.7 ± 8.1 (8)	n.d.	−21.2 (1)	n.d.	−9.6 ± 10.6 (19)	−13.8 ± 8.3 (19)
North of Corral (HOBO)	15/2/04–7/4/04	−18.7 ± 6.7 (5)	−18.9 ± 1.9 (2)	−17.8 ± 2.2 (5)	n.d.	−14.2 ± 10 (2)	−15 ± 7.8 (39)
N. of Corral (no station)	1/12/04–14/3/05	—	—	—	—	—	—
N. of Corral (no station)	15/3/05–1/5/05	—	—	—	—	—	—
Kougarok-1 (WERC)	15/2/04–7/4/04	−18.3 ± 4.9 (5)	−18.8 ± 0.7 (2)	−18.6 ± 2.6 (2)	n.d.	−13 ± 9.3 (2)	−15.2 ± 8.1 (39)
Kougarok-1 (WERC)	1/12/04–14/3/05	−18.2 ± 3 (11)	−17.1 ± 3.1 (4)	−18.7 ± 8.1 (10)	−8.3 ± 5 (4)	−15.6 ± 3.3 (2)	−15.3 ± 7.9 (73)
Kougarok-1 (WERC)	15/3/05–1/5/05	−13.6 ± 7.3 (8)	n.d.	−22.0 (1)	n.d.	−8.5 ± 9.9 (19)	−12.8 ± 7.8 (19)
Kougarok-2 (WERC)	15/2/04–7/4/04	−17.4 ± 5.7 (5)	−18.9 ± 0.8 (2)	−18.9 ± 2.1 (5)	n.d.	−14.9 ± 10.7 (2)	−15.2 ± 7.3 (39)
Kougarok-2 (WERC)	1/12/04–14/3/05	−18.9 ± 3 (11)	−17.3 ± 3.1 (4)	−21.1 ± 11 (10)	−9.4 ± 3.5 (4)	−15.2 ± 2.5 (2)	−15.4 ± 8.2 (73)
Kougarok-2 (WERC)	15/3/05–1/5/05	−13.5 ± 8.7 (8)	n.d.	−21.3 (1)	n.d.	−10.3 ± 9 (19)	−13.2 ± 7.5 (19)
Nome (NWS ^d)	15/2/04–7/4/04	−13.2 ± 3.7 (5)	−13.7 ± 1.4 (2)	−10.6 ± 2.7 (5)	n.d.	−8.9 ± 9.5 (2)	−10.7 ± 7.6 (39)
Nome (NWS)	1/12/04–14/3/05	−15.4 ± 3.5 (11)	−8.7 ± 5.5 (4)	−13.1 ± 10.8 (10)	−5.6 ± 3.1 (4)	−5.9 ± 4 (2)	−11.3 ± 7.7 (73)
Nome (NWS)	15/3/05–1/5/05	−8.8 ± 7.8 (8)	n.d.	−16.3 (1)	n.d.	−4.8 ± 8.9 (19)	−9.5 ± 6.4 (19)

^aMean data ± 1 S.D. (n); n.d. = no data.

^bWater and Environmental Research Center.

^cHOBO Microstation, Onset Computer Corporation, Bourne, MA, USA.

^dNational Weather Service.

Table 5 Workday average wind speed (m/s) by rating category.

Station	Date	Good days ^a	Minimal days ^a	Poor days ^a	Mixed rating ^a	Unrated days ^a	Days not discussed ^a
Teller (WERC ^b)	15/2/04–7/4/04	6.9 ± 4.1 (5)	8.2 ± 2.9 (2)	4.6 ± 2.1 (5)	n.d.	1.4 ± 1.8 (2)	5.1 ± 2.2 (39)
Teller (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Teller (HOB0 ^c)	15/3/05–1/5/05	4.7 ± 1.1 (8)	n.d.	2.8 (1)	n.d.	3.7 ± 1.7 (19)	3.9 ± 1.9 (19)
Mayuguk (HOB0)	15/2/04–7/4/04	2.9 ± 0.8 (5)	4.9 ± 2.7 (2)	4.2 ± 1.6 (5)	n.d.	1.6 ± 0.7 (2)	3.7 ± 2 (39)
Mayuguk (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Mayuguk (HOB0)	15/3/05–1/5/05	3.8 ± 0.8 (8)	n.d.	2.3 (1)	n.d.	3.2 ± 1.5 (19)	3.8 ± 1.7 (19)
Agiapuk (HOB0)	15/2/04–7/4/04	1 ± 0.5 (5)*	3.8 ± 1.8 (2)	3.1 ± 0.8 (5)**	n.d.	0.7 ± 0.3 (2)	2.1 ± 1.5 (39)
Agiapuk (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Agiapuk (no station)	15/3/05–1/5/05	—	—	—	—	—	—
Corral (HOB0)	15/2/04–7/4/04	1.7 ± 1.2 (5)	3.2 ± 2.5 (2)	2 ± 1.2 (5)	n.d.	0.8 ± 0.3 (2)	2.2 ± 1.9 (39)
Corral (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Corral (HOB0)	15/3/05–1/5/05	2.5 ± 1 (8)	n.d.	2.4 (1)	n.d.	1.4 ± 1.1 (19)	2.3 ± 2 (19)
North of Corral (HOB0)	15/2/04–7/4/04	1.9 ± 2.2 (5)	4.6 ± 2.6 (2)	3.3 ± 1.2 (5)	n.d.	1.1 ± 0.1 (2)	2.8 ± 2.3 (39)
N. of Corral (no station)	1/12/04–14/3/05	—	—	—	—	—	—
N. of Corral (no station)	15/3/05–1/5/05	—	—	—	—	—	—
Kougarok-1 (WERC)	15/2/04–7/4/04	8.1 ± 3.2 (5)*	6.8 ± 2.9 (2)	4.3 ± 1.4 (5)**	n.d.	3.2 ± 2.1 (2)	5.5 ± 2.7 (39)
Kougarok-1 (WERC)	1/12/04–14/3/05	5.5 ± 3.1 (11)	5.1 ± 2 (4)	6 ± 4.1 (10)	4.7 ± 3.2 (4)	5.2 ± 2.9 (2)	5.1 ± 3.5 (73)
Kougarok-1 (WERC)	15/3/05–1/5/05	7.3 ± 4.3 (8)	n.d.	3.2 (1)	n.d.	3.7 ± 1.6 (19)	5.6 ± 3.4 (19)
Kougarok-2 (WERC)	15/2/04–7/4/04	5 ± 2.6 (5)	5.7 ± 1.4 (2)	4.5 ± 0.8 (5)	n.d.	3 ± 0.9 (2)	4.2 ± 2.4 (39)
Kougarok-2 (WERC)	1/12/04–14/3/05	3.3 ± 1.9 (11)	5.2 ± 1.6 (4)	4.5 ± 2.8 (10)	4 ± 2.5 (4)	3.4 ± 2.6 (2)	6.5 ± 3.4 (73)
Kougarok-2 (WERC)	15/3/05–1/5/05	5.4 ± 2.6 (8)	n.d.	2.3 (1)	n.d.	3 ± 1.6 (19)	4.3 ± 2.5 (19)
Nome (NWS ^d)	15/2/04–7/4/04	3.6 ± 2.2 (5)	3.6 ± 3.2 (2)	2.4 ± 1.7 (5)	n.d.	4 ± 3.2 (2)	3.9 ± 2.7 (39)
Nome (NWS)	1/12/04–14/3/05	1.9 ± 2.5 (11)	3.3 ± 2.3 (4)	4.7 ± 4.2 (10)	5.1 ± 3.3 (4)	5.2 ± 1 (2)	4.1 ± 2.3 (73)
Nome (NWS)	15/3/05–1/5/05	4.1 ± 4.4 (8)	n.d.	4.2 (1)	n.d.	2.8 ± 2 (19)	3.4 ± 2.1 (19)

^aMean data ± SD (n); n.d., no data. Single and double asterisks indicate significant differences across rows only ($P < 0.05$).

^bWater and Environmental Research Center.

^cHOB0 Microstation, Onset Computer Corporation, MA, USA.

^dNational Weather Service.

based on a combination of several factors that may have changed throughout the day, or by location. Additionally, our sample sizes were small (i.e., the number of station: and the number of days per rating category). There were several unrated travel days, and potentially many travel days that were not discussed during the telephone conversations. The large ranges for wind speed, temperature and WCT within each rating category indicate that other conditions were more important for how Noyakuk rated daily weather conditions. This agrees with information shared during the interviews about the importance of freeze-up and break-up, local visibility and snow, which we were not able to quantify adequately for comparison among Noyakuk's rated days.

Effects of weather and caribou on herding during the winters of 2003/04 and 2004/05

Several events during the study period illustrated the vulnerability of Noyakuk's herding system to certain weather conditions. These include differences in snow conditions between the two winters, the early break-up in spring 2004, and the delayed freeze-up and frequent

storms in November and December of 2004. The two winters also differed for caribou presence. In 2003/04, there were no satellite-collared caribou on the central Seward Peninsula, and caribou were not a major consideration for Noyakuk. However, satellite-collared caribou were present on Noyakuk's range in late November 2004, and a valuable group of reindeer wandered off-range in December, when caribou were nearby.

Widespread sastrugi and hard, shallow snow hindered herding trips in 2003/04, in comparison with the deeper snow (Table 7) and easier travelling conditions in 2004/05. Poor snow conditions were less of a concern when Noyakuk had a larger herd, antler prices were high and he could afford to buy and maintain several snowmobiles each year. Noyakuk now uses older snowmobiles, and the combination of a poorly functioning ruachin« and marginal weather and trail conditions often prevents him from travelling to the herd. Other herders have mentioned changing their mode of herding in response to changing snow conditions.

When I first got started helping Teddy, it's almost 14 years now, we depended more on snowmachines .. Now it's turned around because of the warm

Table 6 Workday average windchill equivalent temperature (WCT) (°C) by rating category.

Station	Date	Good days ^a	Minimal days ^a	Poor days ^a	Mixed rating ^a	Unrated days ^a	Days not discussed ^a
Teller (WERC ^b)	15/2/04–7/4/04	-26.1 ± 9.8 (5)	-31.4 ± 0.7 (2)	-26.1 ± 4.5 (5)	n.d.	-14 ± 4.4 (2)	-22.9 ± 11 (39)
Teller (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Teller (HOB0 ^c)	15/3/05–1/5/05	-20.6 ± 8.9 (8)	n.d.	-27.1 (1)	n.d.	-13.1 ± 10.6 (19)	-12.6 ± 8 (19)
Mayuguk (HOB0)	15/2/04–7/4/04	-25 ± 9.3 (5)	-29 ± 1.7 (2)	-27.8 ± 3.4 (5)	n.d.	-15 ± 5.2 (2)	-22.8 ± 10.8 (39)
Mayuguk (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Mayuguk (HOB0)	15/3/05–1/5/05	-21.4 ± 9.6 (8)	n.d.	-27.2 (1)	n.d.	-14.1 ± 11.2 (19)	-13.8 ± 8 (19)
Agiapuk (HOB0)	15/2/04–7/4/04	-19.4 ± 6.7 (5)	-26.4 ± 0.3 (2)	-25.3 ± 2.1 (5)	n.d.	-13.8 ± 10.3 (2)	-18.9 ± 10.2 (39)
Agiapuk (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Agiapuk (no station)	15/3/05–1/5/05	—	—	—	—	—	—
Corral (HOB0)	15/2/04–7/4/04	-22.6 ± 8.8 (5)	-24.6 ± 2.4 (2)	-21.8 ± 6.2 (5)	n.d.	-15.4 ± 10 (2)	-19 ± 9.4 (39)
Corral (no station)	1/12/04–14/3/05	—	—	—	—	—	—
Corral (HOB0)	15/3/05–1/5/05	-18.3 ± 8.2 (8)	n.d.	-28 (1)	n.d.	-11.5 ± 10.5 (18)	-13.8 ± 8.3 (19)
North of Corral (HOB0)	15/2/04–7/4/04	-21.2 ± 6.1 (5)	-27.7 ± 0.5 (2)	-25.1 ± 3.4 (5)	n.d.	-14.2 ± 10 (2)	-19.5 ± 10.3 (39)
N. of Corral (no station)	1/12/04–14/3/05	—	—	—	—	—	—
N. of Corral (no station)	15/3/05–1/5/05	—	—	—	—	—	—
Kougarok-1 (WERC)	15/2/04–7/4/04	-29.8 ± 5.7 (5)	-29.8 ± 3.2 (2)	-27.4 ± 4.6 (5)	n.d.	-18.7 ± 8.4 (2)	-24 ± 11.2 (39)
Kougarok-1 (WERC)	1/12/04–14/3/05	-27.3 ± 4.8 (11)	-26.2 ± 2.6 (4)	-27.6 ± 7 (10)	-14.7 ± 8.1 (4)	-24.4 ± 6.6 (2)	-24.2 ± 9.9 (73)
Kougarok-1 (WERC)	15/3/05–1/5/05	-23 ± 8.7 (8)	n.d.	-30.3 (1)	n.d.	-13.7 ± 11.7 (19)	-20.6 ± 9.7 (19)
Kougarok-2 (WERC)	15/2/04–7/4/04	-26.3 ± 6.2 (5)	-29.1 ± 0.2 (2)	-28 ± 2.7 (5)	n.d.	-21.2 ± 11.6 (2)	-22.7 ± 9.8 (39)
Kougarok-2 (WERC)	1/12/04–14/3/05	-25.7 ± 4 (11)	-26.7 ± 4.8 (4)	-28.8 ± 9.6 (10)	-15.5 ± 5.3 (4)	-21.8 ± 6.4 (2)	-22.3 ± 9.5 (73)
Kougarok-2 (WERC)	15/3/05–1/5/05	-21.5 ± 10 (8)	n.d.	-27.8 (1)	n.d.	-14.7 ± 9.3 (19)	-19.5 ± 9.3 (19)
Nome (NWS ^d)	15/2/04–7/4/04	-18.8 ± 4.9 (5)	-19.8 ± 2.4 (2)	-14.3 ± 5.6 (5)	n.d.	-14.2 ± 8.3 (2)	-16.1 ± 9 (39)
Nome (NWS)	1/12/04–14/3/05	-18.4 ± 3.1 (11)	-13.1 ± 2.9 (4)	-19 ± 10.2 (10)	-10.8 ± 4.4 (4)	-12.4 ± 5.7 (2)	-17.6 ± 7.9 (73)
Nome (NWS)	15/3/05–1/5/05	-13.2 ± 7.6 (8)	n.d.	-24.5 (1)	n.d.	-7.4 ± 8 (19)	-14.2 ± 6.7 (19)

^aMean data ± SD (n); n.d., no data.^bWater and Environmental Research Center.^cHOB0 Microstation, Onset Computer Corporation, Bourne, MA, USA.^dNational Weather Service.**Table 7** Snow depth on Noyakuk's range in 2004 and 2005.

Transect site	Date	Snow depth (cm)	n
Mayuguk	15/2/04	26 ± 7 ^a	20
Agiapuk	15/2/04	32 ± 9 ^a	20
Corral	15/2/04	27 ± 12 ^a	20
North of corral	15/2/04	10 ± 16 ^b	20
Mayuguk	19/3/04	30 ± 8 ^a	20
Corral	20/3/04	26 ± 14 ^a	20
North of corral	20/3/04	25 ± 27 ^a	10
Mayuguk	30/3/05	61 ± 13 ^c	20
Agiapuk	30/3/05	65 ± 39 ^c	19 ^d
Corral	30/3/05	69 ± 11 ^c	20
North of corral	29/3/05	40 ± 15 ^c	20

Data are means ± SD.

^aSignificant differences between sites or dates ($P < 0.05$).^bOne point on this transect was dug to 208 cm (snow drift). Another point fell within the drift and was probed at >100 cm, but was not included in the mean.

weather, and he has his 4-wheeler and I have my 4-wheeler. It takes two of us to move the herd now.

(Marie Katchcak, herder from Stebbins, interview 25 March 2004)

Whereas some herders have observed a shift in the dominant snow conditions on their ranges, others, like Noyakuk, are experiencing greater challenges in coping with the variety of snow conditions on their ranges because of the need to respond quickly to migrating caribou, and the lack of financial resources to buy and maintain snowmobiles.

The early break-up in April 2004 prevented Noyakuk from accessing and monitoring his reindeer during the critical early weeks of calving. Above-freezing temperatures were recorded at all but one weather station from 8 to 19 April, corresponding with a rapid decrease of snow in Nome, and deteriorating snow conditions and open rivers on Noyakuk's range. He was not able to travel to

his reindeer from 15 April (the last snowmobile trip that winter) to 29 May (the first boat trip that summer). On the other hand, the early melt may have meant that there was an earlier emergence of high-quality forage for nursing cows and calves (e.g., *Eriophorum vaginatum* flowers; Cebrian 2005).

In November and December 2004, delayed freeze-up, frequent storms and Noyakuk's limited herding schedule made it impossible to gather the reindeer before a satellite-collared steer travelled off-range, where it could not be recovered. Noyakuk and the Reindeer Research Program planned to slaughter 16 bulls and steers for a meat quality study, which prioritized moving the herd to the corral, but multiple storms created extremely unstable ice on Grantley Harbor throughout November. Noyakuk had a construction job in December, which limited herding trips to the weekends. Frequent storms, fog and lack of daylight also reduced the opportunities to corral the reindeer, and the study was postponed.

A satellite-collared steer left Noyakuk's range in late December (Fig. 2), presumably with caribou observed just west of the range. By January, the steer's path overlapped with satellite-collared caribou north-east of the range. Up to 50 reindeer were lost with the steer, including several intended for the meat study. The construction job ended in January, but Noyakuk was so despondent over the lost reindeer that he made few herding trips until his brother and cousin confirmed that there were adequate animals for the meat study, which was rescheduled for 12 March. Noyakuk travelled to his range at least 28 days between 15 March and 1 May 2005, when the break-up started. He was able to monitor his herd during the first 2 weeks of the calving season, when approximately 50 calves were born. Weather, caribou and other, socio-economic, factors shaped and occasionally limited herding activities during the winters of 2003/04 and 2004/05.

local weather variability and climate change

Our weather data illustrate variation for two winters only, and are not indicative of long-term climate trends. Our main analysis was on the role of weather in Noyakuk's herding SES, but information about the impacts of specific weather events point to implications of climate change for herding on the Seward Peninsula. Shorter and warmer winters are predicted for western Alaska both by Arctic residents and climate scientists (Symon et al. 2005; Parry et al. 2007), and these trends are likely to exacerbate reindeer losses via lost opportunities for snowmobile herding.

The timing of freeze-up and break-up are particularly critical, considering the synchrony of these transitional

seasons with caribou influx in early winter and spring calving, respectively. Noyakuk stated that, since 2000, the ice on Grantley Harbor has not been safe for snowmobile travel until December, versus mid-November in the 1990s. Eight other herders reported that freeze-up was later in 2004 than in previous years, and some noted delayed winter onset for several years prior to 2004. Extensive analyses, modelling or downscaling of climate data were not part of this project, but regional data show: an increase in the snow-free season, corresponding with Arctic warming during the 20th century (Stone et al. 2002; Chapin et al. 2005); later freeze-up for 26 lakes and rivers in the Northern Hemisphere (5.7 days earlier for the last 100 years; Magnuson et al. 2000); and earlier break-up of several rivers in western North America over the last 50–100 years (Symon et al. 2005). The onset of 100 thawing degree-days (a proxy for break-up) occurred on average at least one week earlier in Nome between 1977 and 2004 (after the 1976 Pacific Decadal Oscillation shift to warmer temperatures) than between 1947 and 1976, and was two weeks earlier in 2004 than the 50-year average (Rick Thoman, Fairbanks NWS, unpublished analysis of National Climate Data Center data). More analyses are needed of the local mechanisms and long-term trends of climate variables important to Seward Peninsula herding, but modelling and downscaling of climate data can be difficult because of topographical effects on microclimate, Lack of instrumentation and difficulty in ground truthing snow and ice conditions (e.g., Tyler et al. 2007; Rees et al. 2008). A key point here is that the timing of planned herding activities affects perceptions about whether freeze-up and break-up are early or late.

Recent studies demonstrate how non-climate variables shape vulnerability and adaptive capacity to climate change. Tyler et al. (2007) examined the impacts of projected climate change on reindeer pastoralism in Finnmark, Norway. Although the warmer climate that they modelled is expected to affect grazing, and thus herd productivity and profitability, the traditional Saami coping strategy of flexible pasture use (which maintained herding under variable environmental conditions for thousands of years), is now constrained by habitat loss and legal and economic restrictions. These constraints potentially "dwarf the putative effects of projected climate change", but also make the system more vulnerable to the effects of future climate or other environmental stress (Tyler et al. 2007: 191). Rees et al. (2008) show that geographic variation in environmental change and current socio-economic conditions differentially affect reindeer herders across the Barents Region, but they also conclude that declining flexibility in land use and lack of diverse economic opportunity make these herding

systems vulnerable to future environmental or socio-economic hazards. For herders in Russia, the highly unstable political and economic situation in the post-Soviet era greatly supercedes climate change when they discuss vulnerability of their herding systems to further loss of reindeer. although they do worry about the impact of climate change on forage (Krupnik 2000; Helander & Mustonen 2004; Rees et al. 2008).

Direct impacts of climate change to local livelihoods include altered subsistence opportunities with shrinking sea ice, but there is also considerable variation from place to place regarding use and expectations of the natural environment, observed changes specific to local physical geography, and means of coping with the resources available (Gearheard et al. 2006). This is true for reindeer herders on the Seward Peninsula, where the location and terrain of each herder's range significantly affects the influence of weather on daily herding decisions. For example, Noyakuk cannot travel to his range during freeze-up and break-up, but the Davis family in Nome can access their herd by using the road system (Clark Davis, interview 27 March 2005). Directional changes to the timing of freeze-up and break-up would be expected to impact Noyakuk differently than the Davis family.

James Noyakuk, like other Arctic residents, has learned to live and work in a variable environment, but some events may be beyond what he has previously experienced, or occur at an inopportune time. An early break-up, late freeze-up, or long periods of stormy weather typically have a negative impact on herd management, and on mitigating reindeer loss. However, the effects of weather cannot be decoupled from other aspects of Noyakuk's herding situation, such as his work schedule, feelings of hopelessness about continued economic loss, changes in predator levels and forage availability for reindeer.

Herd management and socio-economic changes

Various opportunities and constraints associated with herd ecology and management, and certain socio-economic factors, have affected Noyakuk's adaptations to having fewer reindeer, and to caribou being present on his range. Interactions among some of these factors are illustrated in Fig. 3. The loss of reindeer to migrating caribou reduced Noyakuk's herd to fewer than 200 reindeer by 2001. Fewer meat and antler sales necessitate opportunistic employment in town, and preclude the ability to purchase new snowmobiles. These issues, coupled with poor weather, limit the time available to conduct herding activities, which feeds back to potential new losses of reindeer to caribou or predators when the herd is not being monitored. This snowballing of negative

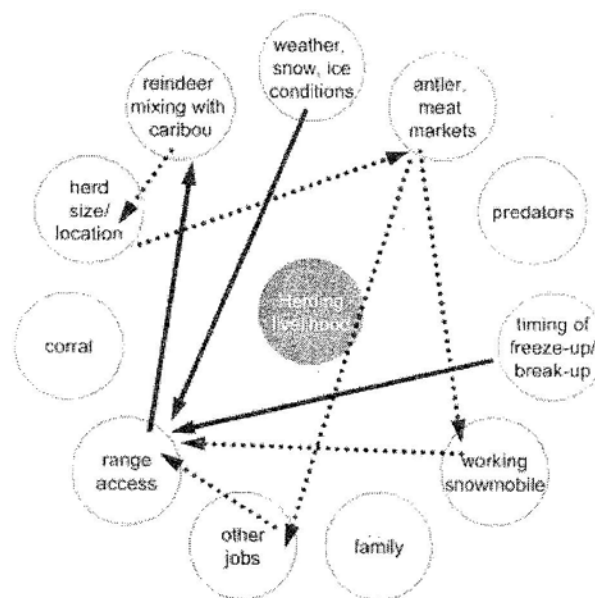


Fig. 3 Key factors and interactions affecting James Noyakuk's livelihood as a reindeer herder. This diagram shows some (but not all) of the factors and interactions affecting Noyakuk's ability to continue herding. The dashed arrows illustrate how migrating caribou can trigger a chain of events involving depleted reindeer stock, financial loss from fewer meat and antler sales, increased need to find other cash employment, and fewer funds to purchase and maintain snowmobiles. These issues, coupled with poor weather and travel conditions, decrease herding time (range access), and may result in potential new losses when the reindeer are not being monitored (bold arrows).

impacts has made herding a precarious endeavour in the last 10 years (Schneider et al. 2005).

Reindeer naturally use small ranges, compared with caribou, but they can become highly mobile in the presence of caribou (Oleson 2005, Finstad et al. 2006). When 225 000–250 000 caribou were on the Seward Peninsula in the winter of 2000/01 (Finstad et al. 2006), satellite-collared reindeer from Noyakuk's herd travelled over 200 km off-range, with one reaching the Brooks Range in autumn 2002 (Oleson 2005). During the study period, Noyakuk based most of his herding decisions on the locations and movements of two female reindeer and one steer that were collared. Satellite collar technology adds some peace of mind and efficiency to herd management, but it also lends a false sense of security if the reindeer are not concurrently monitored on the ground (Menadelook 2003). Furthermore, there have been several occasions when herders could not access their herds because of inclement weather or other reasons, and they watched helplessly on the internet as their satellite-collared reindeer travelled farther and farther off-range. This was Noyakuk's experience in the autumn seasons of 2000 and 2001, and again in December 2004.

Just a few caribou or feral reindeer (i.e., reindeer not habituated to herding) within the herd makes moving or corralling the reindeer considerably more difficult, as these individuals cause the herd to shift direction or splinter unpredictably (Paine 1988; Oleson 2005). Caribou have been widespread on the eastern and central Seward Peninsula each winter, and some groups remain there year-round (Dau 2005). There is also a local population of feral reindeer, as some lost reindeer have returned to the region (Oleson 2005), and several herders no longer manage their remaining reindeer for economic and practical reasons (Carlson 2005; Schneider et al. 2005; Finstad et al. 2006). Herders who still actively manage their herds typically cull caribou or feral reindeer.

The ability to move the herd is affected by herd size, as well as by the seasonal behaviour and body condition of the reindeer. According to Noyakuk, small herds (like his own 200 reindeer) require more frequent contact with humans and snowmobiles, particularly during handlings, than the large herds (1000–6000 reindeer) that were common on the Seward Peninsula in the 1980s. Small herds are more susceptible to caribou or feral reindeer, and they are also more likely to form break-off groups, quickly change direction or balk at the corral (Ingold 1980; Pelto 1987). Noyakuk's herd is currently composed of younger (2–4-year-old) females, bulls and steers. According to Novakuk, these reindeer are leaner and in poorer health mid-winter than when he had a larger herd, with a greater proportion of older animals. Reindeer muscle mass and fat reserves diminish in winter and are replenished in the summer (Gerhart et al. 1996; Parker et al. 2005), but overall body condition and the ability to retain fat and protein improves with age. Novakuk's younger reindeer may be more prone to stress under intensive management, particularly if they are kept in smaller areas (e.g., refugia and Noyakuk's comfort zone), where there may be lower quality forage and/or risks of overgrazing (Oleson 2005).

Many reindeer herders in Alaska (Schneider et al. 2005), and in Chukotka, Russia (Kerttula 2000), state that 200 reindeer are too few to be economically sustainable as a primary source of income. Herder Clifford Weyiouanna, of Shishmaref, Alaska, stated that the cost of managing 155 reindeer is equivalent to managing 1500 reindeer (particularly considering the helicopter costs for summer handlings; Weyiouanna 2002), but the income is at least tenfold less for the smaller herd. Although there are ways to reduce some financial costs, regular monitoring and handling are required to manage a small herd with caribou present. Of four herders with fewer than 300 reindeer, Noyakuk is the

only one to regularly monitor and corral his reindeer. Unlike the other three herders, Noyakuk is single, and does not have children. He contributes considerably to his extended family (e.g., sharing reindeer meat, hauling ice for fresh water and repairing houses and fish camps), but he has stated that he would not be able to make as many lengthy or overnight trips to work with the reindeer if he had children. Recently, Noyakuk has not been able to hire assistants, so he conducts many herding expeditions alone, and the handlings have been much smaller, family-only affairs.

This situation has been further compounded by market conditions. Although antler prices have rebounded somewhat since 2000, they remain half the price that Novakuk enjoyed in the mid-1990s. Noyakuk currently slaughters an average of 12 reindeer per year, compared with 125 when he had 1500 animals. He has fewer large steers, which increases the time and effort of the slaughter (i.e., reduced yield per unit effort). Most of the meat is distributed among family members, and currently Noyakuk does not sell meat outside of the Teller and Brevig Mission area.

Throughout the history of the reindeer industry on the Seward Peninsula, herders have mixed herding with other waged jobs and subsistence activities (Simon 1998; Ellanna & Sherrod 2004; Schneider et al. 2005). Herding was Novakuk's main source of income until most of his herd disappeared in 2000. Non-herding jobs, such as seasonal construction work, now comprise at least 60% of his income, versus 10%, before 2000. These jobs have become critical to afford gas, snowmobile parts, and food and other supplies for handlings.

The Reindeer Herders Association (RHA), Kawerak (the regional Native nonprofit corporation that administers RHA), and federal agencies such as the BIA, US Department of Agriculture (USDA) Farm Services Agency and USDA Natural Resources Conservation Service, provided limited disaster relief in 1999, immediately following what was then the largest influx of caribou and greatest losses of reindeer. There are some continuing programmes from which herders can request assistance for flights to monitor caribou and reindeer, snowmobile fuel for ground monitoring, or range management. Additionally, Noyakuk has established a mutually beneficial relationship with the University of Alaska Fairbanks RRP. The RRP assists with handlings and the collaring programme, while conducting research on meat quality and other aspects of free-range reindeer production. Relationships with these organizations have influenced Noyakuk's herding system throughout the history of his herding enterprise, and may now increase adaptive capacity in sustaining the herd.

Vulnerability and the herding SES

Vulnerability can be assessed via Hazards-to-consequences or consequences-to-hazards pathways, depending on the case at hand (Turner, Kasperson et al. 2003). We investigated the consequences of caribou range expansion as a major environmental change that has become a hazard to the reindeer industry on the Seward Peninsula (although caribou are not considered to be a direct hazard to non-herders). The main mitigation strategy for herders still having reindeer is simple-to-keep their reindeer from mixing with caribou. Mitigation tactics involve increased monitoring of reindeer and caribou locations (through satellite collars and increased travel to the ranges), combined with moving reindeer when necessary and/or retaining reindeer in caribou-safe refugia or enclosures. There are various constraints and opportunities to implementing these tactics, which have also emerged or changed roles as a result of the presence of caribou. Constraints work as a positive feedback on an already vulnerable system, by increasing exposure and sensitivity to further reindeer loss. System opportunities help to reduce exposure and sensitivity, while boosting adaptive capacity associated with increasing herd monitoring, and maintaining options to continue herding. Noyakuk views weather variability, the effects of caribou and feral reindeer on herd management, the ecological, economic and social implications of a smaller herd, and low meat and antler sales, as major constraints on maintaining reindeer. Opportunities include satellite collar technology to monitor reindeer and caribou movements, assistance from his extended family, and working relationships with regional and federal agency, organization and university programmes.

It is important to note that constraints can lead to opportunities, and vice versa. The refugia and enclosures offer herders a way to more closely monitor their reindeer, but may also lead to overgrazing or extensive use of artificial feed, respectively (Oleson 2005; Finstad et al. 2006). Employment in town helps to pay some of the rising costs of herding that can no longer be covered by meat and antler sales, but also limits the time available to monitor the herd. Satellite collars have become a valuable tool for tracking reindeer and caribou, but may also serve as a crutch because they do not represent the entire herd.

Individual choice and perception plays a large role in the responses of human actors to change. Noyakuk is in a unique position among Seward Peninsula herders, in that he is still able to manage his small herd because his range is not consistently impacted by caribou, and because he has fewer family obligations than other herders. Some aspects of this case study can be extended to other herders, but the variability among herders for their

capacity to cope with caribou, as well as their different management styles, social, economic and ecological situations make comparisons difficult. The vulnerability of non-herding families in the region was outside of the scope of this study, but non-herding residents certainly may have a different response to the influx of caribou. Although they have lost employment opportunities associated with herding activities and ready supplies of reindeer meat, they have gained the opportunity to hunt caribou, which is valued in the region. James Noyakuk's herding operation continues to provide a subsistence meat source and an important social activity for his extended family. He continues to herd through his own persistence, paid employment in construction, volunteer assistance from his family, institutional support from the RHA and other governmental agencies, and research collaboration with the RRP. The unique situation of each herder's experience makes the case study approach the best way to understand how environmental factors have interacted with various social and economic realities to shape herding decisions on the Seward Peninsula.

Conclusion

The reindeer herding system on the Seward Peninsula, Alaska, has been significantly transformed by the recent range expansion of the WAH, as over 17 000 reindeer have mixed with migrating caribou and left the region. We worked with herder James Noyakuk to delineate some of the key environmental and socio-economic variables affecting vulnerability and adaptive capacity following caribou range expansion, while highlighting emerging impacts from weather variability. Weather is more critical now than it may have been 20 years ago, and adds another element of uncertainty to a precarious situation. Single weather events in certain years, like delayed freeze-up, early break-up or storms, have had dramatic effects on herd access and retention. It is difficult to quantify the weather conditions that most affect daily herding plans (visibility, timing of freeze-up and break-up, and snow conditions), whereas typical weather parameters such as air temperature, wind speed and wind direction affect herding indirectly, and did not correlate with how Noyakuk rated weather conditions on herding trips. More importantly, perceptions and responses to extreme weather events and changing climate patterns occur through the lens of other interlinked environmental (caribou, predators, reindeer and range health), economic (depressed international antler prices, low meat and antler sales from small herds, rising fuel and equipment costs, need for non-herding employment) and social (inability to hire crews, inefficiency / dangers of solo herding) stresses, as well as increased adaptive capacity

through new technology, institutional support and various mitigation measures. The combined impact of all components and linkages within a social-ecological system influences individual perception and experience, and the emerging importance of different system components for future vulnerability and adaptive capacity.

Acknowledgements

We thank James Ford for inviting this paper and two anonymous reviewers for their comments on an earlier draft. This project would not have been possible without the support and collaboration of James Noyakuk and his extended family, as well as many other herders and their families who welcomed and supported this effort and ongoing research with reindeer on the Seward Peninsula. We are also indebted to Rose Fosdick of the Reindeer Herders Association, Kawerak, Inc., the entire staff of the Reindeer Research Program at the University of Alaska Fairbanks (UAF) and Karl Olson. Weather data (and valuable advice) were provided by David Atkinson (International Arctic Research Center, UAF), Bob Busey (Water and Environmental Research Center, UAF), Ken Irving (Water and Environmental Research Center, UAF), Martha Shulski (Alaska Climate Data Center, Fairbanks) and Rick Thoman (National Weather Service, Fairbanks). Satellite collar data for the WAH were provided by the Alaska Department of Fish and Game in Nome. Laura Henry, Stacia Backensto, Chanda Meek and Martin Robards provided valuable comments on this paper. Funding for this project was made possible by a National Science Foundation Human Dimensions of the Arctic System grant (Reindeer Herding in Transition; NSF-OPP 9979473), and student grants from the Center for Global Change and Arctic System Research, the Institute of Arctic Biology, and the Resilience and Adaptation Program at UAF.

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