WINTER MOVEMENTS OF ARCTIC FOXES IN NORTHERN ALASKA

MEASURED BY SATELLITE TELEMETRY

By

Nathan J. Pamperin

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MEASURED BY SATELLITE TELEMETRY

A

THESIS

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

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Fairbanks, Alaska

December 2008

Abstract

We studied winter movements of 37 arctic foxes (*Alopex lagopus*) collared within a petroleum development area at Prudhoe Bay, Alaska (n = 20), and an undeveloped area in the National Petroleum Reserve-Alaska (NPR-A, n = 17) during the winters of 2004, 2005, and 2006 using satellite telemetry. Comparing Prudhoe Bay and NPR-A, differences in mean movement rates of juveniles was 23.9 ± 2.7 km per duty cycle and 10.6 ± 2.8 km per duty cycle for adults, and mean difference in maximum distance from capture site for juveniles was 265.2 ± 63.2 km and 205.5 ± 128.9 km for adults. Juveniles and adults collared in NPR-A were highly mobile and made long distance movements (up to 782 km) while foxes from Prudhoe Bay remained in or near the oil field throughout winter. Extensive use of sea-ice by three juvenile foxes from NPR-A was documented during the winter of 2005-2006. Three juvenile foxes traveled long distances (904, 1096, and 2757 km) during the winter and remained on the sea-ice for extended periods of time (76, 120, and 156 days). These findings verify the use of sea-ice by arctic foxes and raise concerns that the diminishing ice cover may negatively impact populations by limiting access to marine food sources. We conclude that the oilfields are having a strong effect on the winter movements of arctic fox and suggest differences in movements are likely attributable to the availability of anthropogenic foods at Prudhoe Bay.

Table of Contents

Page

Page

List of Figures

Page

Chapter 1

Chapter 2

List of Tables

Page

Chapter 1

Chapter 2

Acknowledgements

Many thanks go to my graduate committee for their guidance and support during the project. I am particularly grateful to Erich Follmann for giving me the opportunity to work on arctic foxes and for his encouragement over the course of my studies. His unwavering enthusiasm for this project made my graduate studies at UAF truly enjoyable. I am also grateful for his patience and understanding that life goes on outside of graduate school, which allowed me to build a home and pursue a career in Fairbanks while working on my degree. Mark Lindberg and Falk Huettmann provided meaningful comments on the various drafts of my thesis and helped me maintain my focus. Brian Person deserves special thanks for his assistance in the field in addition to his support in all other aspects of the study. Help in the field from Luther Leavitt and Larry Larrivee was greatly appreciated. Craig George of the North Slope Department of Wildlife Management also deserves thanks for his many insights on the ecology of arctic foxes and his interest in the study.

This project was made possible by support from the North Slope Borough Department of Wildlife Management with National Petroleum Reserve-Alaska Program funds available through the State of Alaska Department of Community, Commerce and Economic Development. Additional support from BP Exploration Alaska, Inc. made studying foxes at Prudhoe Bay possible and many thanks go to Bill Streever, Diane Sanzone, Bryan Collver, Bill Dawly and Wilson Cullor. Financial support was received from the Center for Global Change and Arctic System Research at the University of Alaska Fairbanks, the Institute of Arctic Biology summer research fellowship, Department of Biology and Wildlife teaching assistantship, UAF graduate school thesis completion fellowship, and through the Dean Wilson Scholarship provided by the Alaska Trappers Association. I would also like to thank Lara Dehn, Jason Vogel, Andrew Balser, Dan Reed, Heimo Korth, Dick Shideler, Tom Simpson and Madison.

Friends and family always offered their support and sometimes their sense of humor. Many thanks to Sam and Jarrod Decker and Sean Bemis for always being there to listen and share advice about graduate school. I am indebted to Gregg Vinger for helping with the house and for making sure I made it outdoors occasionally. Thanks to Mom, Steve, Dad, Cindy, Candy, Paul, Nikki, and Andy for their encouragement along the way. I am forever grateful to my wife, Kelly, for her patience and support from the very beginning. This thesis is dedicated to the memory of Frank Podraza who quietly showed me the value of hard work and how to appreciate the simple things in life, save the next game of cribbage for me…

General Introduction

Winter movements of arctic foxes (*Alopex lagopus*) have been difficult to study, are not well understood (Burgess 2000) and may have important consequences for the population dynamics of the species. Movements during winter may involve congregating in large numbers at food sources (Chesemore 1967, 1968a), traveling long distances (up to 2000 km, Eberhardt et al. 1983), and even foraging on sea ice (Chesemore 1967, Smith 1976, Andriashek et al. 1985). These winter movement patterns are generally attributed to changes in food availability, with foxes becoming more mobile as food becomes scarce. Potential impacts from activities associated with resource development and changing sea-ice conditions have increased the need for detailed information on the movements of arctic foxes in northern Alaska.

In northern Alaska, arctic foxes experience a seasonally fluctuating prey base with an array of available resources during summer months in contrast to a scarcity of available foods during winter. Lemmings (*Dicrostonyx* spp. and *Lemmus* spp.) comprise the majority of the diet when available and migratory birds and their eggs are important during summer months (Chesemore 1968b, Eberhardt 1977, Garrott et al. 1983, Burgess 1984, Samelius et al. 2007). Terrestrial and marine derived carrion appears to be an important subsidy to their winter diet, particularly when lemming abundance is low (Chesemore 1968a, Fay and Stephenson 1989, Roth 2002).

Extensive industrial infrastructure exists across portions of the coastal plain of northern Alaska, following the 1968 discovery of oil at what is now known as the Prudhoe Bay oil fields. The potential effects of oil development on fox populations on the North Slope of Alaska includes altered behavior from existing operations and associated infrastructure as well as for potential impacts of future development projects (Fine 1980, Eberhardt et al. 1982, Johnson et al. 2001, Burgess et al. 2002). Specifically, congregations of arctic foxes at development sites led to concerns that the availability of anthropogenic foods (garbage, handouts) at these locations could potentially change their movements during winter and also lead to higher fox populations (Eberhardt et al. 1982, 1983, Ballard et al. 2000, Burgess 2000).

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). The use of sea-ice by arctic foxes has been documented by researchers before (Eberhardt and Hanson 1978, Andriashek et al. 1985, Roth 2002), but the degree to which sea-ice is important to arctic foxes is not completely understood. Sdobnikov (1958) and Shibanoff (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 1968b, Smith 1976, Andriashek et al. 1985). Reduced access to the sea-ice may have potentially negative effects on fox populations especially during years when terrestrial food sources are low.

Chapter 1 compares winter movements of arctic foxes from the Prudhoe Bay oil field to those from an undeveloped area of the National Petroleum Reserve Alaska near Teshekpuk Lake, exploring the hypothesis that foxes from undeveloped sites would travel farther during winter than foxes from developed areas. Satellite telemetry was used to track foxes and estimate differences in movement rates and distances traveled by foxes from each area. Chapter 2 describes the extensive use of the sea-ice by three foxes collared in the National Petroleum Reserve Alaska study area (see Pamperin et al. 2008). The importance of detailed movement data from individual foxes while on the sea-ice is discussed in relation to what was previously known about the use of sea-ice by foxes and possible impacts of a diminishing arctic ice cover in the future.

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CHAPTER 1

Petroleum development and winter movements of arctic foxes in Alaska: A comparison between the Prudhoe Bay Oil Field and the National Petroleum Reserve-Alaska

Abstract

We studied the winter movements of 37 arctic foxes (*Alopex lagopus*) collared within a petroleum development area at Prudhoe Bay, Alaska (n = 20), and an undeveloped area in the National Petroleum Reserve-Alaska (NPR-A) (n = 17) during the winters of 2004, 2005, and 2006 using satellite telemetry. Comparing Prudhoe Bay and NPR-A, differences in mean movement rates of juveniles was 23.9 ± 2.7 km per duty cycle and 10.6 ± 2.8 km per duty cycle for adults, and mean difference in maximum distance from capture site for juveniles was 265.2 ± 63.2 km and 205.5 ± 128.9 km for adults. Juveniles and adults collared in NPR-A were highly mobile and made long distance movements (up to 782 km) while foxes from Prudhoe Bay remained in or near the oil field throughout winter. We conclude that the oilfields are having a strong effect on the winter movements of arctic fox and suggest differences in movements are likely attributable to the availability of anthropogenic foods at Prudhoe Bay in the form of garbage and handouts.

Introduction

The ecology of the arctic fox (*Alopex lagopus*) and the environment in which it lives combine to make the species particularly sensitive to the effects of human activities. Food availability varies widely in northern Alaska and arctic foxes face a fluctuating prey base; a wide array of food is available during summer but prey is often scarce during winter. Lemmings (*Dicrostonyx* spp. and *Lemmus* spp.) comprise the majority of the diet when available, and migratory birds and their eggs are important during summer months (Chesemore 1968a, Eberhardt 1977, Garrott et al. 1983, Burgess 1984, Samelius et al. 2007). Terrestrial and marine derived carrion appears to be an important subsidy to their winter diet, particularly when lemming abundance is low (Chesemore 1968a, Fay and Stephenson 1989, Roth 2002). Foxes maintain territories during summer months while rearing young and when natural prey items are abundant. These territories are abandoned during the winter, and foxes typically roam over larger areas in search of food (Chesemore 1967). Winter movements may involve congregating in large numbers at food sources (Chesemore 1967, 1968b), traveling long distances (up to 2000 km, Eberhardt et al. 1983a), and foraging on the sea ice (Chesemore 1967, Smith 1976, Andriashek et al. 1985, Pamperin et al. 2008). These patterns of movement and resource use may be altered by the availability of anthropogenic foods and this may be the case at development sites in northern Alaska, where refuse and handouts can represent a consistent food source.

Extensive industrial infrastructure exists across portions of the coastal plain of northern Alaska, (hereafter North Slope) following the 1968 discovery of oil at what is now known as the Prudhoe Bay oil fields. The effect of oil development on fox populations on the North Slope of Alaska has gained attention for both existing operations and associated infrastructure as well as for potential impacts of future development projects (Eberhardt et al. 1982, Fine 1980, Johnson et al. 2001, Burgess et al. 2002). Eberhardt et al. (1983b) and Ballard et al. (2000) reported higher den densities in Prudhoe Bay than in undeveloped areas, however no pre-development data existed within the Prudhoe Bay oil field. Comparisons between the number of juvenile foxes produced at Prudhoe Bay and undeveloped sites revealed that pup production was more constant at Prudhoe Bay when natural prey items were less abundant (Eberhardt et al. 1982). In a winter movement study, Eberhardt et al. (1983a) found that a portion of foxes radio collared within Prudhoe Bay seemed to travel out of the area during fall and again in mid-winter, but evidence for this was compromised by the inability to consistently relocate the collared animals using conventional (VHF) telemetry. Of the foxes relocated within the oil field, Eberhardt at al. (1983a) noted heavy use of developed sites, particularly during the winter months. Recently, satellite collared foxes were found to reside in the Prudhoe Bay oil field throughout the entire winter season (Follmann and Martin, unpublished data).

Since the mid 1990's, waste management practices within the oil fields have undergone major changes due largely to problems with grizzly bears (*Ursus arctos*) becoming conditioned to garbage and other sources of human food (D. Shideler pers. comm.). Under the revised practices, commercial bear-resistant bins for garbage and other discarded human food were placed at all facilities and work sites. Previously uncovered large, kitchen waste dumpsters were covered with fabricated bear-resistant covers, and construction waste dumpsters at remote job sites were covered with metal cages or mats designed to prevent animals (mainly bears and foxes) from entering and feeding inside. At the landfill, which is located within the oil field, a double fence system consisting of an inner chain link fence surrounded by an electric fence was also erected around the landfill to restrict bears' access to uncovered garbage. These improvements, along with increased training of oil field workers about the importance of waste management and safe behavior around bears and foxes were intended to reduce the attractiveness of oil field facilities to local wildlife and to reduce human-wildlife conflicts. Although Alaska state law (5 AAC 92.230) and internal oil company policies have prohibited intentional feeding of foxes and bears, these measures have been less successful in reducing intentional feeding of foxes than of bears. Problems with grizzly bears have decreased over recent years in response to improved waste management techniques and removal of problem bears (D. Shideler pers. comm.), but information on the response of arctic foxes to improvements in waste management has been lacking.

The potential for changes in winter movement patterns and for increased populations of arctic foxes within oil fields has several important implications. Increased numbers of foxes coupled with the ability of animals to enter the breeding season in better body condition has the potential to increase the effect of fox predation on local populations of waterfowl and shorebirds (Samelius et al. 2007, Liebezeit and Zack 2008). The arctic fox is also a significant reservoir for rabies and the concentration and increase in numbers of these animals near populated industrial sites and villages is a public health concern as it may increase the risk of human contact with rabid animals (Ritter 1981, Follmann et al. 1988).

Little information exists on the winter movements of arctic foxes (Burgess 2000). Detailed information on winter movements of arctic foxes has been difficult to obtain due to the large size of satellite transmitters and the limitations of traditional telemetry techniques. VHF telemetry is not ideal for tracking arctic foxes during winter due to the nature of fox movements and the intensive tracking effort needed to relocate wide-ranging animals at regular time intervals. Additionally, the lack of daylight and severe cold in northern Alaska restricts the use of small aircraft. In the last decade, satellite transmitters have become smaller and lighter in weight, consequently, it is now possible to use satellite transmitters to track the movements of arctic foxes (Follmann and Martin, 2000). Our objective was to estimate potential differences in winter movements of arctic foxes from a developed and an undeveloped area. We deployed 37 satellite radio collars over two years to track movements of foxes from the Prudhoe Bay oil field and from a currently undeveloped portion of the National Petroleum Reserve-Alaska (NPR-A). We hypothesized that foxes from NPR-A would travel more extensively during winter than would foxes from Prudhoe Bay based on the potential influence of anthropogenic foods.

Methods

Study area choice was based on the presence of existing industrial development in Prudhoe Bay, and on the likelihood of future development in a currently undeveloped area of the northeast portion of the NPR-A (BLM 1998, 2008). Additionally, the area around Teshekpuk Lake is important for subsistence activities by North Slope residents and this area has been identified as being valuable for petroleum extraction (BLM 2008). Thus the choice of this site also allowed us to gather important pre-development data on fox movements. Prudhoe Bay was chosen as the developed area because it is an established permanent site and because previous arctic fox studies were conducted there allowing us to compare our results and assess the effectiveness of changes to waste management practices. Both study areas are located on the coastal plain and are similar in topography and vegetation. Topography is generally flat and vegetation regimes in both areas are dominated by wet tundra with sedges, grasses and mosses as the principal vegetation types (CAVM 2003).

We trapped foxes in NPR-A near Teshekpuk Lake (70º 15’ N, 153º 32’ W) in northern Alaska (Fig. 1) during September, 2004, and August, 2005 and in the Prudhoe Bay oil field (70º 15’ N, 148º 22’ W) during August, 2004 and 2005 using box traps (Model 208, Tomahawk Live Trap, Tomahawk, WI, USA) baited with fish. In NPR-A, we placed traps near den sites that appeared to be active. In Prudhoe Bay, we placed traps either at natural den sites or next to facilities known to attract foxes such as dumpsters and areas adjacent to kitchen facilities. After capture in the live trap, we transferred animals to a restraint cage (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 weighing and collar attachment. We aged foxes as either adult or juvenile based on tooth wear, tooth coloration, and canine eruption (Macpherson 1969, Frafjord and Prestrud 1992). Animals were fitted with satellite transmitters (Model A-3110, 190g, Telonics, Inc., Mesa, AZ, USA). We also attached auxiliary VHF transmitters (Model R1840, 8g, Advanced Telemetry Systems, Inc., Isanti, MN, USA) to a subset (n = 9) of collars deployed on foxes in Prudhoe Bay in 2005 to aid in carcass and collar recovery. Fox capture, handling, and collar attachment procedures were approved by the University of Alaska Fairbanks Institutional Animal Care and Use Committee (Protocol Number 05-45).

Satellite transmitters contained temperature, activity, and mortality sensors. Collars were programmed to transmit for a 4-hour period every 96 hours 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 (David Douglas, USGS), hereafter referred to as the Douglas filtering algorithm, implemented in SAS (V 9.1, SAS Institute Inc., Cary, NC, USA) in order to remove redundant locations and to flag potentially implausible locations based on parameters we supplied to the filter. The final data set contained the most accurate location per duty cycle (based on Argos classification errors, see Argos User's Manual, CLS 2007) for each animal from time of deployment until battery failure or mortality. Because we were interested in broad-scale movements, we did not exclude locations based solely on the Argos location quality classification (e.g. LA, LB, L0, L1, L2, L3). For some duty cycles, A, B, or 0 location classes were all that were received for a particular PTT (Platform Transmitter Terminal), but we chose to retain these locations if they passed the Douglas filtering algorithm's plausibility tests and visual inspection of the data.

We used two metrics to compare movements of foxes: mean distance traveled per duty cycle and maximum distance from capture site. We calculated the mean distance traveled per duty cycle from straight-line distances between locations from consecutive duty cycles (every 4 days). In instances where duty cycles passed without a location being obtained (e.g. 8 days between locations), we adjusted the mean distance traveled by the number of duty cycles since the last location to standardize on a 4-day interval. Maximum distance from capture site was obtained by calculating the longest straight line distance between the initial point of capture and the most distant location from this point. Location data were plotted and analyzed using ArcView 3.2 and ArcMap 9.1 software (ESRI, Redlands, California, USA). To compare the relative spatial extent of fox movements, we constructed fixed kernel distributions and associated 50% and 95% probability contour intervals for winter locations for each area using the Animal Movement extension in ArcView 3.2 (Hooge and Eichenlaub 2000). Since we were primarily interested in the difference of winter movements between areas, we calculated one distribution for each area that included all winter fox locations and present the results in map form with the areas of each probability contour.

We defined the winter period as October through May when foxes likely face a shortage of, or reduced access to, natural prey items requiring them to travel farther in search of food. These months incorporate the period when much of the North Slope has persistent snow cover (Zhang et al. 1996). We compared winter movements of foxes between areas by age class and within each area by age class. We graduated juvenile foxes to the adult age class if they survived past one year of age, defined as June 1st of the year following capture. Data for adults are presented for the winters of 2004-2005, 2005-2006, and 2006-2007, and the winters of 2004-2005 and 2005-2006 for juveniles. Mean values are presented ± one standard error (SE) and comparisons in movement are represented as the differences between means ± one SE.

Results

We collared a total of 37 arctic foxes from NPR-A and Prudhoe Bay during August and September, 2004 and 2005 (Table 1). In 2004 we collared three foxes in NPR-A (1 juvenile female, 1 adult female, 1 adult male) and ten foxes from Prudhoe Bay (5 juvenile females, 1 juvenile male, 2 adult females, 2 adult males). In 2005 we collared 14 juvenile foxes in NPR-A (6 female, 8 male) and 10 foxes from Prudhoe Bay (4 juvenile females, 5 juvenile males, 1 adult male, 1 adult female was recaptured and collar replaced). At both study areas, there were instances where we captured multiple foxes at the same location (den site, kitchen facility, etc.) and the possibility exists that some of these collared animals were related.

Collars were very reliable and we only experienced one premature failure (fox 53094, NPR-A). Predicted battery life for the satellite transmitters was 343 days, though we had several collars that transmitted over intervals in excess of 600 days, including a maximum interval of 736 days before battery failure (fox 53113, Table 1). After processing our data with the Douglas filtering algorithm and separating winter-only locations for this analysis, the final data set contained 1,015 locations with the following location quality classes; 74 L0 (7%), 196 L1 (19%), 333 L2 (32%), 290 L3 (28%), 84 LA (8%), and 38 LB (3%).

Differences in movement rates of juvenile foxes between study sites were substantial (Figs. 2, 3). Foxes from NPR-A traveled farther per duty cycle (23.9 ± 2.7 km), and farther from capture locations (265.2 ± 63.2 km) than foxes from Prudhoe Bay. Juveniles from NPR-A maintained higher travel rates across all months of winter (Fig. 4). Mean distance traveled per duty cycle for juveniles pooled over years from NPR-A was 28.0 ± 2.7 km and 4.2 ± 0.3 km for juveniles from Prudhoe Bay (Fig. 2). Mean maximum distance from capture site for NPR-A juveniles was 276.6 ± 63.2 km and 11.4 ± 2.1 km for Prudhoe Bay juveniles (Fig. 5). The maximum distance traveled during a duty cycle for an NPR-A juvenile was 240 km (60 km/day, fox 53113, female) and the maximum distance traveled from a capture site was 782 km (fox 53113, female; Fig. 3). For Prudhoe Bay juveniles, the maximum distance traveled during a duty cycle was 41 km (10 km/day, fox 53125, female) and maximum distance from a capture site was 32 km (fox 53101, male; Fig. 3).

The pattern of differences in movements between adult arctic foxes from NPR-A and Prudhoe Bay was similar to that found for juvenile foxes between areas, though data was available for only four adults from NPR-A. Adults from NPR-A traveled farther per duty cycle (10.6 ± 2.8 km) than adults from Prudhoe Bay, but distance from capture site was similar between sites (205.5 ± 128.9 km). Mean distance traveled per duty cycle was 15.3 ± 2.7 km for NPR-A adults and 4.7 ± 0.3 km for Prudhoe Bay adults when winters were pooled (Figs. 2, 6). Differences in distances traveled during duty cycles were most pronounced during late winter (Fig.

7). Across winters, mean maximum distance from capture site was 229.3 ± 128.9 km for NPR-A adults and 23.7 ± 4.6 km for Prudhoe Bay adults (Fig. 5). The maximum distance traveled during a duty cycle for an NPR-A adult was 204 km (51 km/day, fox 53124, female) and the maximum distance from a capture site was 577 km (fox 53113, female; Fig. 6). For Prudhoe Bay adults, the maximum distance traveled during a duty cycle was 53 km (13 km/day, fox 53108, male) and maximum distance from a capture site was 47 km (fox 53108, male) (Fig. 6).

Juveniles on average traveled farther during duty cycles (28.0 ± 2.6 km) than adults in NPR-A (15.3 ± 2.7 km) where difference in mean travel rate was 12.7 ± 3.8 km (Figs. 2, 3, 6). Maximum distance from capture site was similar (adult = 229.3 ± 128.9 km; juvenile = 276.6 ± 63.2 km) with a mean difference of 47.3 ± 143.5 km (Figs. 3, 5, 6). The case was reversed for adults and juveniles collared in Prudhoe Bay with a small difference in mean distance traveled per duty cycle (mean difference = 0.5 ± 0.45 km) among age classes (adult = 4.7 ± 0.3 km; juvenile = 4.2 ± 0.3 km; Figs. 2, 3, 6), but a larger difference in maximum distance from capture site (mean difference = 12.3 ± 5.1 km) where adults tended to travel farther from their capture sites (23.7 ± 4.6 km) than did juveniles (11.4 ± 2.1 km, Figs. 3, 5, 6).

Adults and juveniles collared in Prudhoe Bay did not move outside the oil field for extended time periods during winter with the exception of one fox. In 2005, a juvenile male (53101) traveled south from the oil field approximately 25 km and occupied a small area west of the Trans-Alaskan Pipeline from September 23 through November 10 before returning to the oil field on *ca*. November 14 (Fig. 3). In contrast, foxes collared in NPR-A traveled extensively with a range of locations that eventually spanned nearly the entire geographic extent of Alaska's North Slope (Figs. 3, 6). Among these movements were two juveniles (53112, 53118) that moved into the Kuparuk and Prudhoe Bay oil fields where they eventually died and their collars were recovered. In addition, three juveniles from NPR-A (foxes 53094, 53113, and 53122) traveled at length on the sea-ice of the Bering and Chukchi seas during the winter of 2005-2006 (Fig. 3); these movements are described in more detail in Pamperin et al. (2008). Similar use of sea ice by collared foxes from Prudhoe Bay was not observed during this study (Figs. 3, 6).

Comparisons of kernel distributions revealed large differences in the areas traveled by foxes from NPR-A and Prudhoe Bay during winter. The spatial extent of fox movements from NPR-A encompassed the majority of the North Slope while Prudhoe Bay foxes generally confined their movements to within the oil field (Figure 8). Differences were most pronounced for the 95% probability contour where there was a 400 fold difference in area between NPR-A (125,620 km^2) and Prudhoe Bay (309 km^2) kernel distributions (Figure 8).

Discussion

Our primary objective was to estimate the differences in winter movements of arctic foxes between a developed and undeveloped area in order to gain a more complete understanding of the potential effects of developed sites where anthropogenic foods are available. This investigation built on previous work that documented long distance movements of arctic foxes in Alaska (Eberhardt and Hanson 1978) and on fox movements within the Prudhoe Bay oil field (Fine 1980, Eberhardt et al. 1983a). The data presented here demonstrate both the capability of arctic foxes to undertake long distance movements during winter and the sensitivity of these movements to the influence of permanent developments. We observed large differences in winter movements between foxes from NPR-A and Prudhoe Bay with differences most apparent in juvenile movements and in the overall spatial extent of fox movements from NPR-A.

We observed a consistent pattern in juvenile movements from NPR-A, with animals that survived through October making directed movements away from capture sites in different directions, both on land and on the sea-ice (Fig. 3). The mean date for movements >20 km from capture site of these juveniles ($n = 12$) was October 7th (range Sept. 7 to Dec. 8). We hesitate to classify these movements as true dispersal without locations from subsequent summers; however, we think that these probably represent exploratory movements as opposed to sporadic or random ones due to the high proportion of animals undertaking such movements.

The low rates of travel and distances moved from capture location of Prudhoe Bay juveniles made identifying dispersal or exploratory movements more difficult than for juveniles from NPR-A. While exploratory movements were probably made by juvenile animals from Prudhoe Bay, the scale at which they occurred obscured them from being detected as easily as those by NPR-A juveniles (with the exception of fox 53101).

Movement metrics demonstrated adults from NPR-A to be more mobile than adults from Prudhoe Bay. Three of the four adults from NPR-A moved extensively during winter, with high movement rates of two of these adults (females 53113, 53124) concentrated towards the end of the winter period in April and May (Figs. 6, 7). Adult movement rates in Prudhoe Bay were more consistent across months (Fig. 7) and we did not observe any extended movements outside the oil field in which animals did not subsequently return (Fig. 6). This is in contrast to the adult “dispersal” reported by Eberhardt et al. (1983a) of two males leaving Prudhoe Bay during fall, following the rearing of pups.

The movements of adult female fox 53124 from NPR-A were surprising with respect to both the timing of, and distances traveled. This individual traveled from the capture site, near Teshekpuk Lake, more than 260 km west to the Chukchi Sea coast during January through March, 2005 and returned to Teshekpuk Lake during April, 2005 (Fig. 6). Shortly after arriving near Teshekpuk Lake in early May, 2005, this fox made a similar 220 km movement to the west over a period of two weeks before returning to Teshekpuk Lake by the first week of June, 2005 (Fig. 6). The fox died at the end of July, 2005 (Table 1) 12 km south of the capture site. The reproductive status of this fox was not known, but the second westward round-trip movement during May and June would be unexpected for a pregnant female as this period coincides with the time period typically associated with birthing.

The spatial extent of winter locations between foxes from NPR-A and Prudhoe Bay was drastically different. Kernel distributions based on pooled winter locations demonstrated the large spatial disparity between areas traveled by foxes. In addition to the generally lower movement rates of Prudhoe Bay foxes during winter, the areas of 50% and 95% kernel distributions show that foxes in the oil field traveled over much smaller areas than foxes from NPR-A (Fig. 8). The distributions also show that Prudhoe Bay foxes seldom leave the oil field during winter. The large area covered by the 95% kernel distribution of NPR-A foxes (125,620 km^2 vs. 309 km^2 for Prudhoe Bay) highlights the mobility of these foxes and suggests they may be facing different prey/resource distributions than Prudhoe Bay foxes.

Due to the novelty of using satellite telemetry to track arctic fox movements, we have relatively few studies to compare our winter movement data with. Average daily travel rates of tagged arctic foxes reported on by Eberhardt and Hanson (1978) ranged from less than 1 km per day to a maximum of 24 km per day. These estimates are of lower temporal resolution since only the endpoints of the movements were known from capture and recovery, but they fall within the range of rates we observed for collared foxes in this study. The highest rate documented by Eberhardt and Hanson (1978) of 24 km per day is greater than any rate we observed for Prudhoe Bay animals however. Because their study, along with others, was conducted while the development of Prudhoe Bay was ongoing, it is possible that foxes may have been moving more extensively at that time and had not completely adjusted to the presence of the developed sites. Maximum average daily travel rates from NPR-A foxes of 60 km per day while on ice (fox 53113) and 51 km per day while on land (fox 53124) are much higher than previously reported for arctic foxes, but are likely due to a difference in tracking method and increased temporal resolution of location data. Distances traveled by NPR-A foxes in this study (up to 782 km) are comparable to records of long distance movements by arctic foxes in winter from Eberhardt and Hanson (1978), 129 to 945 km, and Wrigley and Hatch (1976), 840 km, but far less than the maximum record of 2300 km reported by Garrott and Eberhardt (1987) for a fox tagged in Prudhoe Bay and recovered on the coast of Hudson Bay, Canada. In western Alaska, Anthony (1997) did not observe movements greater than 50 km for radio-collared arctic foxes, which is similar to what we observed for foxes in Prudhoe Bay, but orders of magnitude lower than what we documented for foxes from NPR-A.

Decreases in food availability are often cited as the trigger for winter movements and dispersal of arctic foxes (Tchirkova 1958, Chesemore 1967, Macpherson 1969, Roth 2002), although Eberhardt and Hanson (1978) reported long distance movements of arctic foxes in northern Alaska during winters when lemmings were apparently abundant the preceding summer. Eberhardt et al. (1983b) made a similar conclusion about difference in food availability in relation to differences in den density and pup production or survival between Prudhoe Bay and the Collville River Delta, Alaska. Ballard et al. (2000) also cited garbage and handouts as possible factors affecting the apparent increased density of dens within Prudhoe Bay compared to other areas in the Arctic; acknowledging that without predevelopment data from Prudhoe Bay, this conclusion can not be made with certainty. While we did not directly investigate differences in food availability between NPR-A and Prudhoe Bay, we believe it is the most plausible reason for the differences in winter movements between areas. We realize that differences in natural prey abundance between areas may explain some of the differences in the winter movements of foxes, but we believe that the presence of anthropogenic foods in Prudhoe Bay represents the most marked difference between study areas.

During winter visits to Prudhoe Bay, it was common to see foxes feeding on garbage near dumpsters or at the landfill, and we also saw indirect evidence of intentional feeding both from abandoned food scraps at secluded sites and begging behavior from foxes. Although anthropogenic foods are difficult to distinguish in scat because of their high digestibility, use of these foods has been well documented in summer and winter by a number of studies (Eberhardt et al. 1982, Eberhardt et al. 1983a, 1983b, Garrott et al. 1983). In light of the improved waste management practices started at oil field facilities since the mid 1990's, we assumed that availability and access to anthropogenic foods had probably decreased for arctic foxes compared to the past. Unlike the previous studies at Prudhoe Bay by Eberhardt and Hanson (1978) and Eberhardt et al. (1983a), we did not observe emigration of foxes out of the Prudhoe Bay area during winter. Lack of emigration from the Prudhoe Bay oil field was also documented by Follmann and Martin (unpublished data) who conducted a pilot study with 10 satellite-collared foxes during the winter of 1998-1999. We did, however, observe two instances of immigration into the Prudhoe Bay (53118) and nearby Kuparuk oil fields (53112) by foxes collared in NPR-A.

Lower energy requirements of arctic foxes have been reported for winter compared to summer despite foxes having to cope with extreme temperatures during winter (Underwood 1971, Fuglei and Oritsland 2003). Without the need to defend territories, rear young, or maintain high growth demands (juveniles) during winter, arctic foxes may require fewer resources than during summer. Given this, it may be extremely difficult to manage disposal of trash from developed sites in a way that eliminates fox access to anthropogenic foods and thus the attractiveness of oil field facilities to arctic foxes during winter. It is plausible that even small supplements of anthropogenic foods to the natural winter diet of foxes could be responsible for our observation of foxes permanently remaining in Prudhoe Bay. Future studies should aim to quantify the contribution of anthropogenic foods in the diet of arctic foxes (through stable isotope analyses, etc.) in Prudhoe Bay so we can better understand its influence on their winter ecology.

Satellite telemetry proved to be an effective method of collecting movement data on arctic foxes during winter. With this technology we were able to gather valuable information on movements of individual foxes, which greatly increased our understanding of their winter movements. Data presented on fox movements in this study will also be valuable in assessing the potential impacts of future developments in NPR-A with respect to both populations of foxes and those of their prey. These results further support the hypothesis that anthropogenic food sources available at the Prudhoe Bay development have the potential to influence winter movements of arctic foxes. Despite improvements to waste management practices over the past decades, it appears that more needs to be done to reduce the availability of anthropogenic foods at these sites. Care needs to be taken for future permanent developments in NPR-A, and elsewhere, to assure that waste management practices put in place do not just limit animals' access to anthropogenic food sources, but altogether eliminate it. While foxes will always be attracted to certain oil field facilities because of associated odors, eliminating food rewards will help reduce the likelihood of foxes permanently remaining at these sites. Eliminating access to anthropogenic foods will be an expensive undertaking, but we believe it is important that it be done.

Acknowledgements

This study was supported by the North Slope Borough Department of Wildlife Management with National Petroleum Reserve-Alaska Program funds available through the State of Alaska Department of Community, Commerce and Economic Development. N. Pamperin received additional support from the Center for Global Change and Arctic System Research at the University of Alaska Fairbanks, the Institute of Arctic Biology summer research fellowship, Department of Biology and Wildlife teaching assistantship, UAF graduate school thesis completion fellowship, and through the Dean Wilson Scholarship provided by the Alaska Trappers Association. We would like to thank Brian Person and Craig George of the North Slope Borough Department of Wildlife Management, Luther Leavitt of Barrow, Alaska, and Larry Larrivee of Pollux Aviation for their assistance in the field and logistical support. We thank Dr. Bill Streever and Dr. Diane Sanzone of BP Exploration Alaska, Inc. for providing logistical support for our field work in Prudhoe Bay. N. Pamperin would also like to thank Tom Simpson, Dan Reed, Dick Shideler and Heimo Korth. We also appreciate the insightful comments of Brian Person, Falk Huettmann and Mark Lindberg who reviewed the original manuscript.

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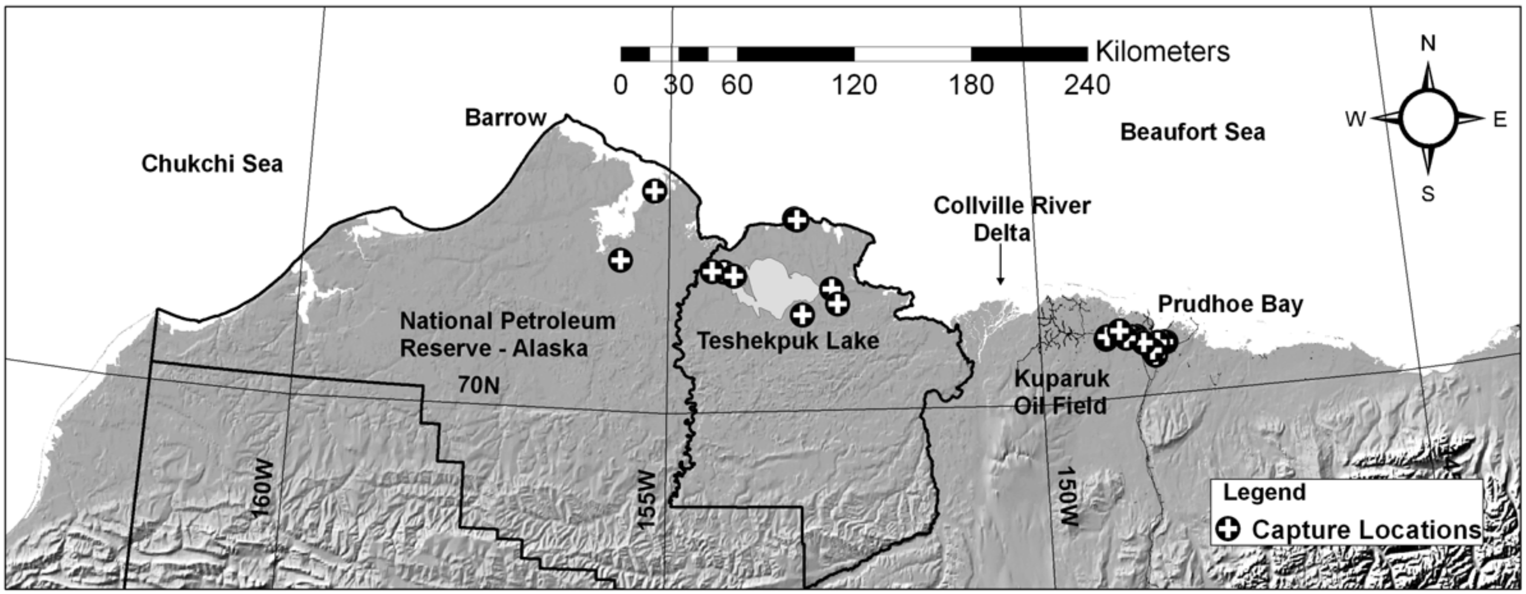

Figure 1. Northern Alaska showing study areas and capture locations of arctic foxes in 2004 and 2005.

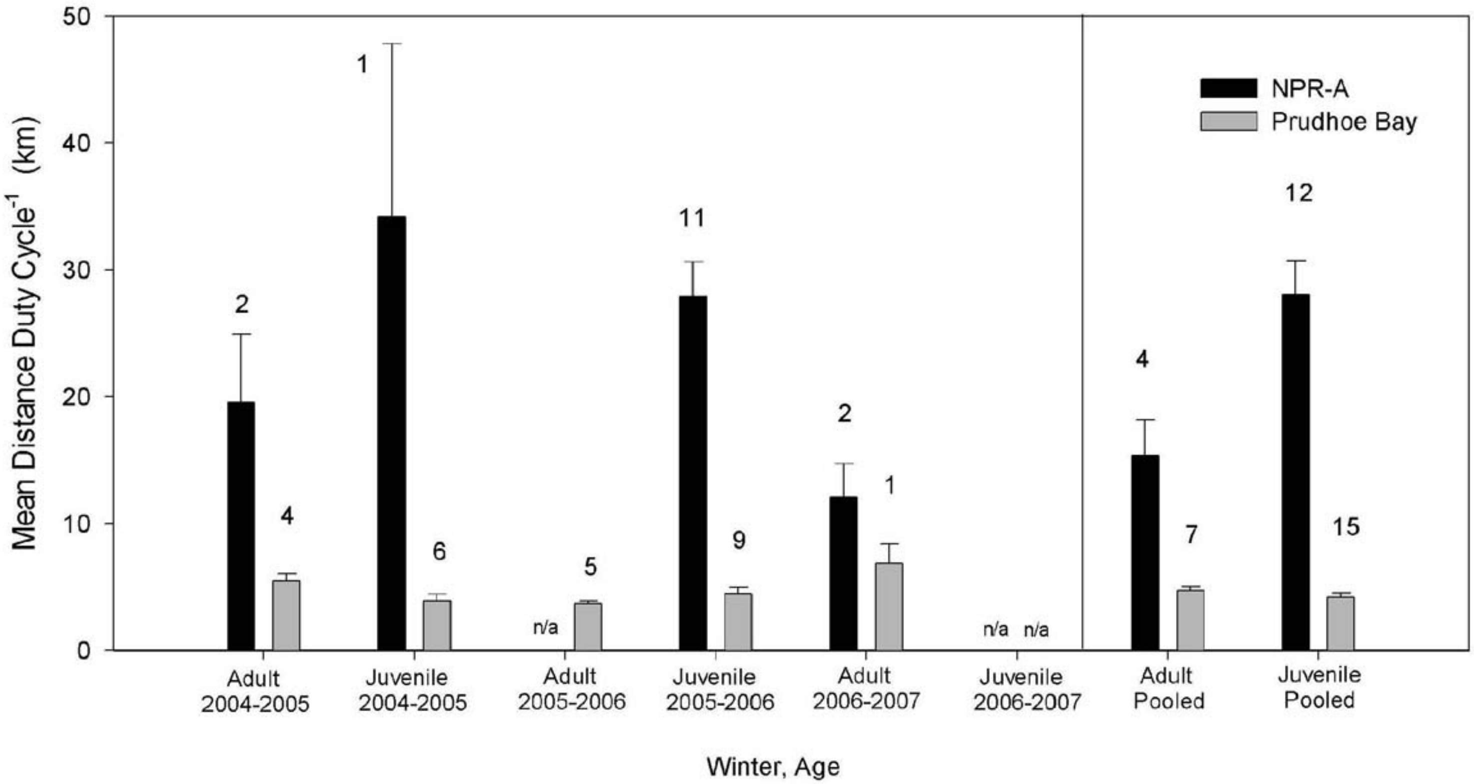

Figure 2. Comparison of travel rates for satellite collared arctic foxes during winter (October – May), from NPR-A and Prudhoe Bay Alaska. Error bars represent one standard error of the mean. Numbers above bars indicate number of animals for which movement data were available.

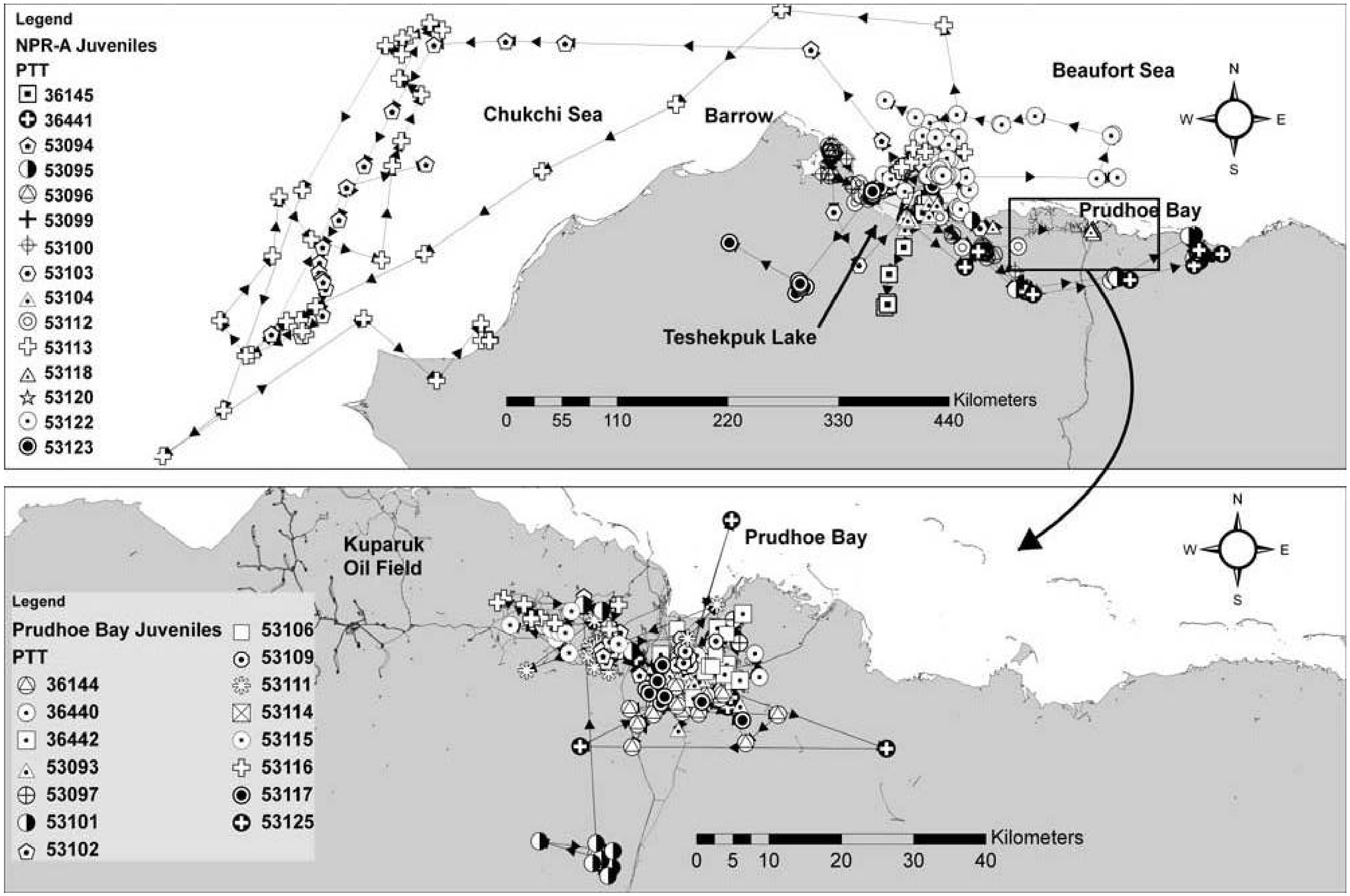

Figure 3. Movements of juvenile arctic foxes from NPR-A (top pane) and Prudhoe Bay (lower pane) during winter (October through May) of 2004-2005 and 2005-2006. Map projection is Alaska Albers Conic Equal-Area, N. American Datum 1927.

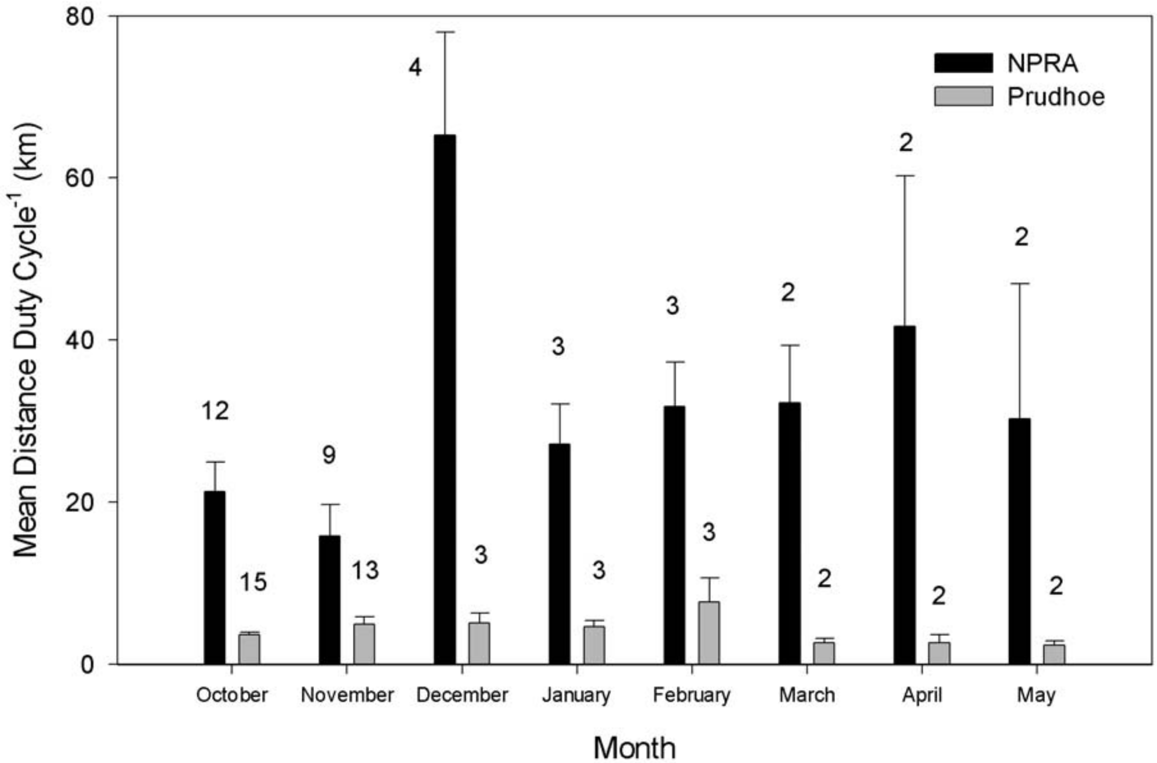

Figure 4. Comparison of travel rates for satellite collared juvenile arctic foxes during winter by month, from NPR-A and Prudhoe Bay, Alaska. Data pooled from winters 2004-2005 and 2005-2006. Error bars represent one standard error of the mean. Numbers above bars indicate number of animals for which movement data were available.

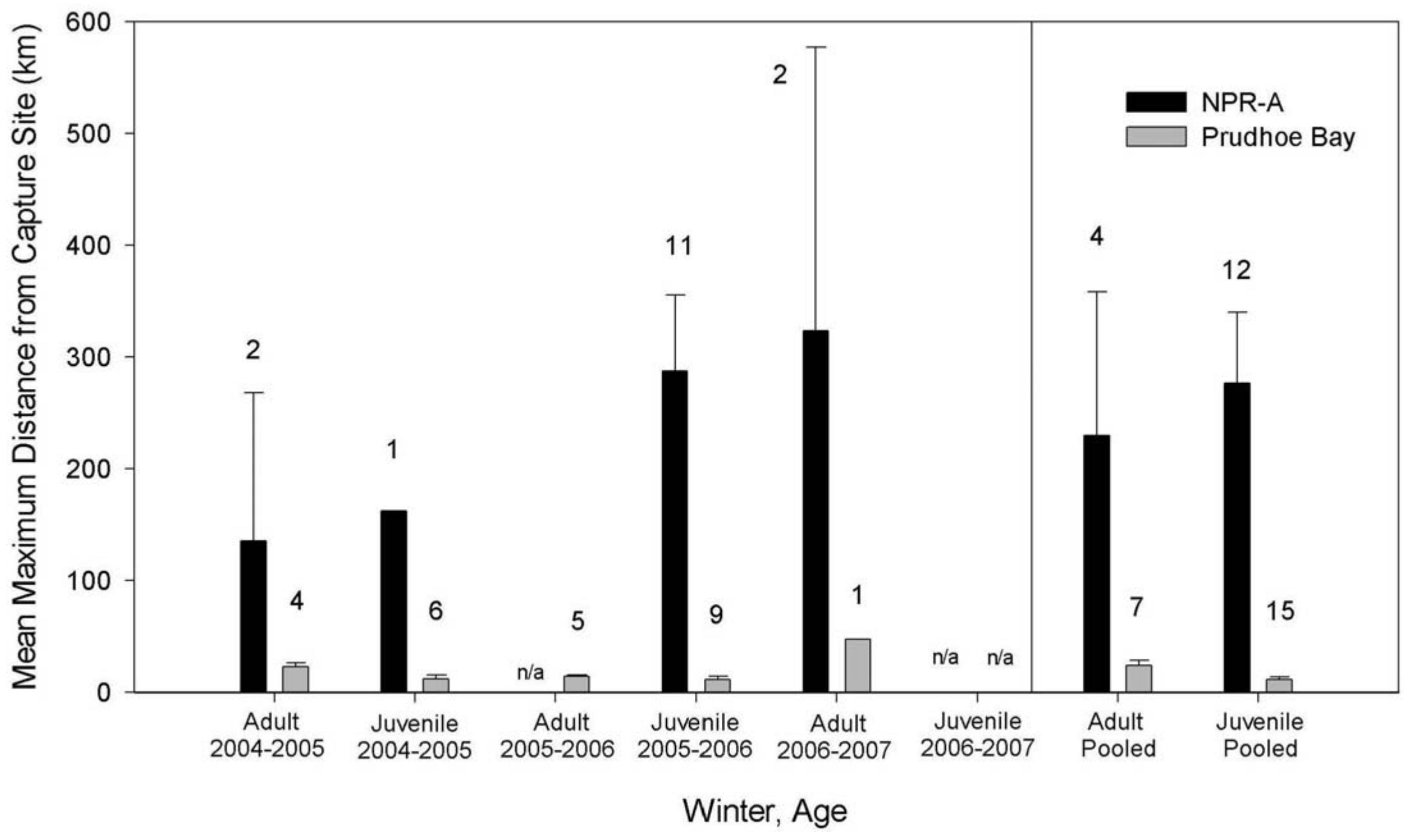

Figure 5. Comparison of maximum distance from capture site for satellite collared arctic foxes during winter (October – May), from NPR-A and Prudhoe Bay, Alaska. Error bars represent one standard error of the mean. Numbers above bars indicate number of animals for which movement data were available.

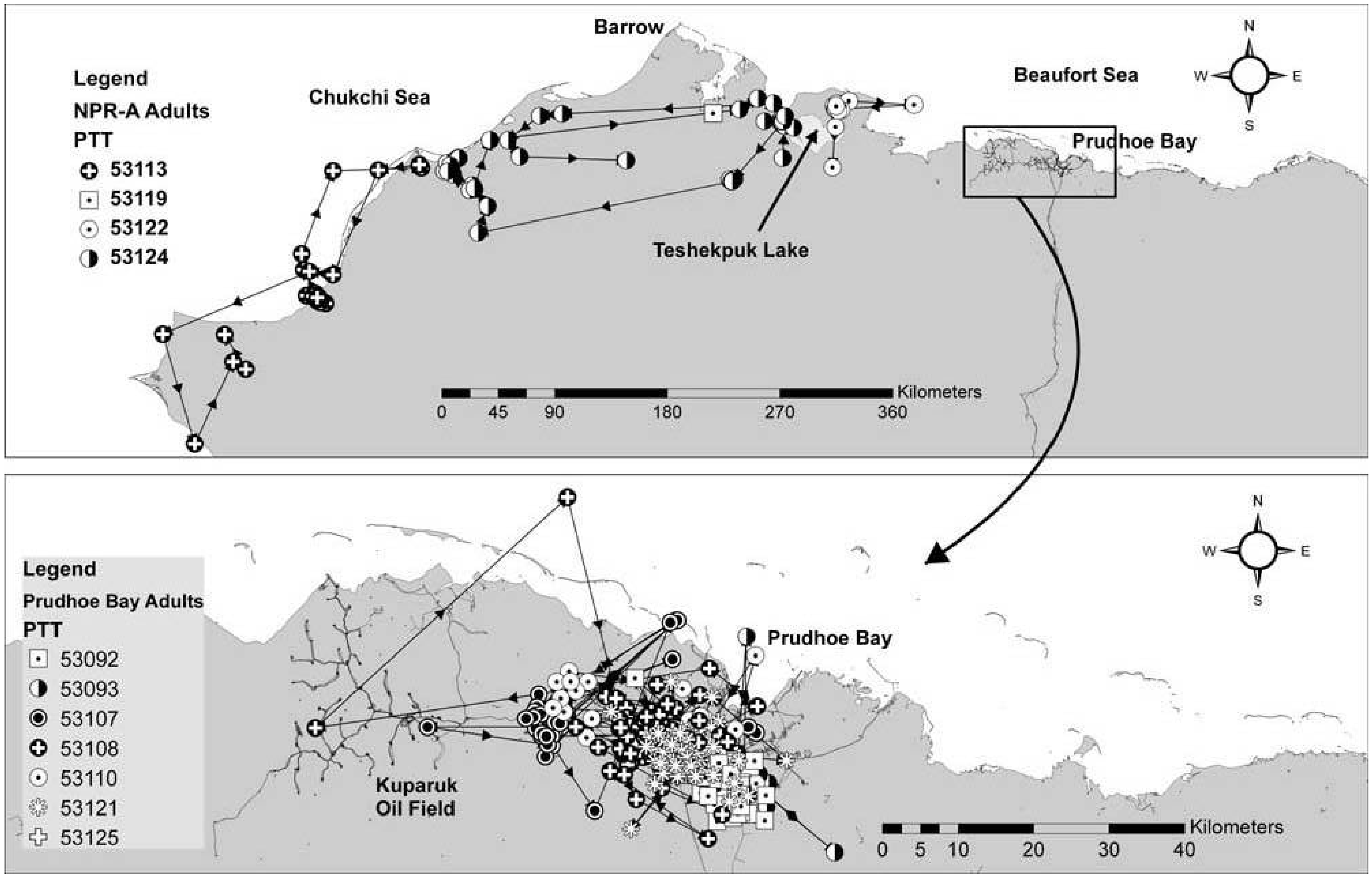

Figure 6. Movements of adult arctic foxes from NPR-A (top pane) and Prudhoe Bay (lower pane) during winter (October through May) of 2004-2005, 2005-2006, and 2006-2007. Map projection is Alaska Albers Conic Equal-Area. N. American Datum 1927.

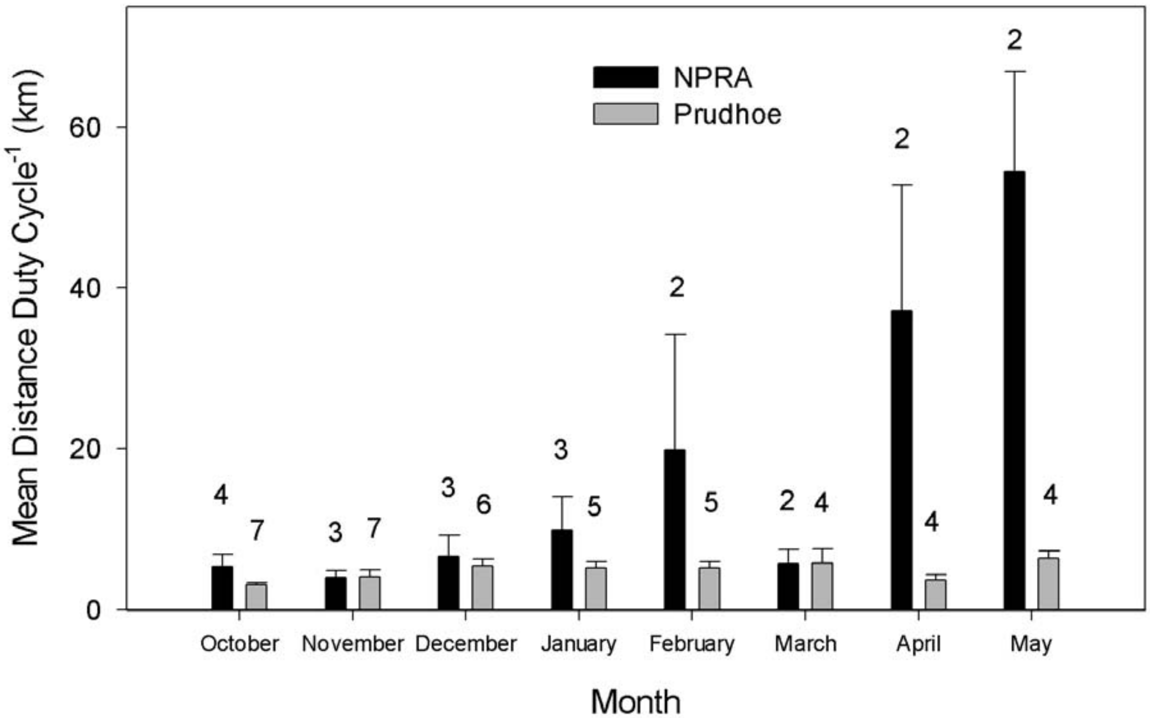

Figure 7. Comparison of travel rates for satellite collared adult arctic foxes during winter by month, from NPR-A and Prudhoe Bay, Alaska. Data pooled from winters 2004-2005, 2005-2006, and 2006-2007. Error bars represent one standard error of the mean. Numbers above bars indicate number of animals for which movement data were available.

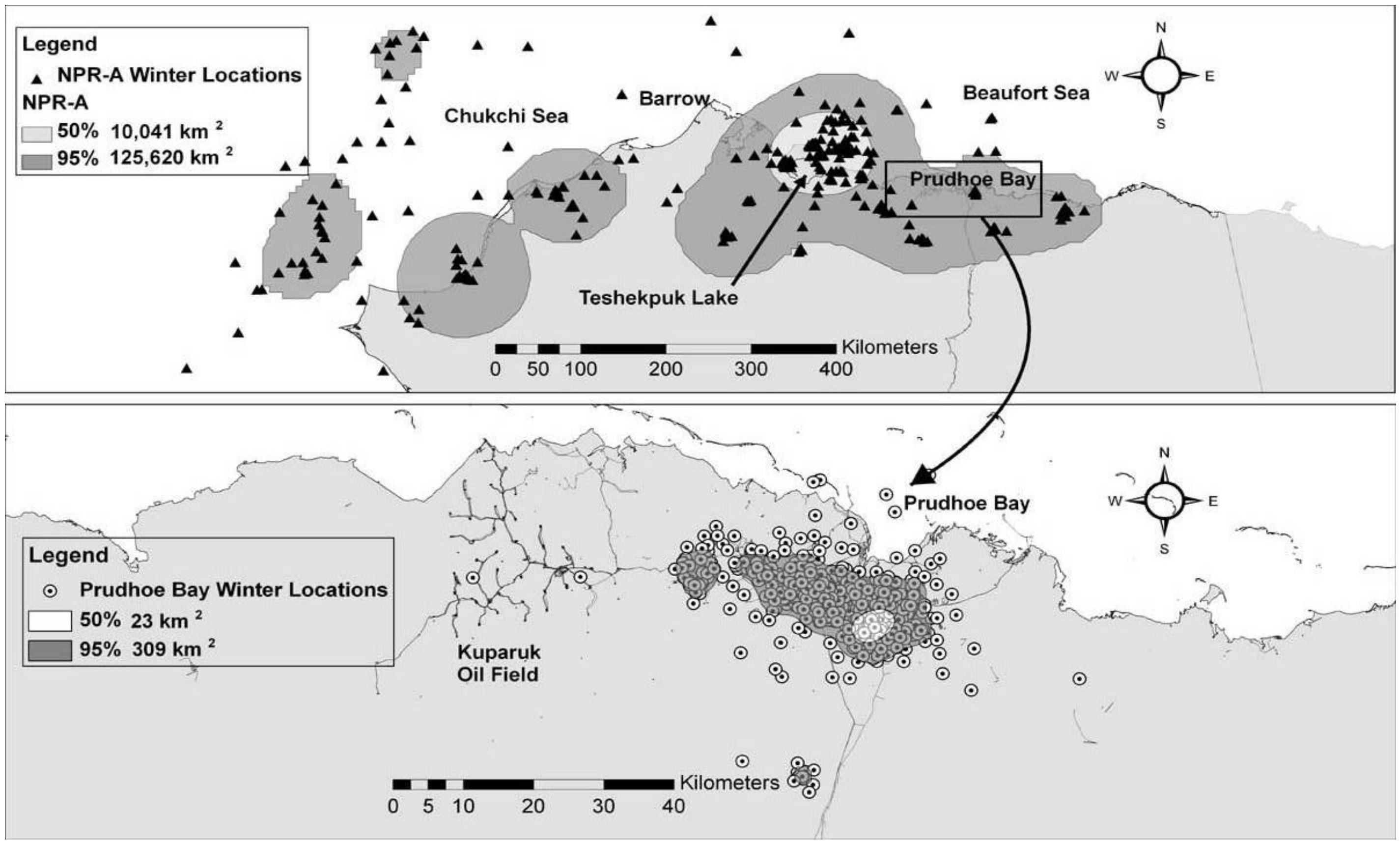

Figure 8. Probability contours of fixed kernel distributions (50%, 95%) of winter (October – May) locations of arctic foxes obtained from satellite collars between 2004 and 2007. Top pane shows locations and distributions of foxes collared in NPR-A (n = 14) and the lower pane shows locations and distributions of foxes collared in Prudhoe Bay (n = 20). Map projection is Alaska Albers Conic Equal-Area, N. American Datum 1927.

Table 1. Summary of arctic fox captures from NPR-A and Prudhoe Bay, Alaska. Juveniles were considered adults after 1 year of age. Number of days collar functional represents span of days collar was functional, not actual number of days the collar transmitted. Duty cycle length = 4 days. Distances traveled during duty cycles and from capture site are calculated as straight line distances. Winter includes the months of October through May.

Fox ID	Sex	Age	Date Collared	Mortality/Collar Off Date	# Days Collar Functional	# Winter Locations	Mean Dist./Duty Cycle Winter (SE) (km)	Max. Dist. From Capture Site (km)
				Prudhoe Bay				
53114	F	Juvenile	Aug. 28 2004	Oct. 10 2004	43	3	3.4 (0.3)	2.6
53125	F	Juvenile	Aug. 28 2004		279	45	4.6 (1.1)	27.1
		Adult		Nov. 22 2005	172	13	1.1 (0.1)	10.8
53097	F	Juvenile	Aug. 28 2004	Nov. 23 2004	87	6	2.7 (0.6)	5.7
53093	F	Juvenile	Aug. 29 2004		278	34	2.7 (0.3)	10.1
		Adult		Aug. 25 2006*	448	43	3.7 (0.6)	17.3
36440	F	Juvenile	Aug. 29 2004	Nov. 7 2004	70	9	3.5 (0.9)	8.3
36144	M	Juvenile	Aug. 29 2004	Mar. 7 2005	178	20	4.8 (0.6)	15.2
53107	M	Adult	Aug. 30 2004	Feb. 11 2005	165	34	11.1 (1.9)	27.5
53110	F	Adult	Sep. 1 2004	Dec. 29 2004	119	23	8.0 (1.4)	28.8
53092	M	Adult	Sep. 1 2004	Jul. 16 2006	683	108	3.2 (0.3)	21.5
53121	F	Adult	Sep. 1 2004	Jun. 26 2006	660	97	3.6 (0.3)	23.7
36442	M	Juvenile	Aug. 26 2005	Nov. 6 2005	72	10	6.0 (1.0)	7.5
53106	F	Juvenile	Aug. 26 2005	Oct. 21 2005	56	5	2.8 (1.1)	7.6
53109	M	Juvenile	Aug. 26 2005	Nov. 2 2005	68	9	2.9 (0.5)	4.6
53111	F	Juvenile	Aug. 26 2005	Nov. 26 2005	92	15	5.8 (1.2)	15.2
53102	M	Juvenile	Aug. 26 2005	Nov. 30 2005	96	13	3.1 (0.5)	11.0
53117	F	Juvenile	Aug. 27 2005	Nov. 2 2005	67	9	4.5 (1.2)	11.0
53101	M	Juvenile	Aug. 28 2005	Nov. 26 2005	90	15	5.4 (2.0)	32.6
53115	F	Juvenile	Aug. 29 2005	Nov. 6 2005	69	10	3.8 (0.7)	8.3
53116	M	Juvenile	Aug. 29 2005	Nov. 2 2005	65	9	4.2 (1.5)	10.1
53108	M	Adult	Aug. 26 2005	Jul. 3 2007**	676	102	5.3 (0.7)	47.0
				NPR-A				
53124	F	Adult	Sep. 7 2004	Jul. 29 2005	325	57	20.8 (5.6)	267.9
53119	M	Adult	Sep. 12 2004	Oct. 14 2004	32	4	0.9 (0.8)	3.7
53112	F	Juvenile	Sep. 7 2004	Oct. 18 2004	41	5	34.1 (13.6)	162.1

Table 1 Continued

53103	F	Juvenile	Aug. 18 2005	Sep. 27 2005	40	n/a	n/a	164.1
53100	M	Juvenile	Aug. 18 2005	Oct. 29 2005	72	8	25.9 (20.4)	244.8
53096	M	Juvenile	Aug. 19 2005	Nov. 14 2005	87	12	9.3 (3.6)	189.1
53118	M	Juvenile	Aug. 20 2005	Nov. 6 2005	78	10	24.3 (14.3)	219.7
53094	M	Juvenile	Aug. 20 2005	Feb. 22 2006*	186	36	30.7 (7.7)	641.4
53123	M	Juvenile	Aug. 21 2005	Dec. 16 2005	117	20	18.4 (7.2)	146.2
53122	M	Juvenile	Aug. 22 2005		284	59	20.5 (3.6)	209.1
		Adult		Jan. 8 2007	220	20	9.6 (2.8)	109.0
53113	F	Juvenile	Aug. 22 2005		280	55	46.1 (7.6)	782.4
		Adult		Aug. 28 2007*	456	58	12.9 (3.4)	577.1
53120	F	Juvenile	Aug. 22 2005	Sep. 7 2005	16	n/a	n/a	0.8
53099	M	Juvenile	Aug. 22 2005	Oct. 1 2005	40	n/a	n/a	5.3
53095	F	Juvenile	Aug. 24 2005	Nov. 20 2005	98	16	29.3 (10.1)	280.3
36145	F	Juvenile	Aug. 24 2005	Nov. 10 2005	78	11	10.9 (4.4)	102.1
36441	M	Juvenile	Aug. 24 2005	Nov. 6 2005	74	10	32.8 (11.7)	310.1
53104	F	Juvenile	Aug. 24 2005	Oct. 9 2005	46	3	6.5 (2.8)	32.0

* indicates that collar stopped functioning while animal was still alive, mortality date unknown
** indicates collar was removed upon recapture

CHAPTER 2

Sea-ice use by arctic foxes in northern Alaska[1]

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, 1096, and 2757 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 per 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

[1] Pamperin, N.J., Follmann,E. H. and Person, B.T. 2008. Sea-ice use by arctic foxes in northern Alaska. Prepared for Polar Biology.

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. Sdobnikov (1958) and Shibanoff (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. This suggests 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 this 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 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 this habitat is used, specific ice types used (first year ice vs. multi year pack ice), 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 in weight, making their deployment on arctic foxes possible (Follmann and Martin 2000), thus enabling a more complete understanding of their use of sea-ice.

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. To our knowledge, this is the first data set detailing individual arctic fox use of the sea-ice. 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 (Chapter 1).

Methods

We trapped foxes in the northeast section of the NPR-A near Teshekpuk Lake (70º 15’ N, 153º 32’ W) in northern Alaska (Figure 1) during August 2005. Trapping was done opportunistically in the field using baited box traps (Model 208, 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 (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. We aged foxes as either adult or juvenile according to tooth wear and coloration. Animals were fitted with satellite transmitters (Model A-3110, 190g, 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-hour period every 96 hours 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 (David Douglas, USGS) implemented in SAS (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, 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 male, 1 female) were captured and collared at Point Lonely, Alaska during August 2005 (Figure 1). Fox 53113 (female) spent 156 days on the sea-ice from November 26, 2005 until May 1, 2006 (Figure 2). Fox 53122 (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 (Figure 3). The third fox, 53094 (male), was on the sea-ice for at least 76 days from December 8, 2005 through February 22, 2006 (Figure 4). Three more messages were received from this 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 53113 and 53122 continued to function through the winter of 2006-2007, but the use of sea-ice was limited to near shore movements by fox 53113 during April and early May, 2007.

The foxes traveled extensively while on the sea-ice (Figure 1). Total distances traveled by each fox while on the sea-ice were 904 km (fox 53122), 2757 km (fox 53113), and 1096 km (fox 53094). Average distances traveled per day ranged from 7.5 km ± 1.5 (fox 53122) to 17.6 km ± 2.4 (fox 53113) with maximum travel rates of up to 61 km per day (fox 53094) (Table1). 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 (53113, 53094) were consistently located at substantial distances from the coastline, with mean distance from the coast of 128km ± 11.1 and 119km ± 11.8, respectively. Maximum distances from the coast were 86km, 246km and 214km for foxes 53122, 53113, and 53094, 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 53122, 53113, and 53094 outlived the other 11 foxes that remained on land, which had all died by mid-December, 2005. Mortality dates for foxes 53113 and 53094 are unknown due to collar or battery failure. However, fox 53094 survived at least until February 22, 2006 when its collar stopped functioning reliably and fox 53113 survived through at least September 21, 2007 when its collar stopped transmitting. The collar of fox 53122 started transmitting in mortality mode on January 8, 2007, 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 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). Normally these would not be accessible but in areas where ice movements cause ridging, overturned chunks of ice would expose these organisms at the surface making them potentially available to foxes.

While these three juvenile 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. 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 juvenile foxes were captured in close proximity to Pt. Lonely, and the possibility that they may have been from the same litter cannot be ruled out. The potential lack of independence between movements, if these animals were littermates, is likely negligible given that the two remaining foxes (53122 and 53113) ended up settling more than 450 km apart after traveling on the sea-ice (Figure 1). 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 areas. This is consistent with the ecology of arctic foxes in Alaska where juveniles become independent and disperse during the fall and early winter of their first year (Fine 1980).

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. Two extreme cases are possible. Foxes located on free moving ice floes may have been displaced entirely by the forces of wind and ocean currents rather than their own movements. In the second case, the foxes may travel against the primary trajectory of the sea-ice in the form of the “treadmill” as reported for polar bears in the Barents Sea by Mauritzen et al. (2003). 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 per day. Furthermore, since distances traveled are calculated from locations between the 4-day duty cycles as straight line distances, our calculations are likely a gross 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, unpublished data), indicating that such rates are obtainable by arctic foxes irrespective of the medium they travel on.

The distinctive westward movement of foxes 53113 and 53094 (Figures 2, 4) through early January 2006 is consistent with the general westward motion of pack ice in the Chukchi Sea (Norton and Gaylord 2004). This pattern suggests that the primary trajectory of the pack ice may have been responsible for directing the overall movements of these two foxes through mid-winter, but doesn’t necessarily account for the magnitude of the displacements for each fox. Since most of a fox’s time on the ice would be spent scavenging rather than hunting live prey, foxes would need to be actively moving in search of carcasses or other food in order to survive instead of being sedentary and passively moving with the ice.

The lack of distinct patterns in the movements of fox 53122 differs from the movements of foxes 53113 and 53094. Landfast ice typically extends farther from the coast of the Beaufort Sea than it does along the coast of the Chukchi Sea (Mahoney et al.

2007). Fox 53122 remained near the coast of the Beaufort Sea where landfast ice movement typically does not occur from wind and current forces and this may account for the lack of a distinct direction of movement by this animal. While the outward extent of landfast ice from the coast varies from year to year in the Beaufort Sea (Mahoney et al. 2007), it is possible that fox 53122 spent the majority of its time on landfast ice given its average distance from the coast (Table 1).

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. 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. Foxes may be able to respond to such conditions by traveling farther on land during the winter in order to find food, in response to regional fluctuations in small mammal abundance. However, such movements 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. Since similar movement data for adult arctic foxes (> 1 yr) is lacking, we cannot be certain that use of sea-ice is a strategy that the broader fox population employs. However, we believe that broader sampling in the future will reveal that adult foxes use sea-ice in a similar capacity to the juveniles discussed here. Our results show that foxes may 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. Future monitoring of fox movements will be important to our understanding of how a diminishing arctic ice cover will impact future populations. 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 needs to be studied further to fully understand the role that sea-ice plays in the ecology of the arctic fox.

Acknowledgements

This study was supported by the North Slope Borough Department of Wildlife Management with National Petroleum Reserve-Alaska Program funds available through the State of Alaska Department of Community, Commerce and Economic Development. N. Pamperin received additional support through a student grant from the Center for Global Change and Arctic System Research at the University of Alaska Fairbanks, the Institute of Arctic Biology summer research fellowship, Department of Biology and Wildlife teaching assistantship, and through the Dean Wilson Scholarship provided by the Alaska Trappers Association. We would like to thank J. Craig George of the North Slope Borough Department of Wildlife Management, Luther Leavitt of Barrow, Alaska, and Larry Larrivee of Pollux Aviation for their assistance in the field and logistical support. We thank Dr. Bill Streever of BP Exploration Alaska, Inc. for providing logistical support for our field work in Prudhoe Bay. We also appreciate the insightful comments of Falk Huettmann and Mark Lindberg who reviewed the original manuscript.

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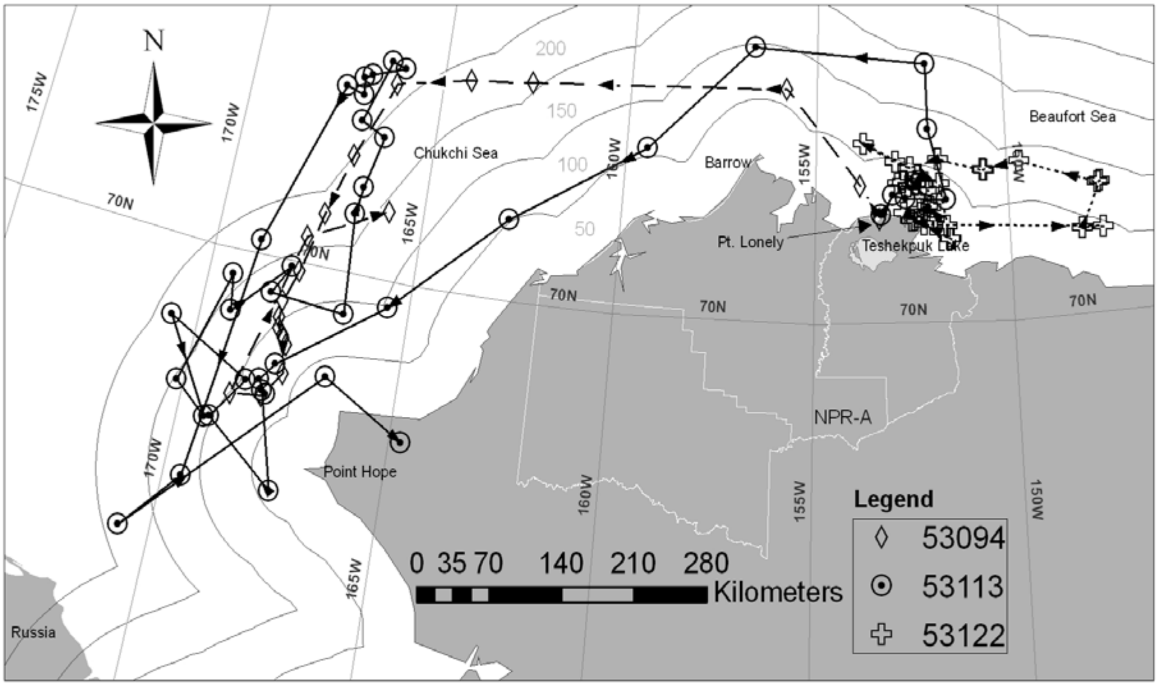

Figure 1. Movements of three satellite collared arctic fox during the winter of 2005-2006 off the northern coast of Alaska. Intervals between individual locations are equivalent to the collar duty cycle of four days. Contours outward from coast are measured in kilometers. Map projection is Alaska Albers Conic Equal-Area, North American Datum 1927.

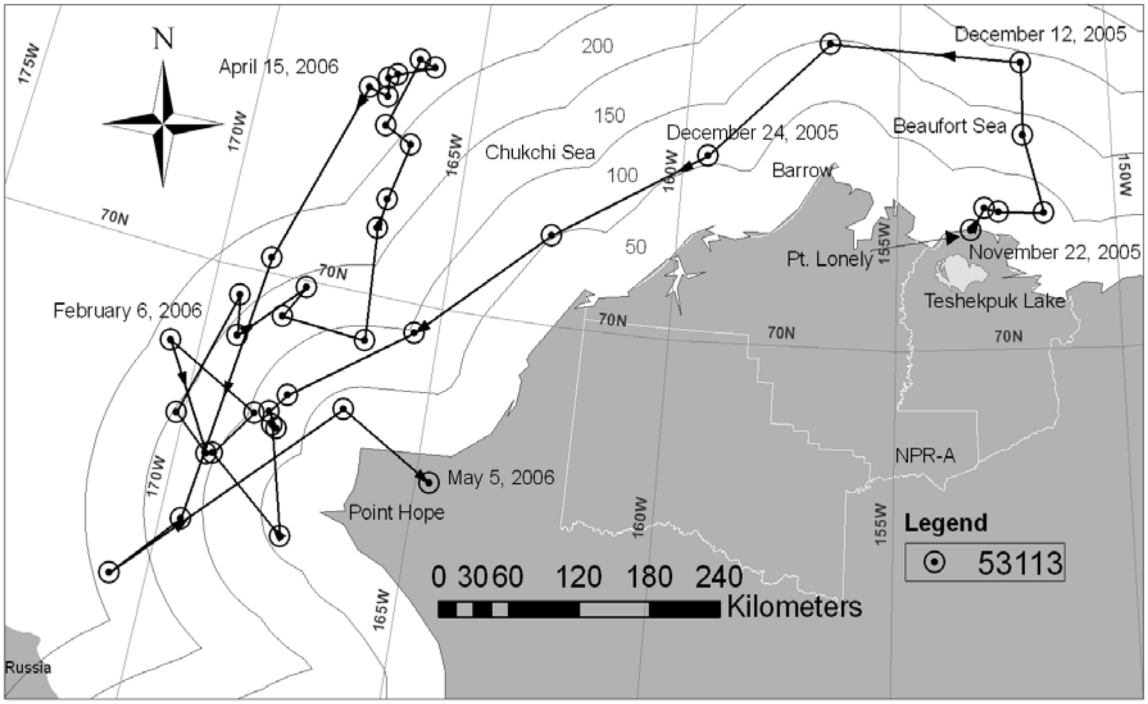

Figure 2. Individual movements of satellite collared arctic fox 53113 (juvenile female) during the winter of 2005-2006 off the coast of northern Alaska. Arrows show direction of movement and dates correspond to the nearest location. Contours outward from coast are measured in kilometers. Map projection is Alaska Albers Conic Equal-Area, North American Datum 1927.

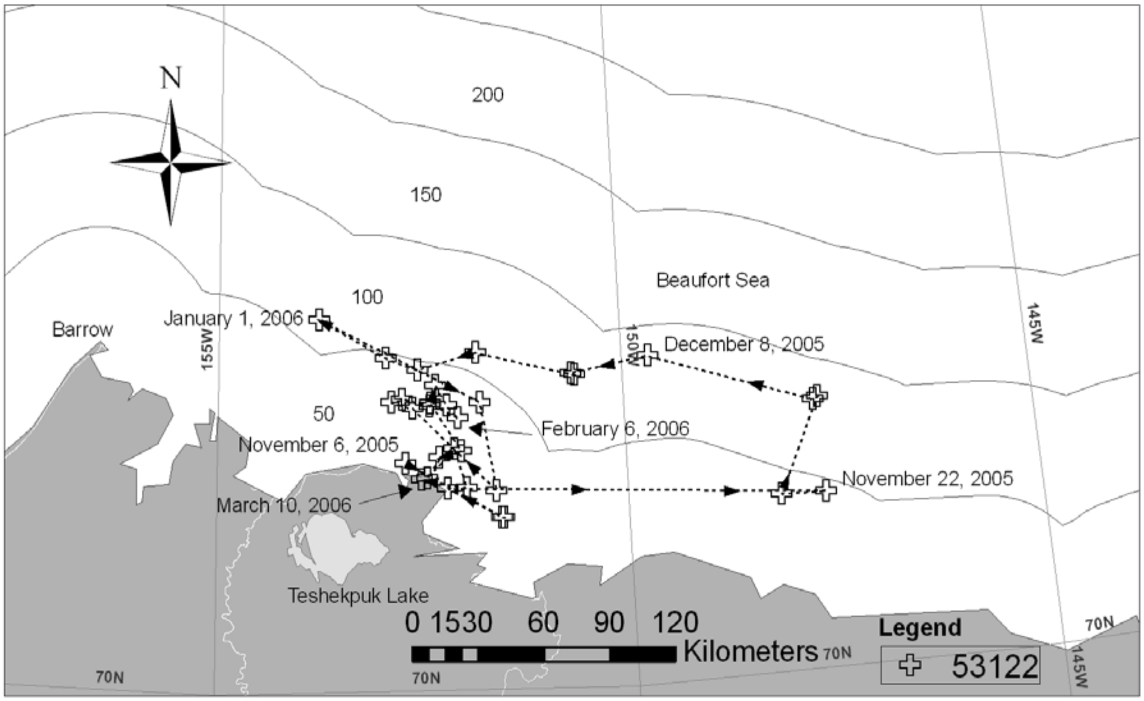

Figure 3. Individual movements of satellite collared arctic fox 53122 (juvenile male) during the winter of 2005-2006 off the coast of northern Alaska. Arrows show direction of movement and dates correspond to the nearest location. Contours outward from coast are measured in kilometers. Map projection is Alaska Albers Conic Equal-Area, North American Datum 1927.

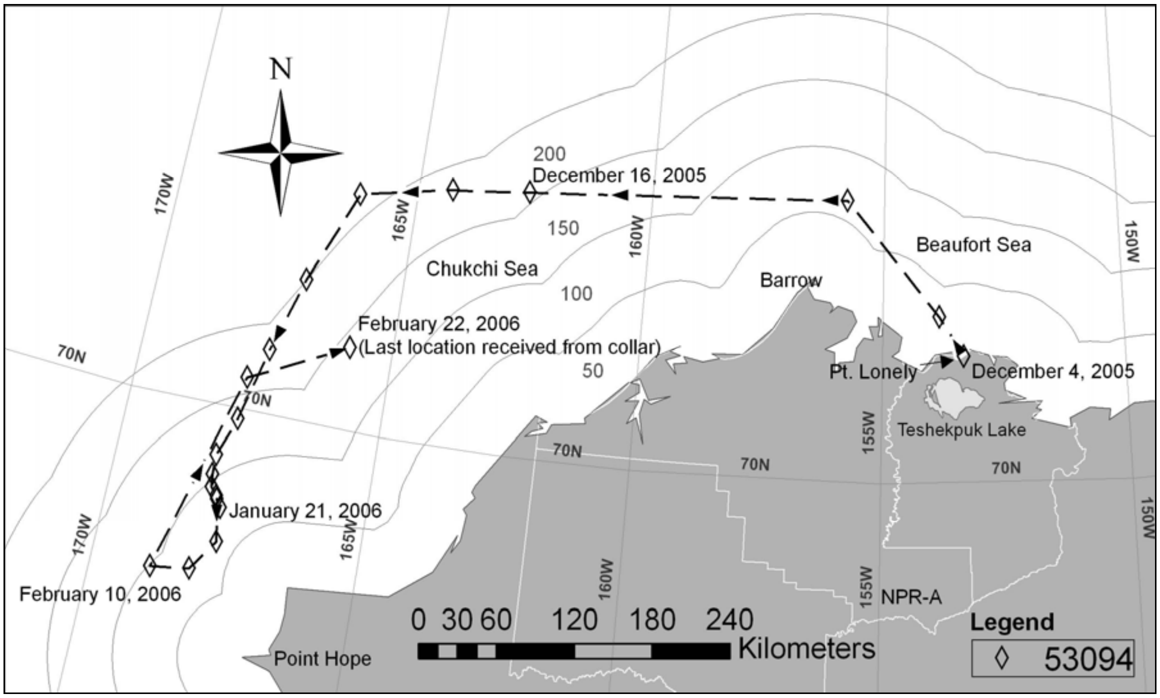

Figure 4. Individual movements of satellite collared arctic fox 53094 (juvenile male) during the winter of 2005-2006 off the coast of northern Alaska. Arrows show direction of movement and dates correspond to the nearest location. Contours outward from coast are measured in kilometers. Map projection 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.

					Distances Traveled				Distance from Coast		
Animal	Age	Sex	Date On/Off Ice	Total Days On Sea Ice	Total Distance Traveled	Avg. Dist. Duty Cycle^{-1} (±SE)	Avg. Dist Day^{-1} (±SE)	Max Rate Day^{-1}	Avg. Dist. From Coast (±SE)	Min.	Max.
53122[a]	Juvenile	Male	Nov. 6- March 6	120	904	30.1 (6.1)	7.5 (1.5)	43	36 (4.6)	0.4	86
53113[b]	Juvenile	Female	Nov. 26- May 1	156	2757	70.7 (9.5)	17.6 (2.4)	60	128 (11.1)	17.0	246
53094[b]	Juvenile	Male	Dec. 8- Feb 22*	76	1096	57.7 (12.6)	14.4 (3.2)	61	119 (11.8)	27.0	214

* collar/ battery failed, no additional locations were obtained after February 22, 2006

[a] wintered on Beaufort Sea, [b] wintered on Chukchi Sea

General Conclusions

Satellite telemetry data showed large variations in winter movements of arctic foxes from developed and non-developed areas in northern Alaska. Location data also documented the long distance movements of arctic foxes on land and on the sea-ice of the Beaufort and Chukchi seas.

We observed large differences in winter movements between foxes from NPR-A and the Prudhoe Bay oil field with differences most apparent in juvenile movements and in the overall spatial extent of fox movements from NPR-A. Foxes collared in NPR-A typically moved extensively during winter while foxes from the Prudhoe Bay area seldom left the oil field during winter. Arctic foxes undertake long distance movements during winter and are sensitive to the influence of permanent developments. Despite improved waste management practices within the oil fields, movement data suggest that anthropogenic food sources available at development sites still have the potential to influence winter movements of arctic foxes in northern Alaska.

Observations of arctic fox movements on the sea-ice improved our understanding of this habitat and the role it plays in the ecology of the arctic fox in northern Alaska. Although only a small proportion of the collared animals used the sea-ice extensively during winter, their survival through winter lends evidence that it may serve as an important habitat and refuge during years when terrestrial food sources may be scarce. Results showed that foxes may 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. While arctic foxes in northern Alaska are capable of living on land throughout the winter, reduced access to sea-ice in the future could be detrimental to arctic fox populations by limiting their access to marine food sources.

Satellite telemetry proved to be an effective method of collecting movement data on arctic foxes during winter. With this technology we were able to gather new and valuable information on movements of individual foxes, which greatly increased our understanding of their winter movements. Data presented on fox movements in this study will be valuable in assessing the potential impacts of future developments in northern Alaska and information gathered on the use of the sea-ice highlights the need for additional data on the use of this habitat by foxes. Integrated approaches using telemetry along with investigations of diet composition (e.g. stable isotopes) will greatly improve our understanding of arctic fox ecology in relation to changes in climate and continued resource development in northern Alaska.