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Abstract. Gobal climate change may affect wolves in Canada's High Arctic (80° N) acting through three trophic levels (vegetation, herbivores, and wolves). A wolf pack dependent on muskoxen and arctic hares in the Eureka area of Ellesmere Island denned and produced pups most years from at least 1986 through 1997. However, when summer snow covered vegetation in 1997 and 2000 for the first time since records were kept, halving the herbivore nutrition-replenishment period, muskox and hare numbers dropped drastically, and the area stopped supporting denning wolves through 2003. The unusual weather triggering these events was consistent with global-climate-change phenomena.

1. Introduction

A pervasive loss of biodiversity has been attributed to global climate change, and an 'improved understanding of the response of biodiversity to change in climatic factors' has been called for (Gitay et al., 2002). This report documents an apparent effect of climate change in a decline of wolves (*Canis lupus*) in an area of the High Arctic and traces the mechanism of the decline through three trophic levels. I studied wolves and their primary prey, muskoxen (*Ovibos moschatus*) and arctic hares (*Lepus arcticus*) in the Eureka area of Ellesmere Island (80° N latitude; 86° W longitude), Nunavut, Canada during summers from 1986 through 2003 (Mech, 1988, 1995). The study area, some 960 km from the North Pole, included a 300-km^2 region of the Fosheim Peninsula in a 180° arc north of Eureka, from Eureka Sound to Remus Creek, and Slidre Fiord to Canon Fiord. It included shoreline, hills, lowlands, creek bottoms and the west side of Blacktop Ridge. Wolves, muskoxen, and arctic hares have long been common in the area (Tener, 1954), and wolves have denned there for decades or even centuries (Parmelee, 1964; Grace, 1976; Mech and Packard, 1990). From at least 1986 through 1997, a pack of 3–13 wolves preyed on muskoxen and arctic hares and produced pups almost annually in traditional dens in the area (Table I). However, after 1997, the wolf-prey system changed critically.

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Table I

Numbers and reproductive status of wolves, muskoxen and arctic hares observed during summer, and carcass remains from previous winter, in Eureka area of Ellesmere Island, Nunavut, Canada (no data in 1999)

Summers	Muskoxen			Arctic hares		Wolves	
	No.[a]	Reproduction?	Carcass remains	No.[b]	Reproduction?	No.	Reproduction?
1986–1997[c]	≤ 151	$\geq 10/12$ years	≤ 2	(≤ 200)	$\geq 10/12$ years	6.8 (3–13)[d]	10/12 years
1998	30	No	9	Few	No	2	No
2000	48	Yes	0	39	?	2	No
2001	16	No	18	8	No	0	No
2002	41	Yes	0	14	Yes	0	No
2003	59	Yes	0	25	?	3	No

[a] Number seen through spotting scope from mountainside overlooking about 250 km^2.
[b] Maximum number seen.
[c] See Mech (2000).
[d] Mean and range.

2. Methods

During each July, 1998, 2000, 2001, 2002, and 2003, an assistant and I spent 5–11 days in this area on all-terrain vehicles (Mech, 1994) searching for wolves, muskoxen and arctic hares. We surveyed the area with binoculars and spotting scope from high points in much the same manner that I had done for 1–6 weeks each summer in the same area since 1986 (Mech, 1988). The area is treeless, open, and snow-free in July, and there were 24 hours of light each day; muskoxen which are very dark, and arctic hares and wolves which are white, were easily seen from many kilometers away. From one vantage point on the side of a mountain we could survey an area of some 250 km^2 through a spotting scope. I obtained long-term data on temperatures, precipitation, and snow cover at a weather station in Eureka near sea level in the study area from Environment Canada. Because the weather station is located on the shore of the Arctic Ocean at sea level, most of the study area is higher than the weather station; thus the actual weather in most places was more severe than the weather station records indicated.

3. Results

During 1998 (Mech and Adams 1999), and 2000, we located only a pair of wolves, but they did not reproduce either year, as evidenced by lack of active teats on the female and lack of attendance at the wolves' traditional dens. In 1999, an injury kept me from the area, but military and weather personnel there, who in previous summers had observed wolf pups, reported no wolf reproduction that year either. In 2001 and 2002, we found no wolves in the area and no wolf scratching (a sign of a territorial pair) in the usual locations, nor any other wolf sign at the traditional dens, indicating no residential use of the area by wolves.

Both in 1998 and 2001, muskox and hare numbers were low and no sign of reproduction was seen (Table I). In 1998, we found remains of nine muskoxen that had perished during winter 1997–1998 and possessed no femoral marrow fat, a sign of nutritional depletion (Mech and DelGiudice, 1985); in 2001, we found 18 similar sets of remains from winter 2000–2001 (Table I). Thus it appeared that some pervasive factor had impaired the nutritional condition of both oxen and hares enough to cause overwinter mortality, to minimize reproduction, and to reduce their populations low enough that they could no longer support wolves. Logically, the most likely factor that could affect all of these population characteristics in two such disparate herbivore species would be weather (Mech, 2000).

From 1947–1990, temperatures and precipitation for August and September had been such that vegetation had remained snow-free every year at the end of August, and an average of only 6.0 cm of snow had covered it even by the end of September (Table II). However, during 1997 and 2000, August and September temperatures dropped below long-term norms, precipitation and snowfall increased above norms, and snow covered the vegetation by Aug. 25, 1997 and August 14, 2000 (Table II), much earlier than usual. No other weather abnormalities were found during these years.

4. Discussion

Herbivores gain most of their nutrition during summer when vegetation grows, and they depend on the fat they store during the summer replenishment period to carry them through the following winter. In this study area, this usual replenishment period only lasts from about July 1, when winter snow has disappeared and vegetation sprouts new growth, to about October 1 when snow covers the vegetation. During 1997 and 2000, however, the summer replenishment period was cut almost in half. Thus this lack of time to replenish nutrition was probably the main factor causing starvation the following winter and minimizing reproduction the following summer (Mech, 2000).

The combination of low temperatures and high precipitation that resulted in summer snow that persisted after mid-August was highly unusual, yet it occurred during two of the last six summers. Although prey and wolf numbers dropped precipitously in the study area, residual numbers of prey survived, and wolves are mobile enough to immigrate back from surrounding areas and resume reproducing in the study area should conditions improve. Nevertheless the climate effect on the muskox, hare, and wolf populations in the study area was so devastating that it is reasonable to suggest that, had similar weather occurred regularly in the past, these species would not have survived in this area.

One of the correlates of global climate change is increased weather variability (Karl et al., 1997; Karl, 1999; Gitay et al., 2002). In the present study, the low summer temperatures, high precipitation, and resulting snow during 1997 and 2000 were the most extreme since weather records were first kept in 1947. Because even normal mean daily August temperatures at sea level in the study area are only 2.9 °C above freezing and most of the study area is up to 600 m higher than sea level and thus colder, even minor temperature decreases would change normal amounts of precipitation from rain to snow. Such a change is critical to herbivores because snow covers their food and increases the energy necessary to obtain it. Even seemingly small amounts of snow can hinder foraging because the constant arctic wind deposits the snow in deep drifts in valleys and depressions, which at 80° latitude is where most of the vegetation grows. In 1997 and 2000, however, not only were August temperatures abnormally low, but precipitation was double and triple monthly norms (Table II).

The resulting herbivore mortality and failure to reproduce caused extreme drops in their populations (Table I). Wolf numbers, then, with little else to sustain them, had to follow. Cascading effects from extreme weather through vegetation to prey and to wolves are well known at lower latitudes (Mech, 1977; Peterson and Page,

Table II

Weather parameters in study area during months preceding winters 1997–1998 and 2000–2001 compared to long-term norms (Environment Canada).[a] Data are presented for 1997 and 2000 because hypothesis is that those aberrant summers caused demographic changes a year later

Month	Daily mean temperature (C)			Monthly precipitation (mm)			Monthly snowfall (cm)			Month-end snow cover (cm)		
	Norm[b]	1997	2000	Norm[b]	1997	2000	Norm[c]	1997	2000	Norm[c]	1997	2000
August	2.9	0.7	0.4	11.8	25.6	33.8	4.0	12.6	23.8	0.0	4.0	3.0
September	−8.3	−10.4	−10.2	9.7	15.6	10.0	10.9	23.4	10.0	6.0	13.0	9.0

[a] For the rest of the winter period each of these two years, these parameters were normal or more favorable.
[b] 1961–1990.
[c] 1947–1990.

1988; Mech et al., 1998), but because these effects are less extreme there, prey and wolf numbers may rebound faster. Thus global climate change effects on wolf-prey systems farther south may not be so noticeable. However, this study shows that at 80° N such changes can be dramatic and devastating to the wolf-prey ecosystem there.

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