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ORIGINAL PAPER

Sea-ice use by arctic foxes in northern Alaska

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Abstract The extensive use of sea-ice by three arctic foxes (*Alopex lagopus*) in northern Alaska was documented using satellite telemetry during the winter of 2005–2006. Here we present the first detailed data on movements of individual foxes while on the sea-ice. Two juvenile males and one juvenile female traveled long distances (904, 1,096, and 2,757 km) and remained on the sea-ice for extended periods of time (76, 120, and 156 days). Average distances traveled per day ranged from 7.5 to 17.6 km and foxes achieved maximum rates of travel of up to 61 km/day. These findings verify the use of sea-ice by arctic foxes and raise concerns that the diminishing arctic ice cover may negatively impact populations by limiting access to marine food sources.

Keywords *Alopex lagopus* · Arctic fox · Beaufort Sea · Chukchi Sea · Satellite telemetry · Sea-ice · Winter movements

Introduction

The use of sea-ice for long distance movements by arctic foxes (*Alopex lagopus*) has been documented from recoveries of tagged foxes (Eberhardt and Hanson 1978; Eberhardt et al. 1983; Wrigley and Hatch 1976), but the reasons for such long movements are not well known. The degree to which sea-ice is important to arctic foxes is not completely understood, although it likely serves as an important habitat to forage within. Shibanoff (1958) and Sdobnikov (1958) suggested that arctic foxes use the sea-ice platform to search for marine resources in years when winter foods are limited in terrestrial habitats. Direct use of sea-ice by foxes for feeding has been confirmed by studies that documented foxes both feeding on seal carrion left from polar bear (*Ursus maritimus*) kills and taking ringed seal pups (*Phoca hispida*) from their birth lairs as well as scavenging on other marine mammal carcasses (Chesemore 1968; Smith 1976; Andriashek et al. 1985). Roth (2002) found that marine foods comprise up to half of arctic foxes' protein intake during years of low lemming (*Dicrostonyx* and *Lemmus* spp.) abundance, suggesting that sea-ice plays a major role in maintaining fox populations throughout winter months in coastal areas when terrestrial resources are scarce.

In recent decades, both the extent and longevity of the polar ice pack have been decreasing in response to a warming climate in the Arctic (Comiso 2002, Parkinson and Cavalieri 2002). Research has revealed an overall reduction in the extent (Vinnikov et al. 1999), lengthening of the melt season (Smith 1998) and thinning of the Arctic ice pack (Rothrock et al. 1999). The potential for these changes to negatively affect the fauna that rely on the sea-ice habitat has received much attention recently. For example, changes in the pack ice may alter polar bears' access to their main source of prey, seals (Stirling and Derocher 1993; Derocher et al. 2004). Derocher et al. (2004) showed that Hudson Bay polar bears came to land with lower body weights in years when the ice pack broke up early, posing additional

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negative effects for reproduction and survival. If polar bear populations are negatively impacted from changing ice conditions, arctic foxes also may be affected from reduction in sea-ice extent because of reduced access to marine foods.

To more completely understand the potential impacts of sea-ice reduction to foxes, data on the timing of fox movements onto and off of the ice, the length of time the habitat is used, and movement rates while on the sea-ice are required. Some foxes may use sea-ice for most of the winter, but studies to date have not continually tracked individual foxes over the winter to confirm this. Detailed information on the use of sea-ice by foxes has been difficult to obtain mainly due to the prohibitively large sizes of satellite transmitters and the shortcomings of VHF telemetry. VHF telemetry is not suitable for tracking arctic foxes on sea-ice because fox movements are extensive and intensive tracking effort would be required to relocate animals at regular intervals during the Arctic winter. In the last decade, satellite transmitters have become smaller and lighter weight, making their deployment on arctic foxes possible (Follmann and Martin 2000), thus enabling a more complete understanding of sea-ice use by arctic foxes.

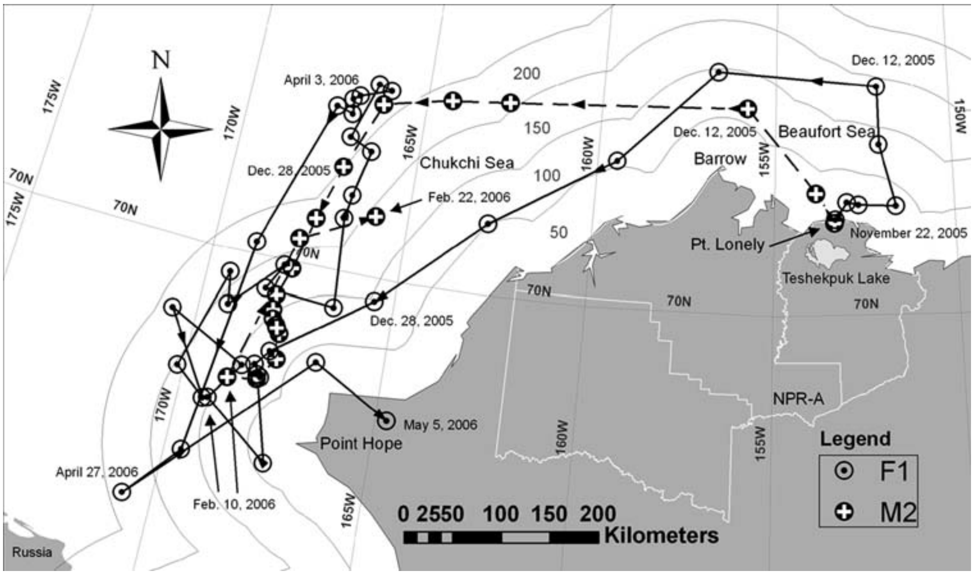
In this paper, we present data on the movements of three arctic foxes that used the sea-ice extensively during the winter of 2005–2006 off the coast of northern Alaska. The foxes reported on here were part of a broader study looking at the difference in winter movements between foxes from the Prudhoe Bay oilfield and foxes from the currently undeveloped National Petroleum Reserve-Alaska (NPR-A). In total, the larger study included 37 collared foxes, 20 from Prudhoe Bay and 17 from NPR-A, three of which are focused on here. Similar use of the sea-ice by the remaining foxes in the study was not observed (Pamperin et al., in preparation).

Methods

We trapped foxes in the northeast section of the NPR-A near Teshekpuk Lake (70º15′N, 153º32′W) in northern Alaska (Fig. 1) during August 2005. Trapping was done opportunistically in the field using baited box traps (Model 208, 106 × 38 × 38 cm, Tomahawk Live Trap, Tomahawk, WI, USA). We placed traps near den sites that appeared to be active and we baited traps with tuna or salmon. After capture in the live trap, we transferred animals to a restraint cage (78 × 30 × 35 cm, Tru-Catch Traps, Belle Fourche, SD, USA) to facilitate intramuscular injection of anesthetic into the hip. A 2:1 mixture of xylazine hydrochloride and ketamine hydrochloride was used to sedate foxes prior to collar attachment (Follmann et al. 2004). We aged foxes as either adult or juvenile according to tooth wear, coloration, and canine eruption (Macpherson 1969; Frafjord and Prestrud 1992). Animals were fitted with satellite transmitters (Model A-3210, 190 g, Telonics, Inc., Mesa, AZ, USA). Fox capture, handling, and collar attachment methods were approved by the University of Alaska Fairbanks Institutional Animal Care and Use Committee (Protocol Number 05-45).

The satellite transmitters contained temperature, activity, and mortality sensors. Collars were programmed to transmit for a 4-h period every 96 h with a predicted battery life of 11 months. Data were collected and processed by CLS America, Inc. (Largo, MD, USA) before being made available for download through their website. We then subjected location data to a filtering algorithm (Douglas 2007, USGS) implemented in SAS (2007, V 9.1, Cary, NC, USA) in order to remove redundant locations and to flag potentially implausible ones. The final data set contained the most accurate location per duty cycle (based on Argos classification errors,

Fig. 1 Individual movements of satellite collared arctic fox M2 (juvenile male) and F1 (juvenile female) during the winter of 2005–2006 off the coast of northern Alaska. Intervals between individual locations are equivalent to the collar duty cycle of 4 days. *Arrows* show direction of movement and dates correspond to the nearest location. Contours outward from coast are measured in kilometers. Map projection is Alaska Albers Conic Equal-Area, North American Datum 1927



see Argos User's Manual, CLS 2007) for each animal from time of deployment until battery failure or mortality.

Movement rates were calculated from straight line distances between points from consecutive duty cycles (every 4 days) and total distance traveled was the sum of these distances for each animal while on the sea-ice. Movement rates and total distance traveled are estimates of actual distances traveled by the foxes and the rates are presented as means ± the standard error (SE). We also report daily average distance to make interpretation easier.

Results

Three juvenile arctic foxes (2 males, 1 female) were captured and collared at Point Lonely, Alaska during August 2005 (Figs. 1, 2). Fox M1 (male) moved onto the sea-ice November 6, 2005 and traveled on the ice for 120 consecutive days, with its last location on the sea-ice on March 6, 2006 (Fig. 2). Fox F1 (female) spent 156 days on the sea-ice from November 26, 2005 until May 1, 2006 (Fig. 1).The third fox, M2 (male), was on the sea-ice for at least 76 days from December 8, 2005 through February 22, 2006 (Fig. 1). Three more messages were received from the collar on March 22, April 15, and May 5, 2006. While none of these messages contained location information, they did contain counts associated with the activity sensor indicating that the fox was probably still alive and that either the battery or transmitter were malfunctioning. The collars of foxes M1 and F1 continued to function through the winter of 2006–2007, but the use of sea-ice was limited to near shore movements by fox F1 during April and early May, 2007. Foxes M1 and F1 both survived beyond their first winter (>9 months old) and were considered adults thereafter.

The foxes traveled extensively while on the sea-ice (Figs. 1, 2). Total distances traveled by each fox while on the sea-ice were 904 km (fox M1), 2,757 km (fox F1), and 1,096 km (fox M2). Average distances traveled per day ranged from 7.5 km ± 1.5 (fox M1) to 17.6 km ± 2.4 (fox F1) with maximum travel rates of up to 61 km/day (fox M2) (Table 1). The maximum rates of travel represent a daily average from the 4-day duty cycle with the greatest displacement for each fox while on the sea-ice.

Two of the foxes (F1, M2) were consistently located at substantial distances from the coastline, with mean distance from the coast of 128 km ± 11.1 and 119 km ± 11.8, respectively. Maximum distances from the coast were 86, 246 and 214 km for foxes M1, F1, and M2, respectively (Table 1).

The three foxes focused on here were part of a larger group of 14 juvenile foxes collared in NPR-A in August, 2005. Foxes M1, F1, and M2 outlived the other 11 foxes that remained on land, which had all died by mid-December, 2005. Mortality dates for foxes F1 and M2 are unknown due to collar or battery failure. However, fox M2 survived at least until February 22, 2006 when its collar stopped functioning reliably and fox F1 survived through at least September 21, 2007 when its collar stopped transmitting. The collar of fox M1 started transmitting in mortality mode on January 8, 2007 south of Teshekpuk Lake, indicating the animal died sometime between January 4 and January 8.

Discussion

The length of time spent on the sea-ice by these foxes provides evidence that during some years, a segment of the arctic fox population may rely heavily on marine based

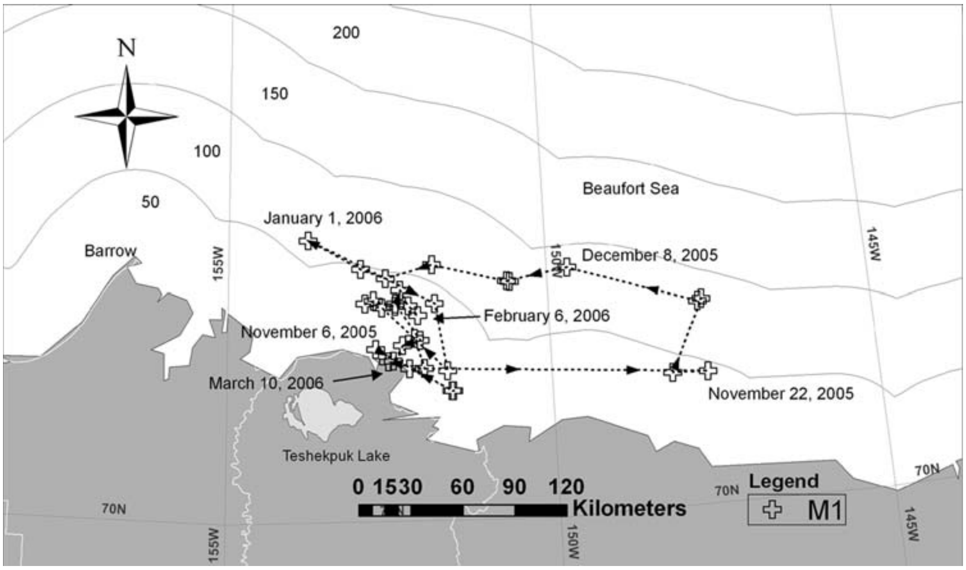


Fig. 2 Individual movements of satellite collared arctic fox M1 (juvenile male) during the winter of 2005–2006 off the coast of northern Alaska. *Arrows* show direction of movement and dates correspond to the nearest location. Contours outward from coast are measured in kilometers. Map projection is Alaska Albers Conic Equal-Area, North American Datum 1927

Table 1 Summary of estimated arctic fox movements on the sea ice and distances from the coast of northern Alaska during winter of 2005–2006. Distances and rates are expressed in kilometers, duty cycle length equals 4 days

Animal	Age	Sex	Weight (kg)	Date on/off ice	Total days on sea ice	Distances traveled				Distance from coast		
						Total distance traveled	Average distance duty cycle^{-1} (±SE)	Average distance day^{-1} (±SE)	Maximum rate day^{-1}	Average distance from coast (±SE)	Minimum	Maximum
M1[b]	Juvenile	Male	3.3	November 6–March 6	120	904	30.1 (6.1)	7.5 (1.5)	43	36 (4.6)	0.4	86
F1[c]	Juvenile	Female	2.6	November 26–May 1	156	2,757	70.7 (9.5)	17.6 (2.4)	60	128 (11.1)	17	246
M2[c]	Juvenile	Male	3.1	December 8–February 22[a]	76	1,096	57.7 (12.6)	14.4 (3.2)	61	119 (11.8)	27	214

[a] Collar/battery failed, no additional locations were obtained after February 22, 2006

[b] Wintered on Beaufort Sea

[c] Wintered on Chukchi Sea

resources to survive through winter. Diets of these foxes were likely 100% marine while on the sea-ice, given their consistent use of the sea-ice at distances from land that would preclude periodic trips to feed on terrestrial resources (Table 1). Seal carcasses left from polar bear kills likely compose the majority of a fox's diet while on the ice, with some foxes being able to take seal pups on their own during spring (Smith 1976). While seal carcasses would be the most consistent source of food on the ice, any accessible marine mammal or bird carcass would likely be utilized by the foxes and larger carcasses (whales and walrus) may be able to sustain numerous foxes for extended periods of time. Another potential source of food is the invertebrate community that lives on the undersurface of the ice. Amphipods, in particular, can be numerous at the ice–water interface (Gradinger 1998).

While these three foxes represent a small proportion (~8%) of our larger sample of 37 foxes, we believe their individual movements add valuable information to understanding the role sea-ice can play in the ecology of arctic foxes residing in coastal areas. The fact that these three foxes outlived 11 others collared in the same area, but who remained on land, indicates that use of sea-ice may be advantageous to survival during some years. In addition to benefits of foraging on the ice when terrestrial foods are scarce, foxes also may reduce their predation risk by traveling and feeding on the ice. Aside from the risk of feeding on seal carcasses near polar bears, encounters with red foxes (*Vulpes vulpes*), wolves (*Canis lupus*), and wolverines (*Gulo gulo*) on the ice would likely be less, although red foxes and wolves are known to travel on the sea-ice (Andriashek et al. 1985). While incidence of predation on arctic foxes by wolves and wolverines in Alaska has not been reported, predation by red foxes is known to occur on the North Slope (Pamperin et al. 2006) and predation by wolverines has been reported in Sweden (Tannerfeldt 1997).

All three foxes were captured as juveniles in close proximity to Pt. Lonely and within 2 km of each other, and it is possible that they may have been from the same litter, though genetic testing was not done to confirm this. The potential lack of independence between movements, if these animals were littermates, is likely negligible given that the two remaining foxes (M1 and F1) ended up settling more than 450 km apart after traveling on the sea-ice (Figs. 1, 2). Additionally, these two foxes were tracked through the following summer and did not return to the capture site, indicating that they had dispersed from their natal area to separate locations.

Because the sea-ice is a dynamic habitat, some of the movements of foxes may be due to the active movement of the sea-ice. Without an intensive analysis of satellite imagery, accurately reconstructing the specific ice trajectories associated with the movements of individual foxes is not feasible. However, general ice trajectories (of low spatial resolution) for the Chukchi and Beaufort seas are calculated weekly and archived by the National Ice Center (NOAA 2006), and upon examination for the times of greatest movement by the foxes, ice movement alone would not account for the total displacement of the foxes. Maximum drift rates of the sea-ice for the periods of greatest fox movements did not exceed 11 km/day. Furthermore, since distances traveled are calculated from locations between the 4-day duty cycles as straight line distances, our calculations are likely an underestimate of the distances actually traveled by the foxes. The maximum travel rates of the foxes on the ice (61 km/day) were similar to the maximum travel rates of collared foxes that remained on land during our study (51 km/day, Pamperin et al. in preparation), indicating that such rates are obtainable by arctic foxes irrespective of the medium they travel on.

The extensive movement of these three foxes on the sea-ice has important implications for the potential spreading of disease both between individual foxes and between populations of foxes. Rabies is enzootic within arctic fox populations in Alaska (Ritter 1981) and long-distance movements of foxes, coupled with their propensity to congregate at food sources during winter, represent a potential pathway for transmission of the virus across large geographic regions. While oral rabies vaccination programs of wild animals have been successful elsewhere in North America and in Europe (Rosatte et al. 2007), movements of foxes such as those described here could thwart the success of potential vaccination programs in northern Alaska.

Concerns about the effects of diminishing Arctic ice extent to polar bear populations have received much attention recently (Derocher et al. 2004, Stirling and Parkinson 2006). While arctic foxes certainly take advantage of, and in some years rely on the presence of sea-ice, it is unlikely that a loss of access to the ice would culminate in the disappearance of the species as has been suggested for the polar bear by some researchers (Derocher et al. 2004). If ample resources are present on land, arctic foxes have the ability to persist without the resources that are available on the sea-ice (see Hersteinsson and Macdonald 1996). If future populations of arctic foxes lose access to sea-ice, the primary negative effects would likely be reduced winter survival and reproduction in those years when small mammal abundance is low since the alternative marine foods present on the sea-ice would not be available. This may lead to increased fox presence at human settlements and industrial sites where anthropogenic food sources are present, thus increasing the potential for human–wildlife conflicts.

The data presented here confirm previous suspicions that the sea-ice represents an important habitat for some arctic foxes during some years and also provides valuable details on the movement capabilities of individual foxes. Our results show that foxes can use the sea-ice for extended periods of time instead of occasionally foraging on the ice and returning to land, highlighting the risk these foxes take by committing to foraging on a dynamic, unpredictable medium. Other important ecological links, such as fluctuations in terrestrial prey, population connectivity and gene flow, health of polar bear populations, marine prey availability, and the interplay between each of these need to be studied further to fully understand the role that sea-ice plays in the ecology of the arctic fox.

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References

Andriashek D, Kiliaan HP, Taylor MK (1985) Observations on Foxes, *Alopex lagopus* and *Vulpes vulpes*, and Wolves, *Canis lupus*, on the Off-Shore Sea Ice of Northern Labrador. Can Field Nat 99:86–89

Chesemore DL (1968) Distribution and movement of white foxes in northern and western Alaska. Can J Zool 46:849–854

CLS (2007) Argos user's manual. https://www.argos-system.org/html/userarea/manual_en.html, Maryland

Comiso JC (2002) Correlation and trend studies of the sea-ice cover and surface temperatures in the Arctic. Ann Glaciol 34:420–428

Derocher AE, Lunn NJ, Stirling I (2004) Polar bears in a warming climate. Integr Comp Biol 44:163–176

Douglas D (2007) The Douglas-Argos Filter Version 7.03. United States Geological Survey, Alaska Science Center. http://alaska.usgs.gov/science/biology/spatial/ douglas.html, Alaska

Eberhardt LE, Hanson WC (1978) Long-distance movements of Arctic Foxes tagged in Northern Alaska. Can Field Nat 92:386–389

Eberhardt LE, Garrott RA, Hanson WC (1983) Winter movements of Arctic foxes, *Alopex lagopus*, in a petroleum development area. Can Field Nat 97:66–70

Follmann EH, Ritter DG, Hartbauer DW (2004) Oral vaccination of captive arctic foxes with lyophilized SAG2 rabies vaccine. J Wildl Dis 40:328–334

Follmann EH, Martin P (2000) Feasibility of tracking Arctic foxes in northern Alaska using the Argos satellite system: preliminary results. Biotelemetry 15:368–374

Frafjord K, Prestrud P (1992) Home range and movements of arctic foxes *Alopex lagopus* in Svalbard. Polar Biol 12:519–526

Gradinger R (1998) Life at the underside of Arctic sea-ice: biological interactions between the ice cover and the pelagic realm. Memoranda Soc Fauna Flora Fennica 74:53–60

Hersteinsson P, Macdonald DW (1996) Diet of arctic foxes (Alopex lagopus) in Iceland. J Zool 240:457–474

Macpherson AH (1969) The dynamics of Canadian arctic fox populations. Canadian wildlife report series number 8. 52 pp

National Ice Center, NOAA (2006) Ice analysis charts for Beaufort and Chukchi Seas. http://www.natice.noaa.gov/products/alaska/index.htm, Washington, D.C.

Pamperin NJ, Follmann EH, Petersen B (2006) Interspecific killing of an arctic fox by a red fox at Prudhoe Bay, Alaska. Arctic 59:361–364

Parkinson CL, Cavalieri DJ (2002) A 21 year record of Arctic sea-ice extents and their regional, seasonal and monthly variability and trends. Ann Glaciol 34:441–446

Ritter DG (1981) Rabies. In: Dieterich RA (ed) Alaskan wildlife diseases. University of Alaska Fairbanks, Alaska, pp 6–12

Rosatte RC, Tinline RR, Johnston DH (2007) Rabies control in wild carnivores. In: Jackson AC, Wunner WH (eds) Rabies, 2nd edn. Elsevier, London, pp 595–628

Roth JD (2002) Temporal variability in arctic fox diet as reflected in stable-carbon isotopes; the importance of sea ice. Oecologia 133:70–77

Rothrock DA, Yu Y, Maykut GA (1999) Thinning of the arctic sea ice cover. Geophys Res Lett 23:3469–3472

Sas Institute Inc (2007) Version 9.1 statistical software. Sas Institute, Inc, Cary, North Carolina

Sdobnikov VM (1958) The arctic fox in Taymyr. Probl North 1:229–238

Shibanoff SV (1958) Dyanamics of arctic fox numbers in relation to breeding, food and migration conditions. Translations of Russian game reports, vol 3 (Arctic and Red Foxes, 1951–1955). Canadian Wildlife Service, Ottawa, pp 5–28

Smith DM (1998) Recent increase in the length of the melt season of perennial Arctic sea ice. Geophys Res Lett 25:655–658

Smith TG (1976) Predation of ringed seal pups (*Phoca hispida*) by the arctic fox (*Alopex lagopus*). Can J Zool 54:1610–1616

Stirling I, Derocher AE (1993) Possible impacts of climate warming on polar bears. Arctic 46:240–245

Stirling I, Parkinson CL (2006) Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian arctic. Arctic 59:261–275

Tannerfeldt M (1997) Population fluctuations and life history consequences in the arctic fox. PhD Dissertation. Stockholm University, Sweden

Vinnikov KY, Robock A, Stouffer RJ, Walsh JE, Parkinson CL, Cavalieri DJ, Mitchell JFB, Garrett D, Zakharov VF (1999) Global warming and Northern Hemisphere sea ice extent. Science 286:1934–1937

Wrigley RE, Hatch DRM (1976) Arctic fox migrations in Manitoba. Arctic 29:147–157