THIRD ANNUAL REPORT

CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2007

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April 2008

Printed on recycled paper.

EXECUTIVE SUMMARY

- Recent discoveries of oil in the northeastern National Petroleum Reserve–Alaska (NPRA) led to a proposal by ConocoPhillips Alaska (CPAI)—the Alpine Satellite Development Program (ASDP)—to expand development from the Alpine facilities on the Colville River delta and into NPRA. The first ASDP facility to be constructed (winter 2004–2005) was the CD-4 drill site and access road. The North Slope Borough (NSB) development permit for CD-4 stipulated that a 10-year study of the effects of development on caribou distribution and movements be conducted within a 48-km (30-mi) radius of CD-4, which also encompasses CD-3 (constructed in winter 2004–2005) and the planned CD-5, CD-6, and CD-7 pads and associated infrastructure and activities proposed by CPAI.
- This report presents results from the third year of the ASDP caribou monitoring study, combining aerial-transect survey data with analysis of radio-telemetry and satellite remote-sensing data. Aerial strip-transect surveys of caribou distribution were conducted in 3 adjacent survey areas (NPRA, Colville River Delta, and Colville East) from May to October 2001–2007. The telemetry analyses used location data from VHF, satellite, and GPS radio-collars in the Teshekpuk Herd (TH) and Central Arctic Herd (CAH) collected by the Alaska Department of Fish and Game (ADFG), the Bureau of Land Management (BLM), the NSB Department of Wildlife Management, and the U.S. Geological Survey (USGS). VHF-collar data were collected during 1980–2005, satellite-collar data were collected during 1990–2007 for the TH and 1986–1990 and 2001–2005 for the CAH, and GPS-collar data were collected during 2004–2007 for the TH (including 23 new collars deployed specifically for this study in July 2006 and June 2007) and 2003–2006 for the CAH.
- The Normalized Difference Vegetation Index (NDVI), derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery from 2002–2007, was used to estimate relative vegetative biomass in the study area and surrounding region during calving (1–10 June; NDVI_calving), peak lactation (21 June; NDVI_621), and during the peak of the growing season (late July 2005–2007; NDVI_peak). The average daily rate of change in NDVI values between calving and peak lactation was estimated (NDVI_rate). In 2007, we also calculated NDVI in late fall. The late-fall NDVI values were used as the baseline NDVI level of standing dead vegetation for individual pixels, thereby improving estimates for NDVI_calving and NDVI_rate over the approach used in 2005 and 2006. Snow cover (subpixel-scale snow fraction) in spring 2005–2007 also was calculated for the ASDP study area from MODIS satellite imagery.
- Caribou were present in the 3 aerial-survey areas during all seasons in which surveys were conducted (2001–2007), although distribution and abundance fluctuated substantially. West of the Colville River, the highest densities of caribou typically occurred in fall; large groups of caribou were present occasionally during mosquito and oestrid-fly seasons, but the occurrence of caribou was highly variable among seasons. East of the Colville River, the highest densities occurred during the calving and postcalving seasons. The mean proportion of collared TH caribou within the ASDP study area during each month ranged between 8% and 30% for satellite collars during 1990–2007 and 0 and 58% for GPS collars during 2004–2007. The mean proportion of collared CAH caribou within the study area during each month varied between 13 and 62% for satellite collars during 1986–1990 and 2001–2005 and between 0 and 53% for GPS collars during 2003–2006.
- Analysis of VHF, satellite, and GPS telemetry data demonstrated clearly that the Colville River delta and ASDP study area are at the interface of the annual ranges of the TH and CAH. Although caribou from both herds occur on the delta occasionally, large movements across the delta are unusual. Unless CAH movement patterns change in the future, the proposed ASDP pipeline/road corridor

extending from Alpine CD-2 into NPRA will have little effect on that herd. TH caribou use the NPRA survey area year-round, however, so detailed analyses focused primarily on the NPRA survey area, in which the proposed road alignment would be located.

- Spatial analysis of caribou distribution among different geographic sections of the NPRA survey area during 2002–2007 showed that the section near the Beaufort Sea coast contained significantly more caribou groups during the mosquito season than would be expected if caribou distribution were uniform, consistent with use of coastal areas as mosquito-relief habitat. Riparian areas along Fish and Judy Creeks contained significantly more caribou groups than would be expected if caribou distribution were uniform during the postcalving season, oestrid fly season, and late summer. The southeastern section of the NPRA survey area, in which the proposed pipeline/road corridor would be constructed, contained significantly fewer groups in all seasons except winter.
- For the years 2002–2007 combined, caribou in the NPRA survey area used flooded tundra significantly less than expected (based on availability) during calving and postcalving. Riverine habitats were used more than expected (based on availability) from postcalving through fall migration, possibly for forage availability and oestrid-fly relief.
- High-density calving occurred east of the Colville River for the CAH (in the southeastern part of the Colville East survey area) and around Teshekpuk Lake for the TH (west of the NPRA survey area). Although some calving occurs in the western half of the NPRA survey area, it is not an area of concentrated calving for the TH. Unusually clear weather in early June allowed us to calculate NDVI and snow cover on multiple days throughout the period of rapid snowmelt and caribou calving. During 2007, caribou in the NPRA survey area selected areas with high estimated values of vegetative biomass during calving, and fall migration. Areas with high estimated levels of vegetative biomass were used less than expected during late summer. Area with high rates of increase in vegetative biomass were only selected during calving, suggesting that caribou were selecting areas of new vegetative growth at that time.
- Caribou use of the NPRA survey area varies widely by season. These differences can be described in part by snow cover, vegetative biomass, habitat distribution, and distance to the coast. The number of TH caribou in the area tends to increase in late summer and fall and fluctuates during the insect season as large groups move about in response to weather-mediated levels of insect activity. Because the NPRA survey area is on the eastern edge of the TH range, a natural west-to-east gradient of decreasing density occurs during much of the year. The southeastern section of the NPRA survey area, in which the proposed ASDP road alignment would be located, has lower caribou densities than do other sections of the survey area. There was little evidence for selection or avoidance of specific distance zones within 6 km of the proposed ASDP pipeline/road corridor. Fewer groups than would be expected if caribou were uniformly distributed occurred around the corridor during the oestrid-fly season, probably because of increased use of riparian habitats along Fish and Judy creeks by fly-harassed caribou. Radio-collared TH caribou have occasionally crossed the proposed ASDP road alignment in past years, primarily during fall migration, but the data collected thus far indicate that the proposed corridor is in an area of low-density use by caribou.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ACKNOWLEDGMENTS

This study was funded by ConocoPhillips Alaska, Inc. (CPAI) and was administered by Caryn Rea, Senior Staff Biologist and Environmental Studies Coordinator for CPAI. CPAI field environmental personnel—most notably Justin Blank and Mary Mae Aschoff—provided assistance and support.

Alaska Department of Fish and Game (ADFG) biologists in Barrow and Fairbanks played crucial roles in this study by capturing caribou for deployment of radio-collars and by providing telemetry data under a cooperative agreement among ADFG, CPAI, and ABR. We thank Geoff Carroll, Lincoln Parrett, Mark McNay, Steve Arthur, Beth Lenart, Patty Del Vecchio, and Ernest Nageak of ADFG for their professional cooperation and assistance. Brian Person of the North Slope Borough (NSB) Department of Wildlife Management provided valuable information and advice on GPS- and satellite-telemetry databases.

Pilots Sandy Hamilton, Bob Mumford, Robert Wing, and Bob Eubank (Arctic Air Alaska) provided safe and efficient operation of survey airplanes under flying conditions that often were less than optimal. Rick Swisher (Quicksilver Air) and Marty Webb (Tundra Air) piloted the aircraft used in the collaring operation. Seth McMillan and Jim Lawler of the National Park Service retrieved and returned a radio-collar from Gates of the Arctic National Park. Mike Donaldson of Far North Aquatics provided valuable technical assistance for the remote-sensing analyses.

The hard work and dedication of ABR staff were key to the success of this study. Field assistance was provided by Torsten Bentzen, Mathias Eriksson, Jeremy Maguire, Tim Obritschkewitsch, Pam Seiser, Julie Parrett, and Ann Wildman, and support during data analysis and report preparation was provided by Dorte Dissing, Allison Zusi–Cobb, Will Lentz, Pam Odom, and Tony LaCortiglia. The draft report was improved through reviews by Robert Burgess of ABR, Caryn Rea and Sally Rothwell of CPAI, and Brian Person of the North Slope Borough Department of Wildlife Management.

INTRODUCTION

BACKGROUND

This study was conducted on the Arctic Coastal Plain of northern Alaska and was centered on the Colville River delta, an area that is used at various times of the year by 2 neighboring herds of barren-ground caribou (*Rangifer tarandus*)—the Teshekpuk Herd (TH) and the Central Arctic Herd (CAH). The TH generally ranges to the west and the CAH to the east of the Colville River delta (Lawhead et al. 2007).

The TH tends to remain on the coastal plain year-round. The area of most concentrated calving is located consistently around Teshekpuk Lake and the primary area of insect-relief habitat in midsummer is the swath of land between Teshekpuk Lake and the Beaufort Sea coast (Prichard and Murphy 2004, Carroll et al. 2005, Person et al. 2007). Most TH caribou winter on the coastal plain, although some caribou occasionally overwinter south of the Brooks Range with the Western Arctic Herd (WAH) (Philo et al. 1993, Kelleyhouse 2001, Carroll 2003, Prichard and Murphy 2004, Carroll et al. 2005, Person et al. 2007). In recent years, a substantial portion of the TH has wintered in areas outside the previous range of the herd, both far east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 (Carroll et al. 2004) and southeast in the winter range of the CAH since 2004–2005 (G. Carroll and L. Parrett, ADFG, pers. comm.; Lawhead et al. 2007, this study).

Concentrated calving activity by the CAH tends to occur in 2 areas of the coastal plain, one located south and southwest of the Kuparuk oilfield and the other east of the Sagavanirktok River and south of Bullen Point, away from most oilfield development (Lawhead 1988, Wolfe 2000, Arthur and Del Vecchio 2007, Lawhead and Prichard 2007). The CAH typically moves to the Beaufort Sea coast during periods of mosquito harassment (White et al. 1975, Dau 1986, Lawhead 1988). In recent years the majority of the CAH has wintered south of the Brooks Range, generally east of the Trans-Alaska Pipeline (Arthur and Del Vecchio 2007).

This caribou monitoring study for the Alpine Satellite Development Program (ASDP) builds on research funded by ConocoPhillips Alaska, Inc. (CPAI) and its predecessors (Phillips Alaska, Inc., and ARCO Alaska, Inc.) and conducted on the Colville River delta and adjacent coastal plain to the east of the delta (Alpine transportation corridor) since 1992 and in the northeastern portion of the National Petroleum Reserve–Alaska (NPRA) since 1999 (see Johnson et al. 2008 for most current listing of CPAI wildlife studies on the Colville River delta). In addition to wildlife surveys, an ecological land survey (ELS) was conducted on the Colville River delta (Jorgenson et al. 1997) and in northeastern NPRA (Jorgenson et al. 2003, 2004) to describe and map features of the landscape. The ELS described terrain units (surficial geology, geomorphology), surface forms (primarily ice-related features), and vegetation, which were used to develop a map of wildlife habitats. The Colville River delta and NPRA studies augmented long-term wildlife studies supported by CPAI and its predecessors since the 1980s in the region of the North Slope oilfields on the central Arctic Coastal Plain. Caribou surveys have been an important part of this research.

Since 1990, contemporaneous studies of caribou in the region west of the Colville River by the Alaska Department of Fish and Game (ADFG), North Slope Borough (NSB), and Bureau of Land Management (BLM), relied primarily on 3 types of radio telemetry (very-high frequency [VHF], satellite, and, since 2004, Global Positioning System [GPS] transmitters) (Philo et al. 1993, Carroll 2003, Prichard and Murphy 2004, Carroll et al. 2005, Lawhead et al. 2007). Consultants working for BP Exploration (Alaska) Inc. also conducted aerial transect surveys over much of the TH calving grounds during 1998–2001 (Noel 1999, 2000; Jensen and Noel 2002; Noel and George 2003).

East of the Colville River, ADFG has conducted annual studies of the CAH since the late 1970s using a combination of VHF, satellite, and GPS telemetry, as well as periodic transect surveys (Cameron et al. 1995, Lenart 2003, Arthur and Del Vecchio 2007). Other oil-company consultants conducted calving surveys of the CAH in the Milne Point oilfield and part of the Kuparuk oilfield in 1991, 1994, and 1996–2001 (Noel et al. 2004).

The current period of oil and gas leasing and exploration in NPRA closely followed the issuance of the Integrated Activity Plan and Environmental Impact Statement (IAP/EIS) for the Northeast NPRA Planning Area (BLM and MMS 1998) and the Record of Decision (ROD) in 1998. Discoveries of oil-bearing geologic formations since the mid-1990s led to strong industry interest in the northeastern portion of the NPRA and a proposal by CPAI—known as the Alpine Satellite Development Plan (BLM 2004)—to expand the Alpine development infrastructure on the Colville River delta and extend westward into NPRA.

The CD-4 drill site and access road on the inner Colville River delta were the first of the proposed ASDP facilities to be built, beginning in winter 2004–2005, followed closely that winter by the CD-3 pad and airstrip on the outer delta. The NSB issued development permit NSB04-117 for the CD-4 project on 30 September 2004, stipulating that a 10-year study of the effects of development on caribou be conducted by a third-party contractor hired by CPAI and approved by the North Slope Borough Department of Wildlife Management (ABR, Inc., subsequently was hired). The study area was specified as the area within a 48-km (30-mile) radius around CD-4 and the study design was to include all other proposed satellite drill sites and infrastructure planned for construction within that 10-year time-frame. Therefore, the scope of this monitoring study also includes the new CD-3 pad constructed in winter 2004–2005, the planned CD-5, CD-6, and CD-7 pads, and all associated infrastructure and activities proposed by CPAI and evaluated in the ASDP EIS (BLM 2004).

PROGRAM GOALS AND STUDY OBJECTIVES

The goal of the 10-year study was specified by the CD-4 permit stipulation: "The purpose of the study will be to evaluate the short- and long-term impacts of CD-4 and other CPAI satellite developments on the movements and distribution of caribou." The study is intended to be cooperative and collaborative in nature and communication of results with NSB stakeholders is a key component: "The study design will be reviewed by the NSB Department of Wildlife Management for review and approval. Additionally, a draft annual report shall be submitted to the North Slope Borough, City of Nuiqsut, Native Village of Nuiqsut, and Kuukpik Corporation for review and comments."

To begin implementing the permit stipulation, representatives of CPAI and ABR met with NSB staff in Barrow on 2 December 2004. The study options discussed at that meeting were developed into a preliminary study design and scope of work that were circulated in early February 2005 for further review. The revised study design and scope of work were approved in late March 2005 and were amended in early July 2005 to accommodate telemetry surveys by ADFG, which were added under the terms of a cooperative agreement among ADFG, CPAI, and ABR that addressed sharing of telemetry data for use in the ASDP caribou monitoring study. Results of the first year of study (Lawhead et al. 2006) were presented to the NSB Department of Wildlife Management on 9 March 2006 and to the village of Nuiqsut on 1 August 2006. Results of the second year of study (Lawhead et al. 2007) were presented to the NSB Department of Wildlife Management on 5 April 2007 and to the village of Nuiqsut on 1 May 2007.

This study addresses specific questions about the potential impacts of petroleum development on caribou in the study area, with the intent of drawing on both scientific knowledge and local/traditional knowledge. The accumulated body of scientific knowledge on the TH and CAH provides a starting point and framework for structuring the study to address the issues identified since North Slope oil development began more than 35 years ago. The extensive knowledge of local residents has been, and will continue to be, crucial for formulating research questions and ensuring that appropriate study methods are used. The combination of observations from both of these knowledge sources regarding development effects on CAH caribou can be grouped into 3 general issues (Cameron 1983, Shideler 1986, Murphy and Lawhead 2000, NRC 2003):

- Avoidance of areas of human activities by maternal caribou with young calves during and immediately following the calving period;

- Interference with caribou movements (delays or deflections), mainly during the summer insect season and seasonal migrations, but also including crossings by caribou (and subsistence users) beneath elevated pipelines in winter; and
- Altered availability of caribou for subsistence harvest at the times and places expected, which may vary over time.

In addition, other issues are expected to arise as development expands westward onto the winter range of TH caribou in NPRA, such as the response of caribou to seismic exploration and construction activities during the winter months.

The CD-4 permit stipulation recognizes impacts as falling into 2 broad categories: those affecting caribou movements and those affecting caribou distribution. Clearly, these categories are linked and not mutually exclusive, but the applicability of study methods differs somewhat between the 2. Information on the potential effects of development on caribou distribution can be collected using a variety of methods, including aerial transect surveys, radio telemetry, and observations by local subsistence users. Information about the potential effects on caribou movements, however, cannot be addressed adequately without employing methods such as radio telemetry that allow tracking of individually identifiable animals.

Several broad study tasks were identified in the scope of work:

1. Evaluate the seasonal distribution and movements of caribou in the study area in relation to existing and proposed infrastructure and activities in the study area, using a combination of historical and current data sets from aerial transect and telemetry surveys. Specific questions included the following:

   a) Which herds use the study area and the vicinity of the proposed pipeline/road corridor that will interconnect the ASDP facilities?

   b) Do the patterns of seasonal use differ between the 2 herds?

   c) How often do caribou cross the existing CD-4 pipeline/road corridor and the proposed ASDP pipeline/road corridor in NPRA, and does this differ by herd?

2. Characterize important habitat conditions, such as snow cover, spatial pattern and timing of snowmelt, seasonal flooding (if possible), and estimated biomass of new vegetative growth in the study area, by applying remote-sensing techniques, for comparison with caribou distribution.

3. Evaluate forage availability (above-ground vegetative biomass) and indices of habitat use by caribou in relation to proposed infrastructure, to allow temporal comparisons among years (before and after construction) and spatial comparisons by distance within years. Specific questions included the following:

   a) Does plant biomass and composition vary by habitat type and distance to the proposed road, and how well does remote sensing describe available biomass?

   b) Can caribou distribution be explained in terms of broad geographic areas, habitat availability, snow cover, or plant biomass?

   c) What are the existing patterns of caribou distribution and density around the proposed road corridor prior to construction?

4. Evaluate the feasibility of remote-sensing techniques to detect and map caribou trails for use in delineating movement routes and zones, both before and after construction.

Field sampling of plant biomass (Task 3) was scheduled to occur 4 times during the 10-year study; the first year of sampling was 2005 and the second year is planned for 2008. Task 4 was evaluated in 2005 (Lawhead et al. 2006) but subsequently was dropped from the study, with concurrence by the NSB Department of Wildlife Management, because the resolution of the available imagery was not high enough to accomplish the objective reliably.

STUDY AREA

The general study area was the central Arctic Coastal Plain of northern Alaska (Figure 1, top). The climate in the region is arctic maritime (Walker and Morgan 1964). Winter lasts ~8 months and is cold and windy. The summer thaw period lasts about 90 days (June–August) and the mean summer air temperature is 5° C (Kuparuk oilfield records: National Oceanic and Atmospheric Administration, unpublished data). Monthly mean temperatures on the Colville River delta range from about –10° C in May to 15° C in July and August (North 1986), with a strong regional gradient of summer temperatures increasing with distance inland from the coast (Brown et al. 1975). Mean summer precipitation is <8 cm, most of which falls as rain in August. The soils are underlain by permafrost and the temperature of the active layer of thawed soil above permafrost ranges from 0° to 10° C during the growing season. Spring is brief, lasting ~3 weeks from late May to mid-June, and is characterized by the flooding and break-up of rivers and smaller tundra streams. In late May, water from melting snow flows both over and under the ice on the Colville River, resulting in flooding on the Colville River delta that peaks during late May or the first week of June (Walker 1983; Baker Engineering & Energy annual reports to CPAI). Break-up of the river ice usually occurs when floodwaters are at maximal levels. Water levels subsequently decrease throughout the summer, with the lowest levels occurring in late summer and fall, just before freeze-up (Walker 1983; Baker Engineering & Energy annual reports to CPAI). Summer weather is characterized by low precipitation, overcast skies, fog, and persistent, predominantly northeast winds. The less common westerly winds often bring storms that are accompanied by high wind-driven tides and rain (Walker and Morgan 1964). Summer fog is more common at the coast and on the delta than farther inland.

The specific study area was defined by the NSB permit as the area within a 48-km (30-mi) radius around the CD-4 drill site (Figure 1, bottom). Aerial surveys were conducted in 3 survey areas, most of which were encompassed by the 48-km radius: Colville East (~1700 km²), Colville River Delta (494 km²), and NPRA (originally 988 km² in 2001, then expanded to 1310 km² in 2002 and to 1720 km² in 2005). The Colville East survey area includes the western and southwestern margins of the Kuparuk oilfield. The Colville River Delta survey area encompasses the original Alpine Development Project facilities CD-1 and CD-2, constructed in 1998–2001, and the newer ASDP facilities CD-3 (previously called Fiord or CD-North) and CD-4 (previously called Nanuq or CD-South), for which construction began in winter 2004–2005 and continued in 2005–2006. The CD-3 development is a roadless drill site, accessible by ice road in winter and by aircraft in summer, that is connected to CD-1 by an elevated pipeline. A road and adjacent elevated pipeline connects the CD-4 drill site to CD-1. The NPRA survey area encompasses 3 more proposed drill sites—CD-5 (also called Alpine West), CD-6 (also called Lookout), and CD-7 (also called Spark)—and a potential gravel mine site (called Clover) that are planned for NPRA (BLM 2004). A new road is proposed by CPAI to connect these sites to the Alpine project facilities at CD-2, which would require a bridge across the Nigliq (Nechelik) Channel of the Colville River.

METHODS

To evaluate the distribution and movements of TH and CAH caribou in the study area, we conducted aerial transect surveys in 2007, adding to the transect database for the NPRA survey area compiled since 2001, and analyzed several telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS) and from GPS collars deployed specifically for this study in 2006 and 2007. The aerial surveys provided broad information on the seasonal distribution and density of caribou within the study area. The satellite and GPS collars provided detailed location and movement data for a small number of known individuals throughout the year. The radio-telemetry data also provided valuable insight into herd identity, which was not available from the aerial survey data. We analyzed caribou distribution and density in relation to an existing habitat map and to estimated plant biomass and snow-cover values estimated from satellite imagery.

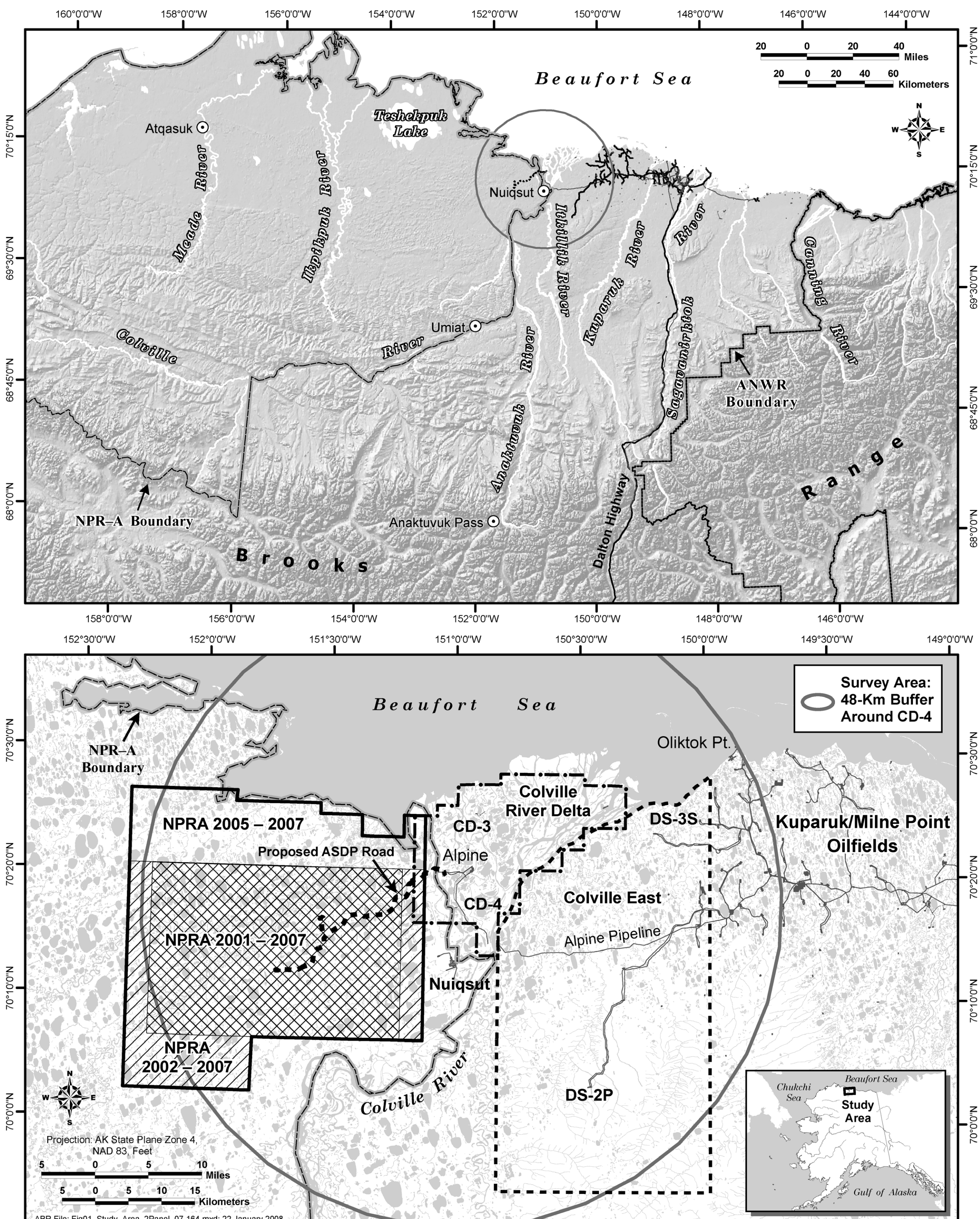


Figure 1. General location of the ASDP caribou monitoring study area (48-km [30-mi] radius around Drill Site CD-4) on the central North Slope of Alaska (top) and detailed view of study area showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2007 (bottom).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Surveys of the NPRA, Colville River Delta, and Colville East survey areas (Figure 1, bottom) were conducted from April or May to October during 2001–2007 by 2 observers looking out opposite sides of a Cessna 206 airplane (Burgess et al. 2002, 2003; Johnson et al. 2004, 2005; Lawhead et al. 2006, 2007; this study). The NPRA survey area was expanded in 2002 and again in 2005. Additional surveys of the Colville East area were conducted during the calving season in 2001–2007 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008). A third observer was present on some surveys to record data. The pilot navigated the airplane on transect lines using a GPS receiver and maintained an altitude of ~150 m (500 ft) agl or ~90 m (300 ft) agl using a radar altimeter. The lower altitude was flown to increase detection of caribou in areas of patchy snow cover during the calving season or occasionally in other seasons when low cloud cover precluded flying at the higher altitude.

Transect lines were spaced at intervals of 3.2 km (2 mi) following section lines on USGS topographic maps (scale 1:63,360) except during the calving season in some areas and years (Colville East in all years and NPRA in 2001), when 1.6-km (1-mi) spacing was used. Observers counted caribou within an 800-m-wide strip on each side of the transect centerline when flying at 150 m agl or a 400-m-wide strip when flying at 90 m agl, thus sampling ~50% of the survey area on each survey. Therefore, the number of caribou observed was doubled to obtain the total estimated number of caribou in the survey area. The strip width was delimited visually for the observers by placing tape markers on the struts and windows of the aircraft, as recommended by Pennycuick and Western (1972).

When caribou were observed within the transect strip, the perpendicular location on the transect centerline was recorded using a GPS receiver, the number of adults (including yearlings) and calves were recorded, and the perpendicular distance from the transect centerline was estimated in 100-m or 200-m intervals, depending on the strip width. For plotting on maps, the midpoint of the distance interval was used (e.g., 300 m for the 200–400-m interval). Thus, the maximal mapping error was estimated to be ~100 m. We calculated confidence intervals for estimates of total caribou and calves with a standard-error formula modified from Gasaway et al. (1986), using transects as the sample units.

RADIO TELEMETRY

VHF Collars

Location data were provided by ADFG for all VHF collars in the CAH and TH during the years 1980–2005. The number of active collars varied between herds (Table 1). Those locations ranged over much of northern Alaska, but data on the specific areas covered on each radio-tracking flight were not available, so it was not possible to identify dates on which the ASDP study area was surveyed. CPAI contracted ADFG to conduct radio-tracking of VHF-collared caribou during summer 2005 in the study area and surrounding area (Lawhead et al. 2006). Radio-collared caribou were tracked from fixed-wing aircraft using strut-mounted antennas and a scanning radio receiver. Although VHF telemetry does not provide movement data that are as detailed as those from satellite or GPS telemetry, this method provided data on group size and behavior. On some surveys, however, visual confirmation was impossible because the aircraft was forced to remain above the cloud cover, so locational accuracy was much lower on those surveys. The sex, age, and reproductive status of collared animals were not available for this analysis, but most were adult females (Cameron et al. 1995, Arthur and Del Vecchio 2007). Location error was estimated to be 0.5–1 km (S. Arthur, ADFG, pers. comm.), although the error appeared to be greater for some locations.

Satellite Collars

Satellite-collar data were obtained from ADFG, NSB, and USGS for TH animals during the period July 1990–August 2007 (Prichard and Murphy 2004, Lawhead et al. 2006, 2007, this study) and for CAH caribou during the periods October 1986–July 1990 and July 2001–September 2005 (Cameron et al. 1989, Fancy et al. 1992, Lawhead et al. 2006) (Table 1). In the TH sample, 102 collared caribou (81 females, 21 males)

Table 1. Characteristics of the VHF, satellite, and GPS telemetry samples from the Teshekpuk and Central Arctic caribou herds analyzed for the ASDP caribou study.

Caribou Herd and Telemetry Sample	Years	Number of Females	Number of Males	Total Number
Teshekpuk Herd				
VHF collars [a]	1980–2005	n/a	n/a	212
Satellite collars	1990–2007	81	21	102
GPS collars	2004–2007	33	0	33
Central Arctic Herd				
VHF collars [a]	1980–2005	n/a	n/a	412
Satellite collars, early	1986–1990	16	1	17
Satellite collars, recent	2001–2005	14	3	17
GPS collars [b]	2003–2006	45	0	45

[a] n/a = not available, but most collared animals were females.
[b] Number of different collared caribou within 48 km (30 mi) of CD-4 at least once.

transmitted signals for a mean duration of 526 days. In the CAH, the 1986–1990 sample included 17 caribou (16 females, 1 male) and the 2001–2005 sample included 17 caribou (14 females, 3 males), transmitting for a mean duration of 546 days. A few caribou moved between herds after collaring (4 TH animals went to the CAH and 5 TH animals went to the WAH). A caribou was assumed to have switched herds if it was in the calving area of another herd during a subsequent calving season.

Data from satellite transmitters were received by polar-orbiting satellites and transmitted through Command and Acquisition Stations to data-processing centers operated by Service ARGOS (Landover, Maryland). TH collar locations were transferred monthly to the NSB for data archiving. In 1990–1991, the TH satellite transmitters were programmed to transmit 6 h/day for a month after deployment, then 6 h/2 days for 11 months. During 1991–2002, most collars were programmed to transmit every other day throughout the year. After 2002, many collars were programmed to transmit once every 6 days in winter and every other day during summer. Most of the TH collars deployed in 2000 malfunctioned and transmitted data only sporadically. The CAH satellite collars deployed during 1986–1990 were programmed to operate 6 h/day or 6 h/2 days, providing 3–4 locations per day for most collars with a mean location error of 0.48–0.76 km (Fancy et al. 1992).

Although satellite-telemetry locations are considered accurate to within 0.5–1 km of the true locations (Service Argos 1988), the data also require screening to remove spurious locations. Using the method of Prichard and Murphy (2004), data were screened to remove duplicate locations, locations obtained before and after collaring or after mortality occurred, and locations for which the Argos-designated location-quality score (NQ) had a score of zero or “B”, indicating unreliability (Service Argos 1988). NQ scores of “A” tend to be more accurate than scores of zero (Hays et al. 2001, Vincent et al. 2002), so they were retained. Locations were removed that obviously were inaccurate because they were offshore or far from other locations. We applied a distance–rate–angle (DRA) filter to remove locations that appeared to be incorrect based on the distance and rate of travel between subsequent points and the angle formed by 3 consecutive points. Any 3 locations with an intervening angle of <20 degrees and both “legs” with speeds greater than 10 km/h were assumed to be inaccurate and were removed, unless the distance of either leg was less than 1 km (Prichard and Murphy 2004). If the distance of any leg was <1 km, then the location was not removed because it was close to a previous or subsequent location and therefore more likely to be accurate. We removed any locations that clearly were inaccurate based on previous and subsequent locations.

In analysis of animal movements, autocorrelation of locations that are collected close together in time may introduce bias (Schoener 1981, Swihart and Slade 1985, Solow 1989). Due to the highly directional movements of caribou during much of the year, movement data often do not meet the requirement of statistical independence for home-range analysis without removal of large numbers of data points (McNay et al. 1994). If too many data points are removed, however, biologically important information can be lost (Reynolds and Laundre 1990, McNay et al. 1994). To achieve operational independence of data points, the time between successive samples should approximate the time necessary to travel anywhere else in a seasonal range (Lair 1987, McNay et al. 1994). In addition, systematic sampling of locations over a given time period can remove bias due to dependent data (White and Garrott 1990).

For the TH and recent CAH data, therefore, we selected one location during each duty cycle, defined as a period of transmission of location data, which typically was 6 h/2 days. Because caribou are capable of rapid movement, we concluded that one location per duty cycle was infrequent enough to provide adequate independence between locations while still maintaining biologically important information. To select one high-quality location per duty cycle, we identified the records with the highest NQ score for each duty cycle. If multiple records in a duty cycle were tied for the highest NQ score, we chose the location with both the highest NQ score and the lowest value of ξ (xi; Keating 1994). ξ is similar to our DRA filter, because it is calculated using 3 successive locations and is a measure of the distance between locations, the angle formed by the 3 locations, and the similarity of length between the 2 legs (Keating 1994). Although the CAH data set for October 1986–July 1990 was screened before we received it (B. Griffith, USGS, pers. comm.), we screened it further to select the first location each day with the highest NQ score.

GPS Collars

A total of 33 GPS collars were deployed on TH caribou during 2004 and 2006–2007 (Table 1). Ten female caribou were outfitted by ADFG with GPS collars (purchased by NSB) in July 2004; the collar model was the Telonics (Mesa, AZ) TGW-3680 GEN 3 store-on-board configuration with Argos satellite uplink. The animals were recaptured and the collars removed in July 2005. All 10 caribou survived for the entire period; 7 had calves in 2005, 2 did not, and one had a calf that died soon after birth. The 10 collars recorded GPS fixes every 3 h (8 locations daily) throughout the entire year. All location data were stored in the collars for downloading after the collars were retrieved, superseding the need to use the location data that had been obtained from the satellite throughout the year (the stored-on-board data provide a higher degree of accuracy and thus are preferred for analysis). Data were screened to remove any locations obtained prior to collaring or after collars were removed, as well as any locations that obviously were incorrect because they were far offshore or far from previous and subsequent locations.

Twelve female caribou from the TH were fitted by ADFG with GPS collars (also Telonics model TGW-3680, purchased by CPAI for this study) during 8–10 July 2006. The collared sample comprised 7 adults aged 3 years or more, 3 2-y-olds, and 2 yearlings. Caribou were captured by firing a handheld net-gun from a Robinson R-44 piston-powered helicopter; in keeping with ADFG procedures for the region, no immobilizing drugs were used. To minimize the risk of injury to animals during collaring, no females with calves were captured in 2006. All 12 collars were retrieved in June 2007 to download the final location data and 12 more GPS collars (same model, again purchased by CPAI) were deployed during 24–25 June 2007, using the same capture procedure as in 2006. The sample collared in 2007 comprised 10 adults, a 2-yr-old, and a yearling. All but one caribou in the 2007 sample had been collared previously; 6 had been outfitted with GPS collars in 2006, 3 had been collared originally in 2004, and 2 had been collared originally in 2003. Only females were selected because the GPS collar model used is subject to antenna problems when deployed on male caribou, as a result of increased neck size during the rutting season (C. Reindel, Telonics, pers. comm.).

The GPS collars deployed in 2006 and 2007 were programmed to record fixes at 2-h intervals (12 locations daily) throughout the year, but battery-life constraints dictated that only 25–50% (depending on the seasonal uplink schedule) of the data collected each day could be transmitted to the Argos satellite. Therefore, fewer than half of all GPS locations were available for analysis before the scheduled retrieval of the 2007 collars in summer 2008; the full data set will be available after the collars are retrieved and downloaded. Satellite uplinks in both years were programmed to occur once daily between 16 April and 15 November and once every other day between 16 November and 15 April. Data reports were received by e-mail from CLS America (Largo, MD). Although one collar failed to transmit to the satellite after deployment in 2007, the other 11 collars were transmitting data at the end of 2007 (the last locations used in this report were from 31 December). The VHF transmitter on the twelfth collar should allow it to be relocated for collar retrieval in summer 2008 along with the other GPS collars.

For the CAH animals outfitted with GPS collars during 2003–2005 (Table 1), all location data recorded within the 48-km study area radius of CD-4 were provided by ADFG. The CAH samples comprised 24, 24, and 33 female caribou in 2003, 2004, and 2005, respectively, of which 19, 18, and 19 collared caribou were recorded at least once within the 48-km radius. Most of the CAH locations were obtained at 5-h intervals, but occasionally 2 locations were recorded over a shorter time period. In most such cases, one of the locations appeared to be obviously wrong. We plotted each of those cases individually and removed the location that appeared to be inaccurate based on previous and subsequent locations. The duration between consecutive locations was calculated for every point.

REMOTE SENSING

The Earth-Observing System (EOS) *Terra* and *Aqua* satellites, launched in 1999 and 2002, respectively, each carry a Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor. MODIS data from the *Terra* platform were used to characterize snowmelt and vegetation green-up over the ASDP study area (and surrounding region, due to the wide swath covered on each satellite pass). At least one satellite image over the study area was acquired daily during 20:00–24:00 UT (12:00–16:00 local time). Browse images were reviewed to identify those with substantial cloud-free views of the study area. For each date, the following data products were obtained from the Level 1 and Atmosphere Archive and Distribution System (LAADS, Goddard Space Flight Center, Greenbelt, MD):

- MOD02QKM (MODIS/*Terra* Calibrated Radiances 5-Min L1B Swath 250 m)
- MOD02HKM (MODIS/*Terra* Calibrated Radiances 5-Min L1B Swath 500 m)
- MOD021KM (MODIS/*Terra* Calibrated Radiances 5-Min L1B Swath 1 km)
- MOD03 (MODIS/*Terra* Geolocation Fields 5-Min L1A Swath 1 km)
- MOD10_L2 (MODIS/*Terra* Snow Cover 5-Min L2 Swath 500 m)

SNOW COVER

The MOD10_L2 data product provides a binary snow map at nominal 500-m resolution over the onshore portion of the study area (except for areas obscured by clouds). Snow is one of the only natural materials that is both highly reflective in visible wavelengths and absorbed in the middle infrared, so the MODIS snow-mapping algorithm is based on these properties. The Normalized Difference Snow Index (NDSI) is calculated from MODIS Band 4 (0.545–0.565 m) and Band 6 (1.628–1.652 m) as follows:

NDSI = (Band 4 – Band 6) ÷ (Band 4 + Band 6).

Pixels are classified as snow if the following conditions are met: NDSI > 0.4, MODIS Band 4 reflectance > 0.10, and MODIS Band 2 reflectance > 0.11.

The binary nature of the standard MODIS snow product limits its usefulness during the period of active snowmelt, when snowdrifts and patchy snow conditions occur at finer scales than 500-m pixels. Several algorithms have been proposed to infer subpixel-scale snow cover using MODIS data, including 2 specific to the Kuparuk River watershed. Salomonson and Appel (2004) compared binary snow maps from 30-m Landsat 7 imagery to MODIS NDSI and developed a simple linear function to calculate subpixel-scale snow fraction from the MODIS NDSI. Déry et al. (2005) tested this algorithm with 2 additional Landsat-7 images and added a 9th-order polynomial correction term to the linear model to address underestimation of snow cover at low snow-cover fractions. We calculated snow fraction for late winter and spring 2007 and 2006 using the Salomonson and Appel (2004) algorithm. In 2005 we used the Déry et al. (2005) algorithm (Lawhead et al. 2006), which was intended for hydrological studies in the Kuparuk River watershed, but we subsequently concluded that it was not the most appropriate for our habitat analyses because it includes a corrective intercept term that enforces a minimum of 6% snow cover for all pixels. Although that 9th-order correction may make sense when driving a hydrological model with a temporal domain extending through 31 May, it does not reflect reality during early summer when snow cover is clearly absent from most of the landscape.

MOD02HKM swath granules were gridded to 50-m resolution and then aggregated to 500-m resolution. Digital number (DN) values were converted to reflectance using the scale factor from the metadata. NDSI was calculated, and then the subpixel-scale snow fraction was calculated as

$$\mathit{Snow\ Fraction} = 0.06 + (1.21 * \mathit{NDSI}).$$

Missing or otherwise bad data were flagged by the occurrence of DN values over 32,767 (per the L1B EV 500m File Specification–Terra 2005) and any 500-m cells containing data flagged as unusable were masked. Cloud-obscured pixels were identified using the standard cloud mask, which was extracted from the MOD10_L2 snow product. However, that cloud mask frequently misclassified cloud-free pixels having partial snow cover as clouds. Clouds could be distinguished easily from snow visually using a false-color display of MODIS bands 7/6/5, so a polygon was manually delineated around the actual cloud-obscured areas. Outside of the delineated area, "cloud" pixels were treated as false cloud detections and ignored, whereas inside this area, cloud-obscured pixels were masked out.

A time-series of images covering 21 May–22 September 2007 was processed in this manner. A composite was compiled to identify the first date with 50% or lower snow cover for each pixel.

VEGETATIVE BIOMASS

The values of the Normalized Difference Vegetation Index (NDVI; Rouse et al. 1973) are used to estimate of the quantity of green vegetation within a pixel of satellite imagery at the time of image acquisition. The rate of increase in NDVI between 2 images acquired on different days during green-up has been hypothesized to represent the amount of new growth in that time interval (Wolfe 2000, Kelleyhouse 2001, Griffith et al. 2002). NDVI was calculated as

$$\mathit{NDVI} = (\mathit{NIR} - \mathit{VIS}) \div (\mathit{NIR} + \mathit{VIS})$$

where *NIR* = near-infrared reflectance (wavelength 0.841–0.876 µm for MODIS) and *VIS* = visible light reflectance (wavelength 0.62–0.67 µm for MODIS) (Rouse et al. 1973; http://modis.gsfc.nasa.gov/about/specs.html).

NDVI values for 2007 were calculated using satellite imagery acquired several times during the calving period (1–10 June; NDVI_calving), at the presumed peak of lactation for parturient females (21 June; NDVI_621; Griffith et al. 2002), in early August around the peak of the growing season (peak biomass; NDVI_peak), and in late September just before snow covered the landscape (late fall NDVI, referred to as "winter" NDVI by Beck et al. 2006). The snow-free late fall imagery allowed us to estimate the baseline value of NDVI for non-photosynthetic vegetation, from which we then could estimate the NDVI value of new vegetation based on the increase from that baseline level. This approach was an improvement over previous years, when we had to set negative NDVI values to zero and assume that the baseline value of non-photosynthetic vegetation was zero because we did not have a good NDVI measurement after the end of the growing season. Using late fall NDVI as the baseline had particularly large effects on the values of NDVI_calving and NDVI_rate. Because the image-processing methods differed somewhat between the 2002–2003 imagery and the 2004–2006 imagery, caution should be used in interannual comparisons of absolute values (see Lawhead et al. [2006] for details).

NDVI values near peak lactation (NDVI_621) were interpolated from images obtained before and after 21 June in 2002–2005, because the sky was not clear on 21 June in any of those 4 years. In 2006 a maximum-value composite of interpolated data and actual data from 21 June was used. In 2007 a maximum-value composite of data from 20–21 June was used, with most data coming from 21 June. We calculated the daily rate of change of NDVI (NDVI_rate) between calving and 21 June by subtracting NDVI_calving from NDVI_621 for each pixel and dividing by the number of intervening days. Several cloud-free days occurred during snowmelt in 2007, so we conducted a sensitivity analysis of the zero-baseline NDVI method with NDVI_calving estimated from 4, 5, and 7 June. Finally, NDVI_peak was calculated from late July imagery (2005 and 2006) or early August imagery (2007).

The presence of waterbodies, snow, and ice depress NDVI values and decouple them from their relationship to vegetation properties (Macander 2005). We removed the effect of large waterbodies in the study area by excluding pixels with 50% or greater water cover (determined by overlaying a regional map layer of lakes and ponds). To facilitate comparisons between NDVI (calculated at 250-m resolution) and snow cover (calculated at 500-m resolution), the mask was constructed at 500-m resolution, so that all 500-m cells with >50% water cover, and all 500-m cells containing one or more 250-m cells with >50% water cover, were excluded. This correction lessened, but did not eliminate, the negative bias from open water and ice.

CARIBOU DISTRIBUTION ANALYSES

Caribou group locations from aerial transects in the NPRA survey area were analyzed in relation to various geographic sections of the survey area, habitat type, snow cover, and estimated vegetative biomass levels to evaluate which factors influenced caribou distribution before oil development began. We also compared group locations and density among different distance zones around the proposed ASDP road to characterize the preconstruction baseline level of use of the area by caribou.

Because the distribution of caribou is influenced by different factors during different seasons, we grouped the aerial-transect survey data into 8 different seasons (adapted from Russell et al. 1993): winter, 1 December–30 April; spring migration, 1–29 May; calving, 30 May–15 June; postcalving, 16–24 June; mosquito, 25 June–15 July; oestrid fly, 16 July–7 August; late summer, 8 August–15 September; and fall migration, 16 September–30 November.

GEOGRAPHIC LOCATION

Visual inspection of caribou distribution from aerial transects suggested different levels of caribou use across the NPRA survey area, so we tested whether caribou locations varied among different geographic areas. We divided the 2002–2004 and 2005–2007 survey areas (which differed in size) into 6 sections (Figure 2): (1) the area within 4 km of Fish and Judy creeks (River); (2) the area within 4 km of the Beaufort Sea coast (Coast); (3) the area north of Fish and Judy creeks (North); (4) the area west of Fish and Judy creeks (West); (5) the western half of the area south of Fish and Judy creeks (Southwest); and (6) the eastern half of the area south of Fish and Judy creeks (Southeast). The proposed ASDP road would be constructed almost entirely in the Southeast section. The number of caribou groups in each section was quantified for all seasons and years and a chi-square goodness-of-fit test was used to test whether the number of groups in each section differed significantly from expected values, assuming a uniform distribution (Neu et al. 1974, Byers et al. 1984). If significant differences were found, individual sections were compared using Bonferroni multiple-comparison tests (Neu et al. 1974, Byers et al. 1984).

HABITAT USE

To compare habitat use with availability, we overlaid the data from aerial-transect surveys of the expanded 2005–2007 NPRA survey area on the NPRA earth-cover classification created by BLM and Ducks Unlimited (2002; Figure 3). A different map product created for CPAI studies—the ELS habitat map (Jorgenson et al. 1997, 2003, 2004)—did not cover our entire NPRA survey area and classified habitats for birds as well as mammals. We chose the NPRA earth-cover classification (30-m pixel size) for the habitat analysis because it covered our entire NPRA survey area, had fewer habitat classes than did the ELS classification, and the classification system appeared to better reflect habitat characteristics important to caribou.

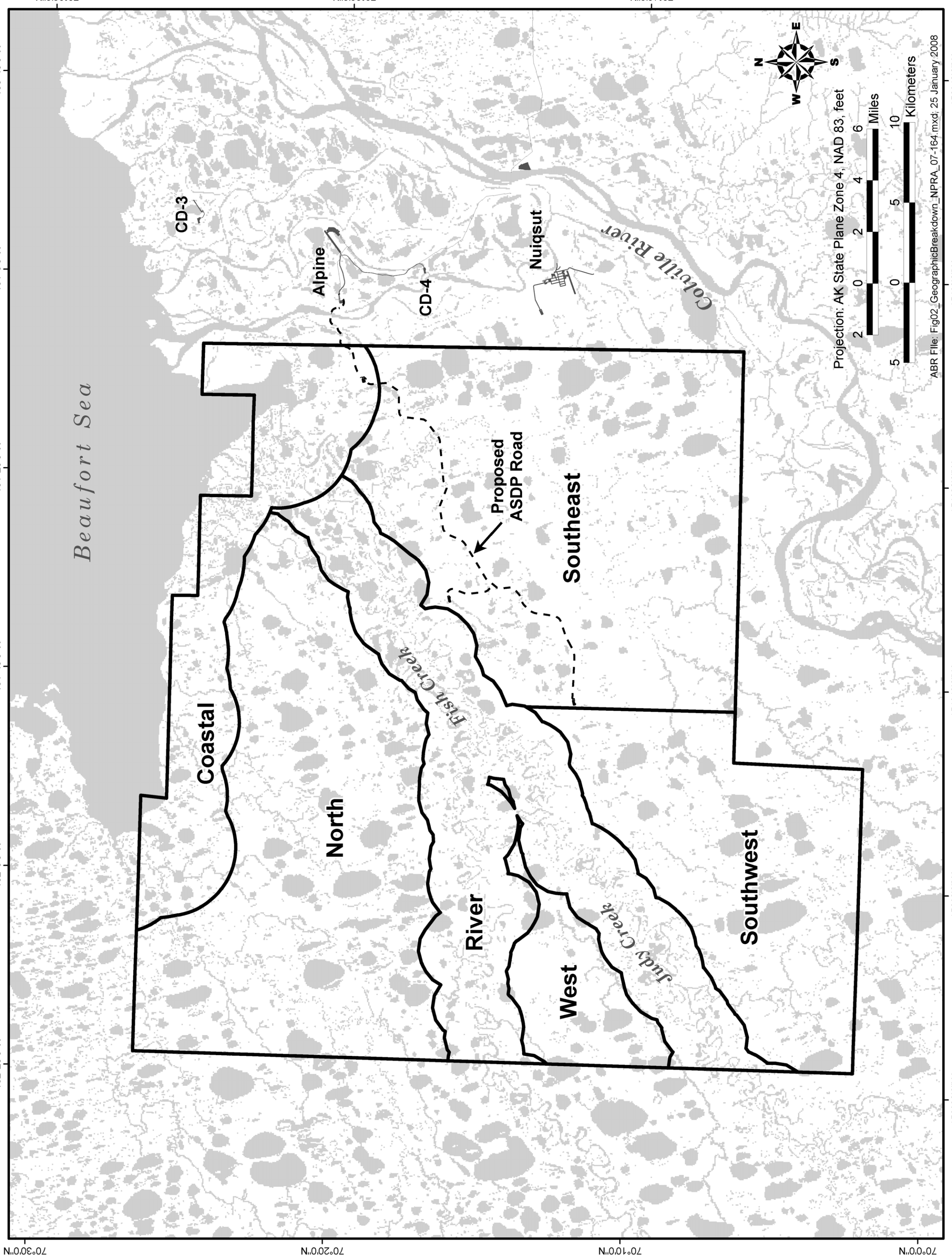


Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2007.

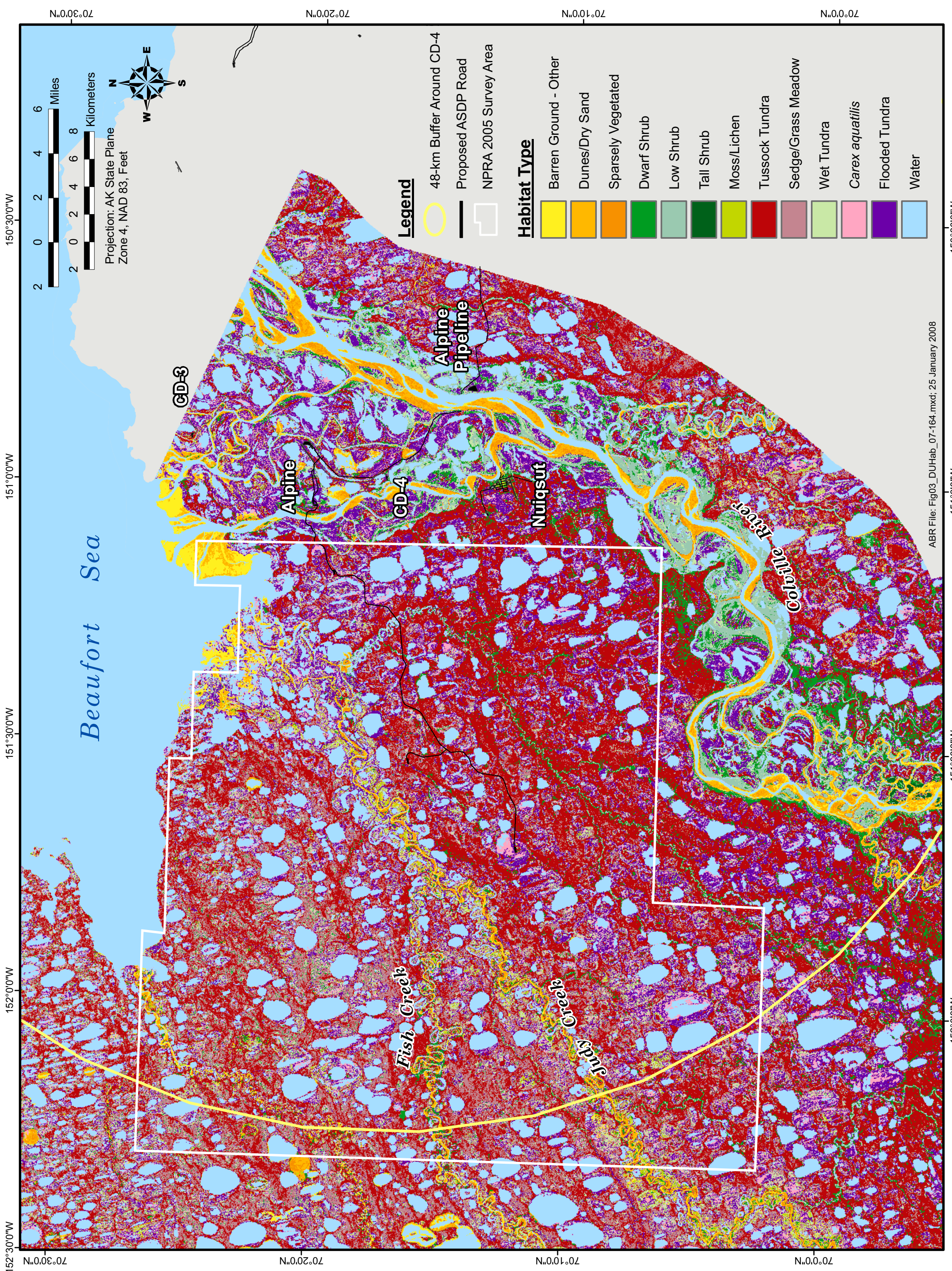


Figure 3. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2007.

Using the NPRA earth-cover classification, our NPRA survey area contained 15 cover classes (Appendix A), which we collapsed into 10 types to analyze habitat use. The barren ground/other, dunes/dry sand, and sparsely vegetated classes, which mostly occurred along Fish and Judy creeks, were combined into a single riverine class. The 2 flooded-tundra classes were combined as flooded tundra and the clear-water, turbid-water, and *Arctophila fulva* classes were combined into a single water class; these largely aquatic types are used little by caribou, so the water class was excluded from the use–availability analysis.

The use of habitat types by caribou was calculated by selecting all pixels within a 100-m radius of the location coordinates for each group, thereby adjusting the percentage to reflect the positional accuracy of the location. We calculated the percentage of each of the habitat types (excluding water) within the selected pixels. Water was treated separately to calculate the proportion of terrestrial habitat used. The mean proportion of each habitat type used in each season then was calculated by taking the mean of all estimated proportions for all groups.

To test whether the observed proportions of habitat use differed significantly from availability, 10,000 random locations were created within the 2005–2007 NPRA survey area using *ArcView 3.2a* GIS software. Locations in lakes were removed, leaving a total of 8268 random locations (6424 in the 2002–2004 survey area). A 100-m-radius buffer was created around each random location and the proportion of each habitat type was calculated. A number of random locations equal to the number of caribou groups observed during the time period of interest were selected randomly (with replacement) and the mean proportion of each habitat type in those locations was calculated. This process was repeated 5000 times. If the proportion of a habitat type for a caribou group location was more extreme than the average of 95% or 99% of resampled random locations, we concluded that the observed proportion was significantly different from random at $P = 0.05$ or $P = 0.01$, respectively.

SNOW COVER

Numerous clear days occurred during the calving period in 2007, allowing calculation of snow cover on multiple days throughout the calving period, unlike 2006, when persistent cloudy weather limited the satellite imagery available to estimate snowmelt during calving.

The values of snow cover (%) on 3, 4, 6, and 7 June were determined for each caribou group location on 9 June (not including pixels with >50% water) and those values were compared with availability using bootstrap estimates. Random samples of snow-cover fractions equal to the number of caribou observed were selected with replacement from all pixels used by caribou during that time period. The mean of the new data set was calculated and a new sample was generated in the same manner; this process was repeated 5000 times to generate mean values. The resulting 5000 mean values were compared with the availability of snow-cover values in the survey area. If the mean snow-cover value of all pixels within the survey area was more extreme than 95% or 99% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.05$ or $P = 0.01$, respectively.

VEGETATIVE BIOMASS

We compared caribou group locations in the NPRA survey area in 2007 with estimated vegetative biomass (NDVI values). The values of the variables NDVI_calving, NDVI_621, NDVI_rate, and NDVI_peak were determined for each caribou group location (not including pixels with >50% water) and those values were compared with availability using bootstrap estimates. For each season, random samples of NDVI values equal to the number of caribou observed were selected with replacement from all pixels used by caribou during that time period. The mean of the new data set was calculated and a new sample was generated in the same manner; this process was repeated 5000 times to generate mean values. The resulting 5000 mean values were compared with the availability of NDVI values in the survey area. If the mean NDVI value of all pixels within the survey area was more extreme than 5% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.05$ and if the mean NDVI value of all pixels within the survey area was more extreme than 1% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.01$.

DISTANCE TO PROPOSED ROAD

The group locations from aerial-transect surveys in the NPRA survey area constitute the baseline data set on caribou density for the area in which the proposed ASDP road may be constructed. Thus, these data are the primary source of information regarding caribou distribution, including attraction and avoidance, in relation to natural factors in the road corridor.

The number of groups and the density of caribou by year and season were calculated within 5 distance-to-road zones: 0–2 km from the road, 2–4 km north or south of the road, and 4–6 km north or south of the road. All areas within 6 km of existing roads (the Alpine infield road between CD-1 and CD-2) were removed to ensure that they did not influence the results. We calculated the number of groups and the caribou density in each zone for each combination of year and season, then used a chi-square goodness-of-fit test to determine if the observed number of groups in each category differed significantly from expected values, assuming a uniform distribution (Neu et al. 1974, Byers et al. 1984). If significant differences were found, individual distance categories were compared using Bonferroni multiple-comparison tests (Neu et al. 1974, Byers et al. 1984).

A repeated-measure analysis (*SPSS* version 13.0 software, SPSS Inc., Chicago, IL) was used to test for differences in annual density among the different distance zones, with zone as a within-subject effect and season as a between-subject effect. Simple contrasts were used to determine if density in any of the 2–4-km or 4–6-km zones differed significantly from the 0–2-km zone containing the proposed road alignment. We used Tukey's *post-hoc* multiple-comparison test to look for significant differences among seasons. A natural-log transformation (*ln* [*density +1/6*]) was applied to the density data to better meet the assumption of normality required for parametric statistical testing (Mosteller and Tukey 1977). The single survey in the 2005 oestrid-fly season was removed from the analysis to eliminate the undue influence on the test results that would have resulted from the large groups observed on that survey.

CARIBOU DENSITY ANALYSIS

To test the effects of multiple independent variables on the density of caribou in the NPRA survey area, the transect strips in the 2002–2004 and 2005–2007 NPRA survey areas were subdivided into 124 and 164 grid cells, respectively. Each grid cell was 1.6-km wide by 3.2- or 4.8-km long, depending on the transect length (Figure 4). Within each cell we calculated the caribou density by season, mean NDVI values from 2007, proportion of tussock-tundra habitat (as a proportion of land area), proportion of wet habitat (a combination of the *Carex aquatilis*, flooded tundra, wet tundra, and sedge/grass meadow classes as a proportion of land area), distance from the Beaufort Sea coast (km), percent snow cover on 3 June 2007, transect number (a measure of a west-to-east density gradient), presence or absence of Fish Creek or Judy Creek, and presence or absence of the proposed ASDP road corridor.

A natural-log transformation (*ln* [*density* + *1/6*]) was applied to density data to better meet the assumption of normality. The spatial pattern of NDVI_peak was highly correlated across years (r >0.9 for 2005–2007 within the 163 grid cells in the NPRA survey area), so we used the value of NDVI_peak from 2007 in multi-year analyses. NDVI_rate from 2007 was used only in analysis of calving density.

We tested various models for calving density in 2007 and the density in each season for the years 2002–2007 combined. Data from 2001 were not included in this analysis because the NPRA transect-survey area that year was smaller than in subsequent years. A series of models (analysis of covariance, or ANCOVA; Neter et al. 1990) was used to determine which factors had a significant relationship with caribou density. We used an information–theoretic approach (Burnham and Anderson 1998, Anderson et al. 2000) to compare a predetermined set of candidate models with different combinations of independent variables. We calculated Akaike Information Criteria with the adjustment for small sample size (AIC_c) and used the Akaike weights (Burnham and Anderson 1998,

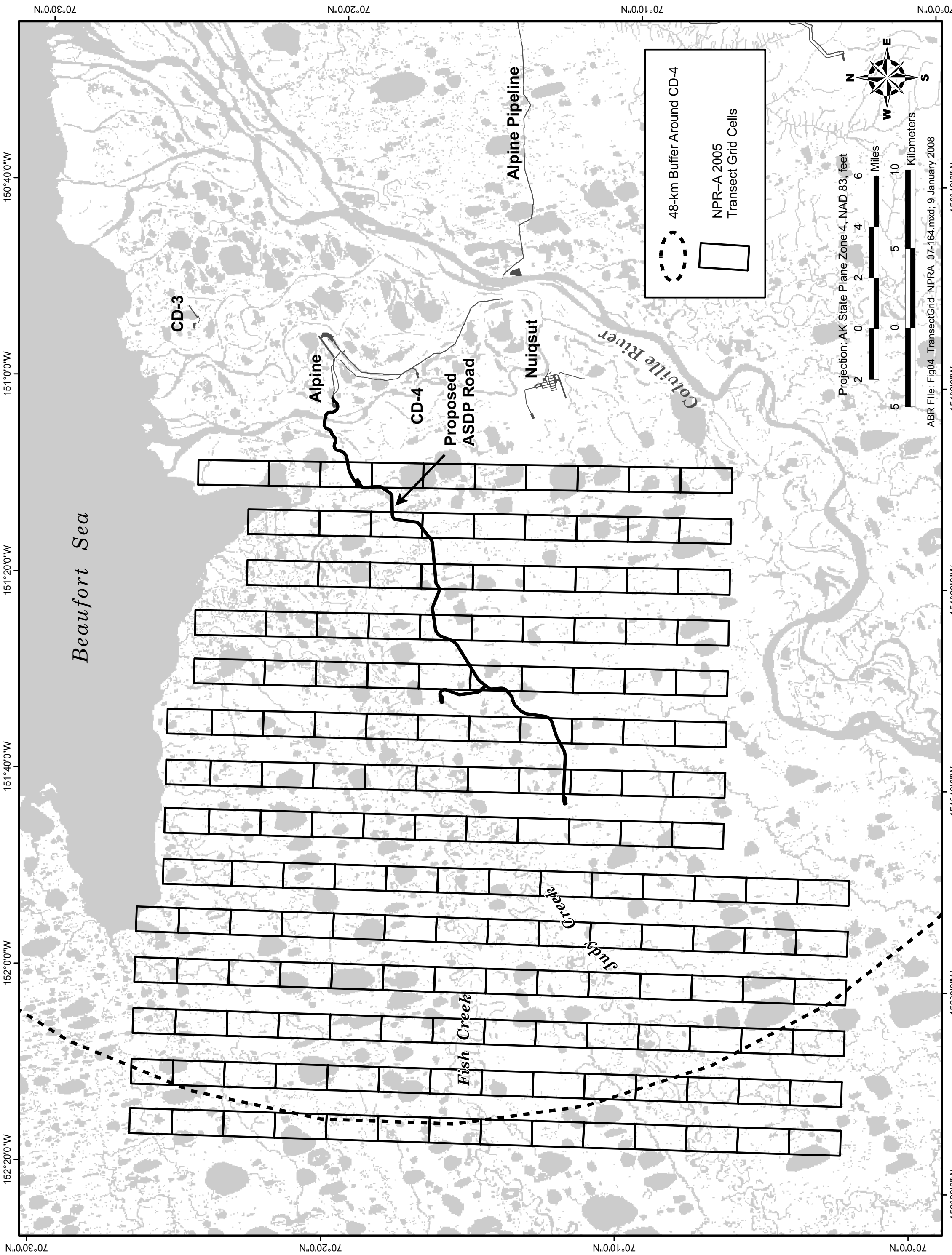


Figure 4. Locations of transect grid-cells (n = 164) used to analyze caribou density in the NPRA survey area, 2005–2007.

Anderson et al. 2000) to estimate the relative probability of each model being the most parsimonious model in the candidate set. We then calculated the model-averaged parameter estimates and standard error (SE) by calculating the mean of the estimated parameter values for each model containing the variable of interest, while weighting the average by the Akaike weight (Burnham and Anderson 1998). These model-averaged parameter estimates and standard errors are preferred over model-specific parameters because they incorporate estimates from all possible models and take into account the uncertainty in choosing the best model. Therefore, it is not necessary to base results on a single "best" model.

The presence of Fish and Judy creeks and of the proposed road were included in all 19 candidate models for calving density in 2007. The different models had various combinations of NDVI_peak, NDVI_rate, snow cover on 3 June 2007, transect number (west–east gradient), proportion of tussock tundra, and proportion of wet habitat. Independent variables with Pearson correlations greater than 0.5 were not included in the same model. NDVI_621 was excluded because it was highly correlated with NDVI_peak, so the latter variable was used instead. We removed one grid cell located on the Colville River delta because it contained very little suitable habitat and was an outlier in most analyses, leaving a total of 163 grid cells in the analysis.

A total of 15 candidate models were used for seasonal tests over all years (2002–2007) combined. For these models, the year-specific variables (snow-cover fraction and NDVI_rate) were dropped and the distance-to-coast variable was added; only those grid cells that were surveyed in all 5 years (n = 124) were included.

RESULTS AND DISCUSSION

WEATHER CONDITIONS

The timing of snowmelt in spring and the severity of insect harassment in midsummer varied considerably during the years in which aerial surveys were conducted in the ASDP study area (Appendix B). The timing of snowmelt was delayed in 2001, advanced in 2002, and about average in 2003–2007. Air temperatures in late winter and spring 2007 were colder than average. Snow depth was close to the long-term average in early April, but significant snowfall on 5–6 May resulted in the snow depth on 15 May being the highest on record for the Kuparuk airstrip. The average daily temperature at the Kuparuk airstrip exceeded freezing for the first time on 4 June. The cumulative sum of thawing-degree days (TDD) was slightly above average in early June (Appendix B).

Snow cover began melting rapidly by the end of May and was mostly gone by the end of the first week of June. Snow cover was patchy during the first calving survey in the Colville East survey area on 2–5 June. The complex visual background created by snowmelt required adjustment of the early June counts for low detectability by applying a sightability correction factor (SCF) for large caribou (Lawhead et al. 1994). Most of the snow cover had melted in the survey areas by the time of the NPRA survey on 9 June and the second calving survey in the Colville East area on 10–12 June. The snow remaining at that time consisted mostly of deep linear drifts along upland drainages and lake edges and was not great enough to warrant use of the SCF.

Information on summer weather was compiled for reference in interpreting insect-season conditions and the severity of insect harassment. The occurrence of air temperatures conducive to insect activity (as indicated by TDD sums) in 2007 was below the long-term averages for late June and July and was slightly higher than average in early August (Appendix B). Weather conditions can be used to predict the occurrence of harassment by mosquitoes (*Aedes* spp.) and oestrid flies (*Hypoderma tarandi* and *Cephenemyia trompe*). The estimated probabilities of mosquito activity based on daily maximum temperatures (but ignoring wind speed; Russell et al. 1993) at the Kuparuk airstrip were below average in June, close to average in July, and above average in August (Lawhead and Prichard 2008). Thus, the available weather data indicate that the levels of insect activity and resulting harassment of caribou were low to average early in the summer and slightly greater than average in August.

Variability in weather conditions typically results in large fluctuations in insect activity and caribou density during the insect season as aggregations move rapidly through the study area. Caribou typically move toward the coast in response to mosquito harassment and then disperse inland when mosquito activity abates in response to colder temperatures or high winds.

Weather conditions can exert strong effects on caribou population dynamics. Deep winter snow and icing events increase the difficulty of travel, decrease forage availability, and increase susceptibility to predation (Fancy and White 1985, Griffith et al. 2002). Severe cold and wind events also can cause direct mortality of caribou (Dau 2005). Late melting of snow cover can delay spring migration and cause lower calf survival (Griffith et al. 2002, Carroll et al. 2005) and decrease future reproductive success (Finstad and Prichard 2000). In contrast, hot summer weather can depress weight gain and subsequent reproductive success by increasing insect harassment at an energetically stressful time of year, especially for lactating females (Fancy 1986, Cameron et al. 1993, Russell et al. 1993, Weladji et al. 2003).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

NPRA Survey Area

Nine surveys of the NPRA survey area were flown between 14 May and 22 October 2007 (Table 2, Figure 5). The general pattern of caribou occurrence in the survey area was relatively high numbers in spring, low numbers in summer, and the highest numbers during fall migration. The estimated density of caribou ranged from a high of 1.77 caribou/km² on 22 October to a low of 0.05 on 12 August (Table 2). The density of caribou during calving (0.85 caribou/km² on 9 June) in the NPRA survey area was essentially identical to mid-May (0.87 caribou/km²; Table 2), underscoring the relatively low use of the area for calving compared with neighboring areas. The density during calving in 2007 was higher than the range of 0.15–0.66 caribou/km² (6–9 June) observed in the NPRA survey area during 2001–2006 (no calving survey was conducted in 2004), but only 47 calves (6.4% of the total number of caribou) were observed in the NPRA survey area on 9 June.

Annual surveys since 2001 demonstrate that the NPRA survey area (used mainly by TH caribou) is not a high-density calving area, in contrast to the Colville East survey area (used mainly by CAH caribou) (Appendices C–I; Lawhead and Prichard 2007). This conclusion is supported by analyses of telemetry data (Prichard and Murphy 2004, Carroll et al. 2005), which show that most TH females calve around Teshekpuk Lake, west of the ASDP study area. Although a few collared CAH caribou have calved west of the Colville River in isolated years (most notably 2001), it is a rare occurrence (Lenart 2003, Arthur and Del Vecchio 2007).

Unlike 2005 (Lawhead et al. 2006), we did not observe large mosquito-harassed groups during aerial surveys in 2007, although no surveys were conducted in July when mosquito and oestrid-fly harassment typically peak. During insect season, transect surveys produce unpredictable results due to the rapid movements by caribou across broad areas in response to fluctuating insect activity levels. Radio-telemetry data provide better information on movements during the insect season and indicated that large groups did move into the NPRA survey area in mid-July 2007 (see Radio Telemetry section below).

Caribou densities observed on transect surveys of the NPRA area were relatively low in August and September (0.05–0.34 caribou/km²; Table 2) but increased to 0.63 caribou/km² in early October and 1.77 caribou/km² in late October. Since our surveys began in 2001, the highest densities in the NPRA survey area typically have occurred in late September or October (annual maxima of 1.2–3.5 caribou/km² during 2001–2005). Relatively high densities also have been recorded occasionally in late winter (2.4 caribou/km² in April 2003) and postcalving (1.5 caribou/km² in late June 2001) (Appendices C–H).

Other Mammals

During aerial surveys in the NPRA survey area in 2007, a single group of 25 muskoxen (21 adults and 4 calves) was seen in mid-May west of the Fish Creek delta (Appendix J). That group was observed ~25 miles offshore on the sea ice in Harrison Bay in early June 2007 and later moved back onshore north of Kogru, east of Teshekpuk Lake (G. Carroll and S. Arthur, ADFG, pers.

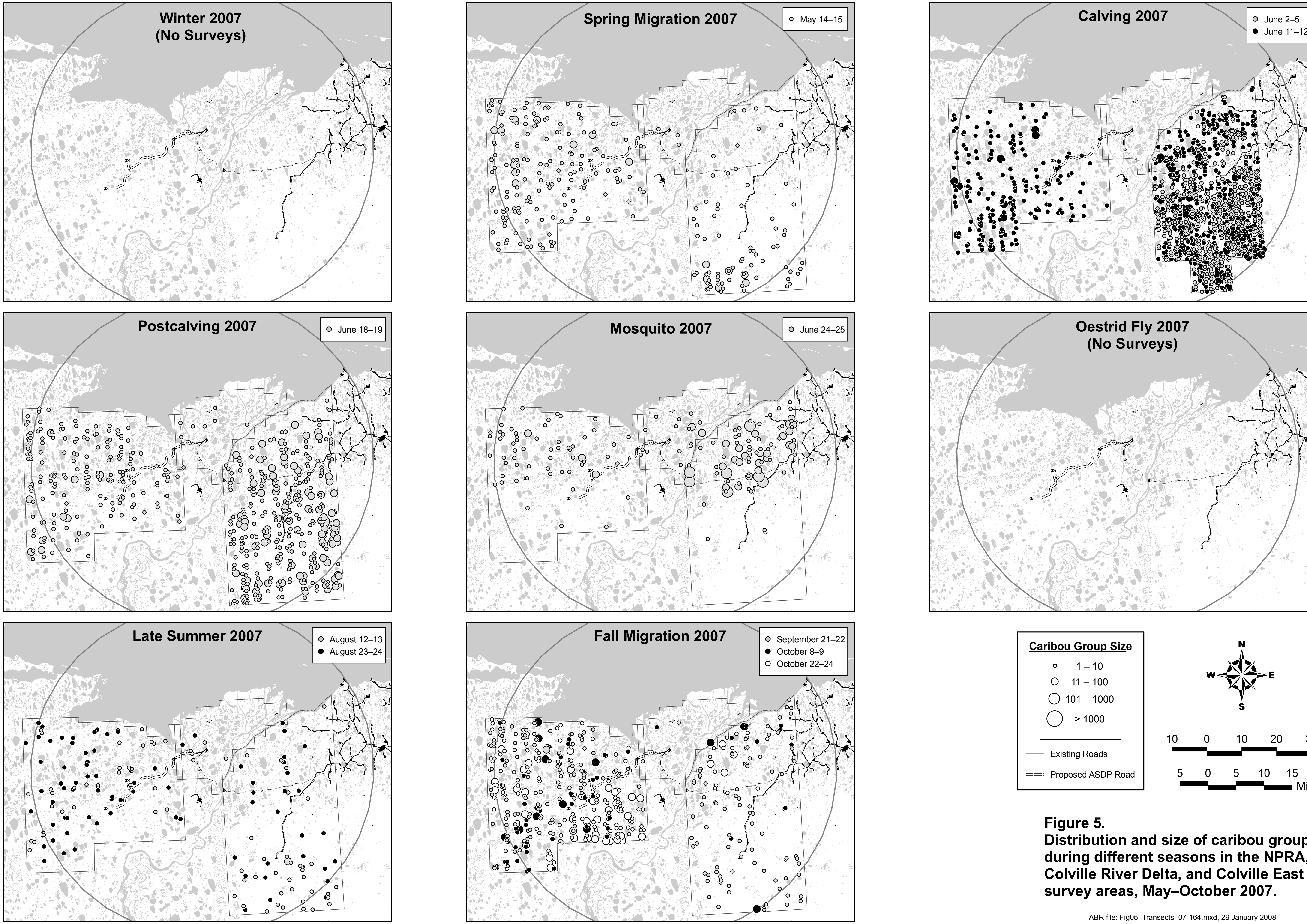


Figure 5.
Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2007.

ABR file: Fig05_Transects_07-164.mxd, 29 January 2008

Table 2. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2007.

Survey Area (Size) and Date	Large Caribou [a]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density ($caribou/km^2$) [e]	Mean Group Size
NPRA (1720 km^2) [f]							
May 14	746	0	746	1492	175.6	0.87	4.7
June 9	686	47	733	1466	188.0	0.85	3.7
June 18	645	49	694	1388	173.9	0.81	3.9
June 25	229	0	229	458	62.8	0.27	3.7
August 12	41	1	42	84	10.6	0.05	1.4
August 24	64	2	66	132	20.4	0.08	1.2
September 21	286	5	291	582	66.9	0.34	2.7
October 8 [g]	291	nr	291	1092	225.3	0.63	5.2
October 22	1519	nr	1519	3038	282.6	1.77	8.2
COLVILLE R. DELTA (494 km^2) [f]							
May 15	28	0	28	56	20.4	0.11	5.6
June 19	19	2	21	42	14.5	0.09	2.6
June 25	78	1	79	158	53.0	0.32	4.9
August 13	10	0	10	20	11.2	0.04	2.0
August 24	4	1	5	10	4.3	0.02	1.7
September 21	3	0	3	6	3.0	0.01	1.5
October 8–9 [g]	17	nr	17	64	17.8	0.13	8.5
COLVILLE EAST (1696 km^2) [f]							
May 15	380	0	380	760	105.1	0.45	4.9
June 2, 4–5 [g,h]	558	51	609	2290	477.3	1.60	1.9
June 11–12 [h]	4015	1298	5313	10,626	597.9	7.42	7.7
June 18	3389	569	3958	7916	1086.0	4.67	11.7
June 24	1555	347	1902	3804	800.5	2.24	24.1
August 13	80	1	81	162	38.3	0.10	2.3
August 23	33	1	33	66	10.1	0.04	1.3
September 21-22	215	14	229	458	42.9	0.27	2.8
October 9 [g]	84	nr	84	315	76.1	0.19	7.0
October 24 [i]	147	nr	147	735	304.5	0.43	6.4

[a] Adults + yearlings.
[b] nr = not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage) or × 4 (for 25% sampling coverage).
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (860 km^2 were surveyed in NPRA, 247 km^2 on the Colville R. Delta, and 848 km^2 in Colville East).
[g] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994).
[h] Survey of calving-season transects (1.6-km spacing) at 90-m altitude for 50% coverage; SE calculated based on 3.2 km-long transect segments (Lawhead and Prichard 2008).
[i] Partial survey only (339 km^2) due to fog.

comm.). That group evidently was the same one that was observed previously near the Kalikpik River in the northwestern portion of the survey area in 2005 and 2006, numbering between 8 and 23 animals at various times (Lawhead et al. 2006, 2007). Before 2005, muskoxen were observed in the NPRA survey area only in June 2001 (Burgess et al. 2002), although the species occurs regularly on the Colville River delta and adjacent coastal plain to the east (Johnson et al. 1998, 2004; Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007) and historical records of the species exist for northeastern NPRA (Bee and Hall 1956, Danks 2000).

Grizzly bears were recorded on 7 occasions in the NPRA survey area between May and October 2007 (Appendix J). Five sightings were of a sow with 2 large cubs, including an observation of a sow with cubs digging a den in the northwestern portion of the survey area in October.

No moose were observed in any of the 3 ASDP survey areas in 2007. A few moose have been seen in the study area sporadically in previous years (Lawhead et al. 2006).

<u>Colville River Delta Survey Area</u>

Seven surveys of the Colville River Delta survey area were flown between 15 May and 9 October 2007 (Table 2, Figure 5). Similar to most years, the estimated density of caribou was low during all surveys (0.01–0.32 caribou/km²); the maximal estimate recorded in 2007 was 158 caribou (0.32 caribou/km²) on 25 June. However, other observers reported large influxes of caribou onto the Colville delta several times in July 2007 (see Radio Telemetry section below).

Large numbers of caribou have been recorded occasionally during past summers (such as 1992 and 1996) as large aggregations moved onto or across the delta during or after periods of insect harassment (Johnson et al. 1998, Lawhead and Prichard 2002). The most notable such instance was a large-scale westward movement onto the delta by at least 10,700 CAH caribou in the third week of July 2001, ~6000 of which continued across the delta into northeastern NPRA (Lawhead and Prichard 2002, Arthur and Del Vecchio 2007) and moved west through the area of the proposed ASDP road. It is difficult to record the dynamic movements of insect-harassed caribou with periodic transect surveys. The highest number recorded on transect surveys during 2001–2007 (Table 2, Appendices C–H) occurred on 2 August 2005, when 994 caribou were found on the Colville delta (2.01 caribou/km²; Appendix G).

<u>Colville East Survey Area</u>

Ten surveys of the Colville East survey area were flown between 15 May and 24 October 2007. The estimated density of caribou ranged from the peak of 7.42 caribou/km² during calving on 11–12 June to a low of 0.04 caribou/km² on 23 August (Table 2). The density was low in mid-May, peaked during calving, and then decreased during the 2 postcalving surveys. No surveys were conducted in July. Density was low on the 2 surveys in August and increased to 0.43 caribou/km² by late October. In view of the high density of TH caribou migrating through the NPRA survey area at the time, it is likely that the density on the late October survey of Colville East was greater; only part of the area could be surveyed due to persistent fog and low cloud ceilings.

In 2007, similar to 2004 and 2005, calving densities were higher in the Colville East survey area than in the Kuparuk South survey area to the east (Lawhead and Prichard 2005, 2006, 2008). In most years since 1993, the Kuparuk South survey area had higher calving density than the Colville East area (Lawhead and Prichard 2007). The 11–12 June 2007 calving density was the highest observed in the Colville East area (Appendix I). The area also hosts high densities of caribou during postcalving as CAH caribou move northward prior to mosquito emergence (Lawhead et al. 2004; Lawhead and Prichard 2006, 2007, 2008). Inland portions of the Colville East survey area often are used during the insect season when cooler weather depresses insect activity and caribou move south away from the coast.

RADIO TELEMETRY

Mapping of the telemetry data from VHF, satellite, and GPS collars clearly shows that the ASDP study area is at the interface of the TH and CAH annual ranges (Figure 6; GPS collar movements for the CAH sample are not depicted in the figure because they were available only inside the ASDP study area). The majority of collar locations for the TH and CAH occurred west and

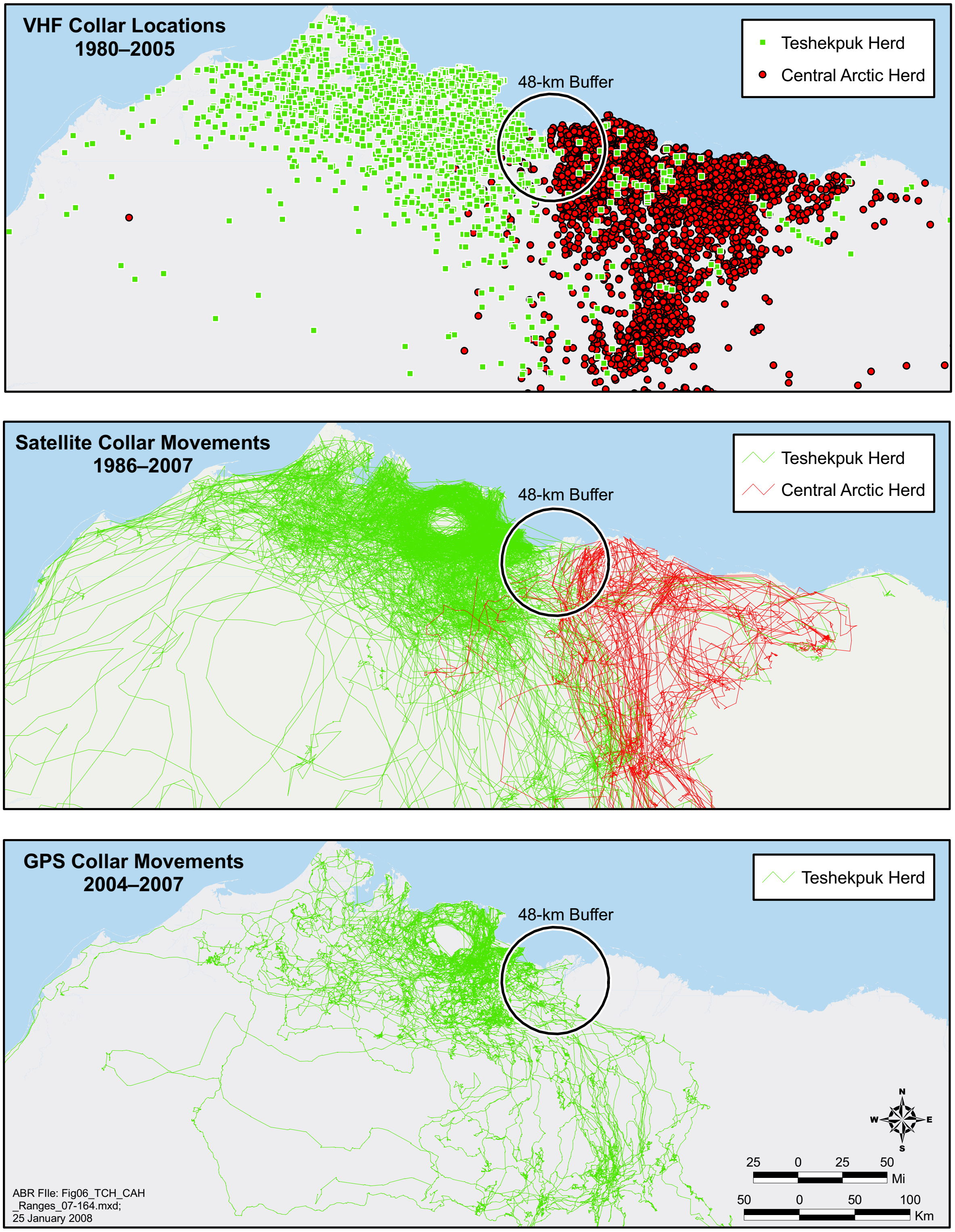


Figure 6. Ranges of the Teshekpuk and Central Arctic caribou herds in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2007.

east of the center of the CD-4 study area, respectively. In addition to the summary maps, the monthly proportion of the collared sample from each herd within the ASDP study area was quantified to characterize the pattern of occurrence by each herd (Tables 3 and 4). Although it is generally not warranted to consider each collared caribou as representing a specific number of unmarked caribou in the herds, the monthly percentages provide reasonable estimates of the relative abundance of each herd in the study area throughout the year.

VHF Collars

Interpretation of VHF telemetry data is limited by the fact that the locations of collared individuals are restricted by the number, location, and timing of tracking flights. Therefore, the distribution of collars on each flight is a snapshot that allows only general conclusions to be drawn regarding caribou in the area surveyed and movements between successive flights. Previous VHF collar locations were discussed by Lawhead et al. (2006); no new VHF data were available for the 2007 season.

Satellite Collars

Combining observations for each month over all years of data, the percentage of satellite-collared TH animals (with at least 5 active duty cycles per month) in the ASDP study area ranged between 8% and 30% of the total collared samples during each month (Table 3). The highest overall percentages occurred in July, August, and October and the lowest percentages in June and December–April (Table 3, Figure 7); the greatest use by TH caribou occurred in the western half of the study area. The monthly percentages varied substantially within and among years, largely due to small samples of collared animals in most years. Seven satellite-collared TH caribou crossed the alignment of the proposed ASDP road in the NPRA survey area 8 times during January–August 2007 (no data were available after August). One crossing occurred in June, 4 occurred in late July, and 3 occurred in early August. Two satellite-collared TH caribou crossed the proposed alignment in October 2006.

The satellite-collar data indicate that many TH caribou occupied the ASDP study area in 2007, mostly in July and August when 58–61% of the satellite collars were present (Table 3). Eleven satellite-collared TH caribou were in the study area in July and August (another collared caribou also was in the study area in July 2007 but subsequently joined the CAH).

Satellite telemetry data showed more use of the eastern half of the ASDP study area by CAH caribou than by TH animals (Figure 7). No satellite-collared CAH animal crossed the proposed ASDP road alignment in the NPRA survey area in any year for which data are available (1986–1990 and 2001–2005). Several collared CAH individuals moved through the vicinity of the Alpine project facilities in July 1989, 9 years before construction began. Combining observations for each month over all 8 years of data (no month had more than 8 years of data), the percentage of the total sample of satellite-collared CAH caribou in the study area ranged from 12% to 62% each month (Table 3). The highest occurrence of collared CAH caribou was in June and July (62% and 51% of the total sample, respectively) and the lowest was during October–February (12–18%) (Table 3, Figure 7). As with the TH sample, the monthly percentages varied substantially (0–89%) within years, at least in part due to small samples of collared animals. The number of collared CAH animals using the ASDP study area during the winter months appeared to be higher during 1986–1990 than during 2001–2005 (Table 3). The apparent difference in winter use between the 2 periods may have been affected by the timing and location of collaring, but that information was not available. The bulk of available data show that CAH caribou normally move far inland to the foothills and mountains of the Brooks Range during winter, so the occurrence of collared animals on the outer coastal plain in winter was unusual.

In most years, use of the Colville River delta by satellite-collared caribou peaked during the summer insect season (mosquito and oestrid-fly periods, late June to early August) and primarily involved CAH animals (Table 3, Figure 7). The annual harvest of caribou by Nuiqsut hunters peaks during July–August and October (Pedersen 1995, Brower and Opie 1997, Fuller and George 1997); lower harvests in September may result from

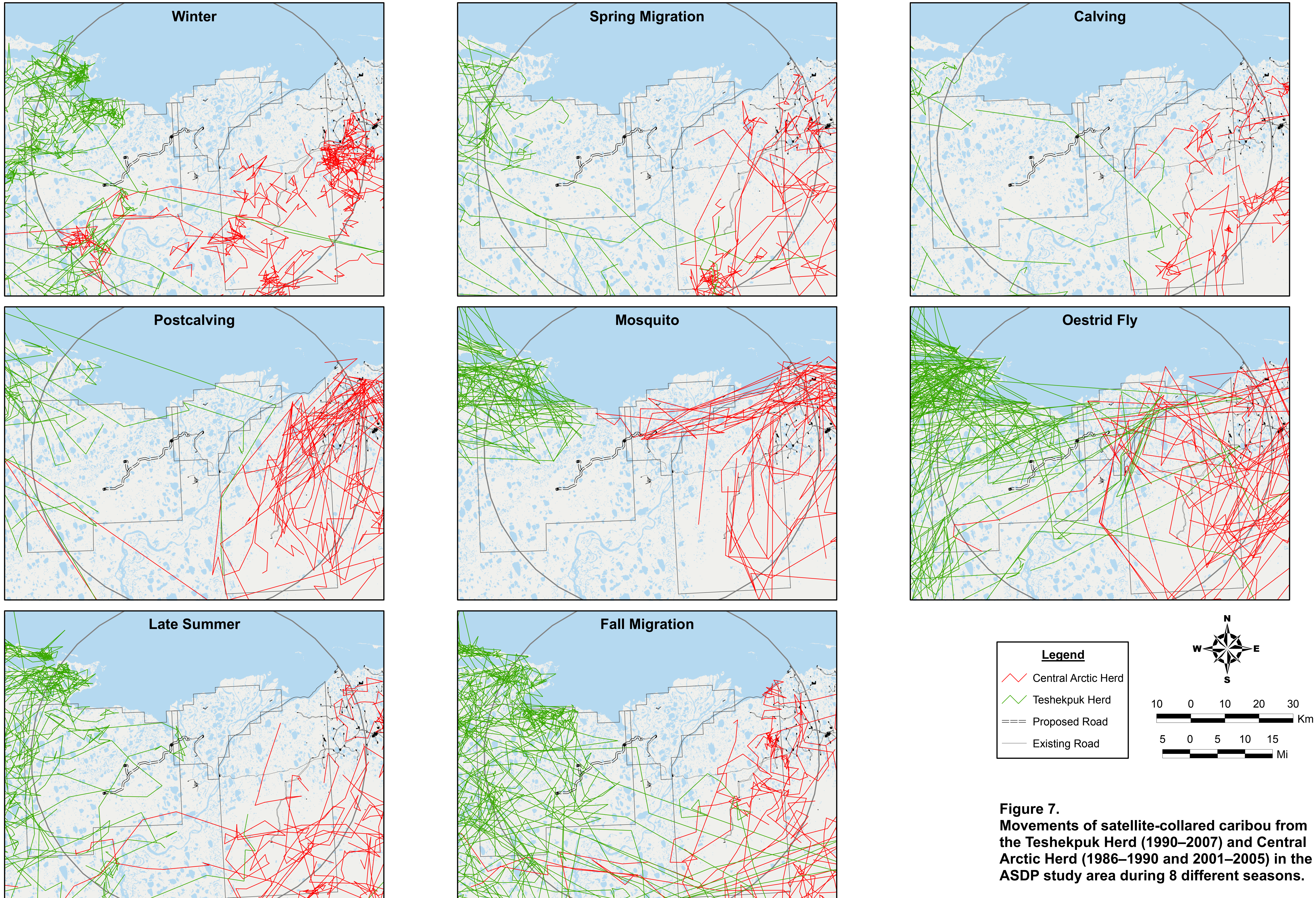


Figure 7.
Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2007) and Central Arctic Herd (1986–1990 and 2001–2005) in the ASDP study area during 8 different seasons.

ABR file: Fig07_Sat_07-164.mxd, 25 January 2008

Table 3. Percentage of satellite-collared caribou samples (*n*) from the Teshekpuk (TH) and Central Arctic (CAH) herds that were within 48 km of CD-4 at least once in each month. Caribou with <5 active duty-cycles per month were excluded.

Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec
TH	1990	–	–	–	–	–	–	50 (6)	17 (6)	33 (6)	0 (6)	0 (6)	0 (6)
	1991	0 (6)	0 (5)	0 (5)	0 (5)	20 (5)	33 (3)	67 (3)	67 (3)	33 (3)	50 (4)	50 (4)	0 (3)
	1992	0 (3)	0 (2)	33 (3)	50 (2)	50 (2)	33 (3)	25 (8)	33 (6)	33 (6)	33 (6)	67 (6)	67 (6)
	1993	80 (5)	0 (1)	0 (1)	0 (1)	0 (1)	100 (1)	0 (6)	0 (5)	0 (5)	25 (4)	0 (3)	0 (3)
	1994	0 (3)	0 (3)	0 (3)	0 (2)	0 (2)	0 (2)	0 (2)	50 (2)	0 (2)	0 (1)	0 (1)	0 (1)
	1995	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	13 (8)	38 (8)	25 (8)	25 (8)	14 (7)	14 (7)
	1996	14 (7)	14 (7)	14 (7)	14 (7)	14 (7)	0 (7)	14 (7)	0 (7)	0 (7)	0 (7)	0 (7)	0 (6)
	1997	0 (6)	0 (4)	0 (4)	0 (4)	0 (3)	0 (3)	0 (3)	–	0 (2)	0 (2)	0 (2)	0 (2)
	1998	0 (2)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	33 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
	1999	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	33 (3)	–	0 (2)	0 (2)	0 (2)	0 (1)
	2000	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	67 (3)	0 (2)	0 (2)	0 (2)	–	0 (2)
	2001	0 (3)	0 (3)	0 (1)	0 (3)	0 (4)	25 (4)	0 (1)	9 (11)	0 (11)	9 (11)	9 (11)	9 (11
	2002	9 (11)	10 (10)	9 (11)	9 (11)	17 (12)	9 (11)	10 (10)	11 (9)	12 (17)	13 (16)	8 (13)	0 (11
	2003	8 (13)	18 (11)	40 (10)	20 (10)	18 (11)	9 (11)	0 (25)	27 (22)	27 (22)	18 (22)	11 (18)	6 (17
	2004	6 (17)	8 (13)	7 (15)	7 (14)	13 (15)	0 (15)	0 (13)	8 (13)	17 (12)	73 (11)	45 (11)	40 (1(
	2005	38 (8)	25 (8)	29 (7)	25 (8)	38 (8)	0 (8)	35 (26)	64 (25)	29 (24)	35 (23)	23 (22)	18 (2:
	2006	18 (22)	18 (22)	14 (22)	9 (22)	29 (21)	14 (21)	58 (36)	6 (34)	13 (32)	34 (29)	0 (27)	0 (27
	2007	4 (25)	8 (25)	8 (24)	0 (23)	4 (23)	14 (22)	58 (19)	61 (18)	–	–	–	–
	Total	12 (137)	11 (121)	13 (120)	8 (119)	16 (121)	10 (118)	30 (182)	27 (174)	17 (164)	25 (157)	15 (143)	11 (13
CAH	1986	–	–	–	–	–	–	–	–	–	0 (3)	38 (8)	50 (8)
	1987	50 (8)	38 (8)	50 (8)	50 (8)	50 (8)	50 (8)	50 (8)	50 (8)	71 (7)	38 (8)	50 (8)	57 (7)
	1988	43 (7)	60 (5)	75 (4)	75 (4)	75 (4)	50 (4)	67 (6)	67 (6)	25 (4)	0 (6)	0 (5)	0 (5)
	1989	0 (4)	0 (4)	0 (4)	0 (4)	17 (6)	60 (5)	75 (8)	13 (8)	0 (7)	22 (9)	0 (7)	0 (7)
	1990	40 (5)	33 (6)	33 (6)	40 (5)	40 (5)	40 (5)	0 (1)	–	–	–	–	–
	2001	–	–	–	–	–	–	–	33 (9)	50 (8)	0 (10)	0 (10)	0 (1(
	2002	0 (10)	0 (9)	0 (9)	0 (9)	56 (9)	89 (9)	78 (9)	22 (9)	18 (11)	0 (11)	0 (11)	0 (11
	2003	0 (11)	0 (9)	17 (6)	0 (6)	20 (5)	75 (4)	0 (4)	0 (3)	0 (3)	33 (6)	0 (6)	0 (6)
	2004	0 (5)	0 (6)	0 (6)	0 (6)	33 (6)	67 (6)	17 (6)	0 (5)	0 (2)	0 (2)	0 (2)	0 (1)
	2005	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	–	–	–
	Total	18 (51)	17 (48)	23 (44)	21 (43)	41 (44)	62 (42)	51 (43)	29 (49)	28 (43)	13 (55)	12 (57)	15 (5:

Table 4. Percentage of GPS-collared caribou samples (*n*) from the Teshekpuk and Central Arctic herds that were within 48 km of CD-4 at least once in each month.

Month	Teshekpuk Herd (by year) 2004	2005	2006	2007	Total	Central Arctic Herd (by year) 2003	2004	2005	2006	Total
Jan.	–	10 (10)	–	0 (12)	5 (22)	–	0 (24)	0 (33)	0 (29)	0 (86)
Feb.	–	0 (10)	–	0 (12)	0 (22)	–	0 (24)	0 (33)	0 (29)	0 (86)
Mar.	–	0 (10)	–	0 (12)	0 (22)	–	0 (24)	0 (33)	0 (29)	0 (86)
Apr.	–	0 (10)	–	0 (11)	0 (21)	4 (24)	4 (24)	0 (33)	0 (29)	2 (110)
May	–	20 (10)	–	18 (11)	19 (21)	54 (24)	33 (24)	24 (33)	38 (29)	36 (110)
June	–	20 (10)	–	40 (10)	30 (20)	75 (24)	58 (24)	45 (33)	38 (29)	53 (110)
July	10 (10)	–	50 (12)	55 (11)	39 (33)	8 (24)	13 (24)	33 (33)	55 (29)	29 (110)
Aug.	20 (10)	–	8 (12)	73 (11)	33 (33)	13 (24)	4 (24)	27 (33)	0 (29)	12 (110)
Sep.	20 (10)	–	0 (12)	27 (11)	15 (33)	21 (24)	42 (24)	21 (33)	34 (29)	29 (110)
Oct.	70 (10)	–	67 (12)	36 (11)	58 (33)	8 (24)	0 (24)	9 (33)	14 (29)	8 (110)
Nov.	30 (10)	–	0 (12)	27 (11)	18 (33)	0 (24)	0 (24)	–	–	0 (48)
Dec.	30 (10)	–	0 (12)	18 (11)	15 (33)	0 (24)	0 (24)	–	–	0 (48)
Total	90 (10)	30 (10)	75 (12)	–	–	79 (24)	75 (24)	58 (33)	69 (29)	69 (110)

participation by many hunters in fall whaling. The timing of hunting in relation to seasonal use of the study area by caribou suggests that caribou harvested on the Colville delta by hunters in July and August were from the CAH in most years. In contrast, caribou harvested in the study area in October are much more likely to be TH animals migrating to winter range. Summer 2007 provided an exception to this general pattern, however, in that TH caribou appear to have used the delta more than did CAH caribou during the insect season (see Telemetry Summary section below).

GPS Collars

The percentages of the GPS-collared sample from the TH that were present at least once each month in the ASDP study area during 2004 and 2006–2007 were similar to those from satellite-collared caribou. Only 0–5% of the total sample of GPS-collared TH caribou was in the study area sometime between January and April (Table 4, Figure 8). The monthly percentages increased to 15–39% during May–September, peaked at 58% in October, and then declined to 15–18% during November–December. The percentages of the GPS-collared sample from the CAH that were present in the study area at least once during each month in 2003–2006 varied between 0 and 8% during the winter months of October–April (Table 4, Figure 8). The monthly percentage increased to 36% in May, peaked at 53% in June, and decreased to 12–29% in July–September.

The detailed movement tracks of the 11 TH caribou fitted with GPS collars in 2007 were examined in relation to the ASDP study area from late June through December (Figures 9 and 10). The seasonal movement patterns were broadly similar to the movement patterns of the 12 caribou outfitted with GPS collars from July 2006 to June 2007 (Appendices K and L), but several of the individuals collared in 2007 spent more time in the ASDP study area than did the collared animals in 2006, providing more baseline data on preconstruction use of the NPRA survey area. Eight of the 10 adult cows collared in 2007 had calves. Two (16.7%) of the 12 caribou collared in early July 2006 (Lawhead et al. 2007) died during late winter and spring 2007: Caribou 0627, a 2-yr-old female, died on 9 or 10 March on the North Fork of the Koyukuk River (Gates of the Arctic National Park; Appendix K) and Caribou 0616, an adult female, died on 14 May on the western bluff of the Colville River, 13 km downstream from the Anaktuvuk River confluence (Appendix L).

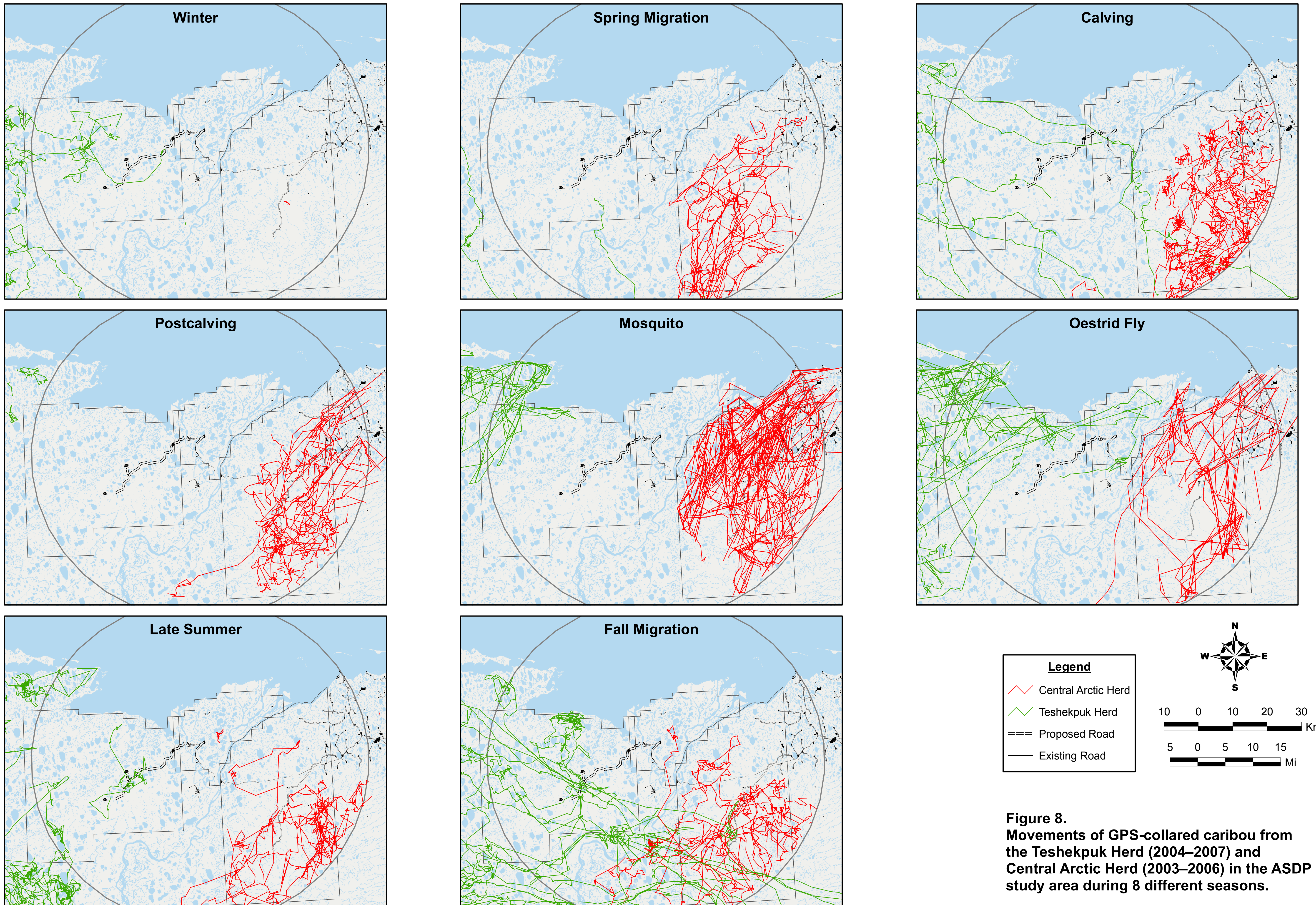
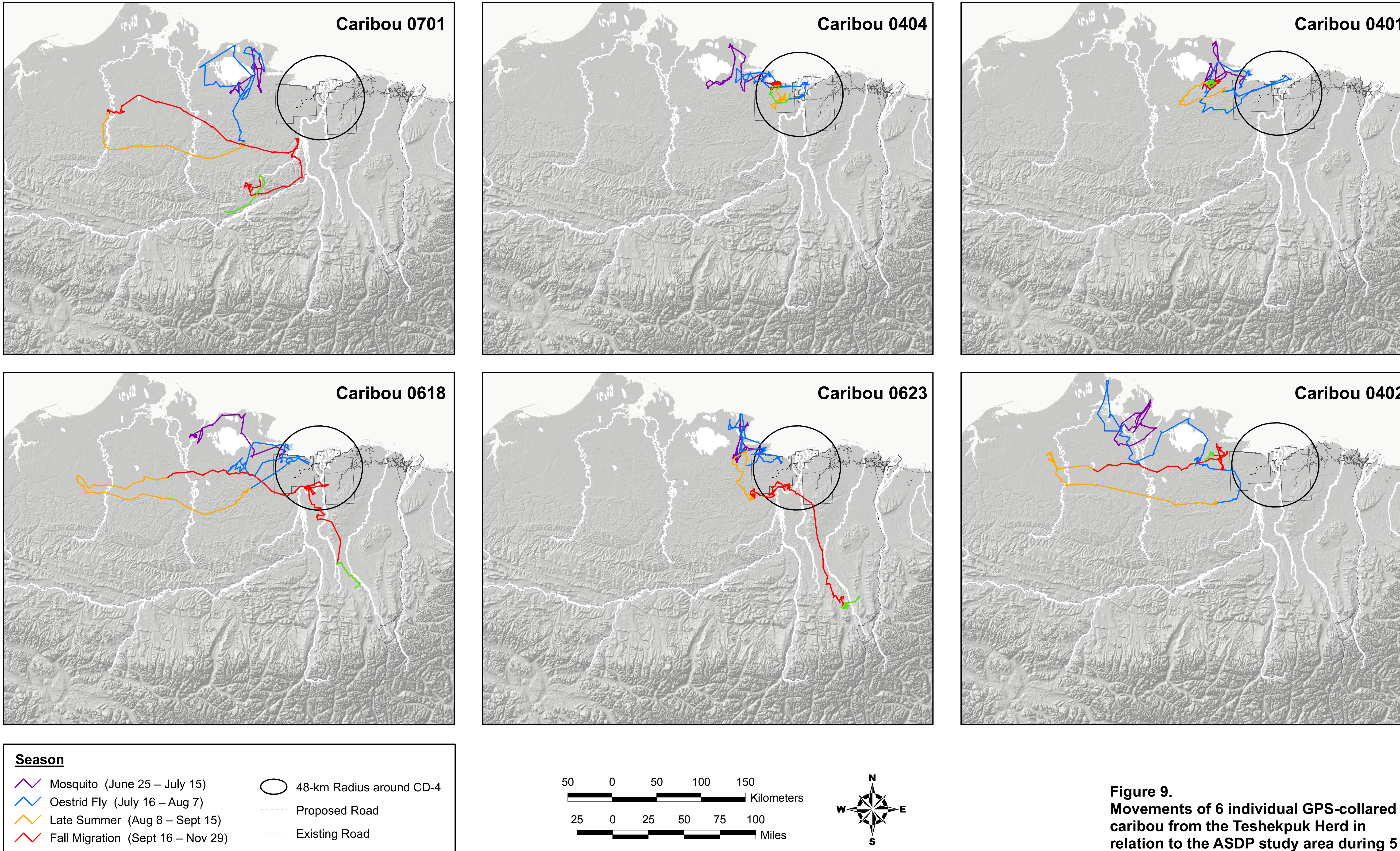


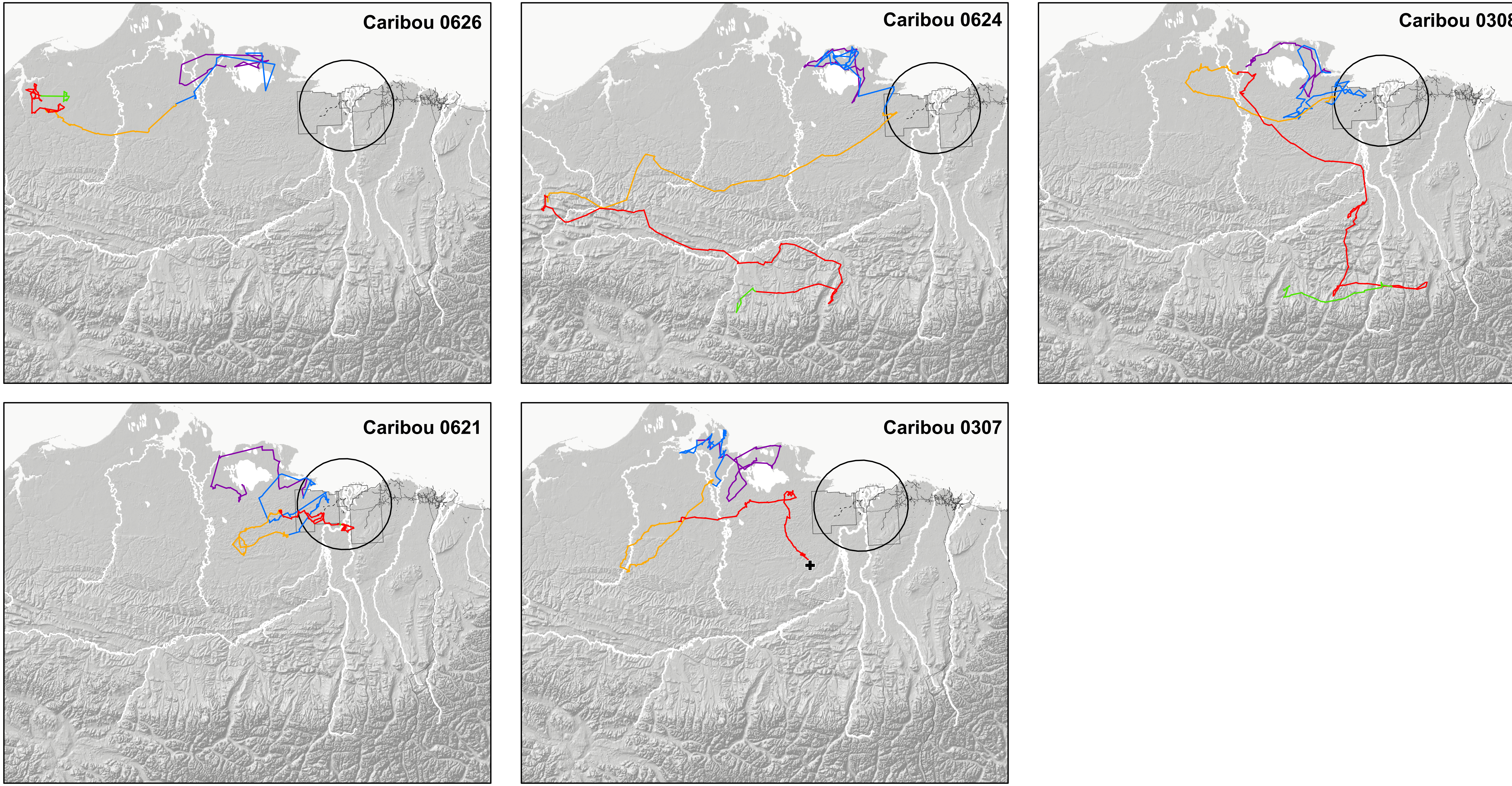
Figure 8.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2007) and Central Arctic Herd (2003–2006) in the ASDP study area during 8 different seasons.

ABR file: Fig08_GPS_07-164.mxd, 25 January 2008



ABR file: Fig09_TCH_GPS2007_07-164.mxd, 30 January 2008

Figure 9.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 5 different seasons, June–December 2007.



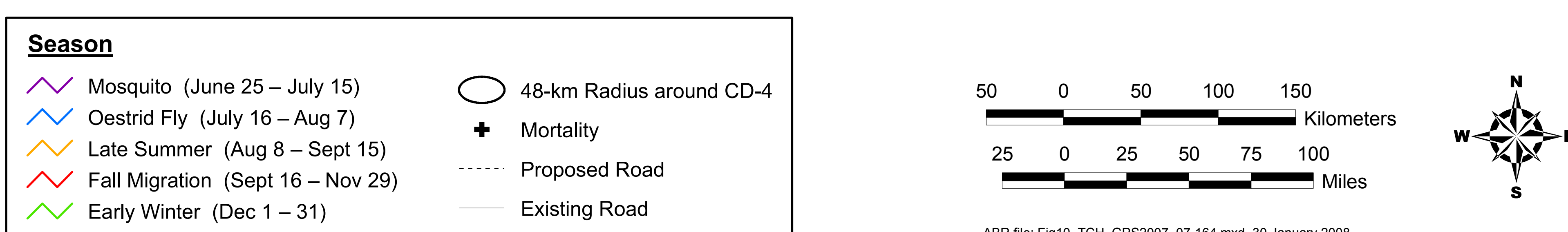


Figure 10.
Movements of 5 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 5 different seasons, June–December 2007.

In 2007, the area around Teshekpuk Lake was used extensively during the mosquito and early oestrid-fly seasons before the collared animals dispersed across the coastal plain later in the oestrid-fly season and in late summer. Eight of the 11 transmitting GPS collars moved into the ASDP study area during July or August (Table 4, Figures 9 and 10). Five collared caribou entered the study area in mid-July and 3 more entered the area in late July–early August. Several collared caribou moved very little in late summer but movements increased substantially in the fall as TH caribou began migrating southeast. Four of the 8 caribou in the study area in August moved out in that month, one left in October, one left in November, and 2 remained in the study area through December. At the end of December, 4 of the GPS-collared caribou were on the coastal plain southeast of Teshekpuk Lake, one was on the western coastal plain near Wainwright Inlet, and 5 were farther south along the northern side of the Brooks Range or the Upper Colville River. One animal died in mid-November and the whereabouts of the twelfth collar that was not transmitting to the Argos satellite were unknown. The identification numbers (shown on the map figures and in the individual narratives below) of recollared animals remained the same as originally assigned (03*xx* for 2003, 04*xx* for 2004, and 06*xx* for 2006 collar deployments).

Caribou 0701 — This yearling was newly collared southeast of Teshekpuk Lake on 25 June and remained near the lake during the mosquito and oestrid-fly seasons. It moved west toward Atqasuk during late summer, then east again to the Colville River during fall migration, and was still near the Colville River in December. It did not enter the ASDP study area in 2007.

Caribou 0404 — This adult cow was accompanied by a calf when she was recollared southeast of Teshekpuk Lake on 24 June. She remained between Teshekpuk Lake and the Colville delta throughout the rest of the year and was in the ASDP study area for most of the period between 13 July and the end of December.

Caribou 0401 — After this adult cow was recollared east of Teshekpuk Lake on 25 June, she remained between Teshekpuk Lake and the Colville delta for the rest of 2007; she was accompanied by a calf when collared. She moved onto the Colville delta briefly in late July before moving west toward Teshekpuk Lake, and spent the rest of the year west of the ASDP study area.

Caribou 0618 — This adult cow was accompanied by a calf when recollared west of Teshekpuk Lake on 25 June. She spent the mosquito season near Teshekpuk Lake, moved east to the western edge of the Colville delta during the oestrid-fly season, moved west of the Meade River and then east again during late summer, migrated to the upper Itkillik River during fall, and was in the upper Kuparuk River drainage during December.

Caribou 0623 — After being recollared east of Teshekpuk Lake on 24 June, this adult cow (which had a calf in 2007) remained north and east of Teshekpuk Lake during the mosquito and oestrid-fly seasons, briefly entering the northwestern portion of the ASDP study area in late July and early August. She remained west of the study area during late summer, crossed through the southern part of the study area during fall migration, and was near the upper Kuparuk River in December 2007.

Caribou 0402 — This adult cow was recollared west of Teshekpuk Lake on 25 June and spent the mosquito season west of Teshekpuk Lake; she was not accompanied by a calf when collared. During the oestrid-fly season, she first moved north toward Barrow and then southeast around Teshekpuk Lake, crossing into the western part of the ASDP study area briefly in early August. It moved west of the Meade River during late summer and then returned to the area southeast of Teshekpuk Lake, where it remained in December.

Caribou 0626 — An adult cow without a calf, this caribou was recollared west of Teshekpuk Lake on 25 June and remained near the lake for most of the mosquito and oestrid-fly seasons. She then moved west, almost to Wainwright Inlet, during late summer, where she remained through December. This caribou did not enter the ASDP study area in 2007.

Caribou 0624 — This adult cow was accompanied by a calf when recollared north of Teshekpuk Lake on 24 June, but probably had calved east of the Colville River (G. Carroll, ADFG, pers. comm.). She remained near Teshekpuk Lake for most of the mosquito and oestrid-fly seasons and moved into the western part of the ASDP study area briefly in early August. She moved southwest to the western Brooks Range, near the Utukok River, during late summer and turned east along the northern edge of the Brooks Range during fall migration. She was in the central Brooks Range in December 2007.

Caribou 0308 — This adult cow was accompanied by a calf when recollared west of Teshekpuk Lake on 25 June. She spent the mosquito season near Teshekpuk Lake, moved into the northern portion of the NPRA survey area in late July and early August, and then moved south of Teshekpuk Lake in late summer. She moved south to the northern Brooks Range foothills during fall and was northwest of Anaktuvuk Pass in December.

Caribou 0621 — A 2-year-old cow, this caribou was recollared south of Teshekpuk Lake on 24 June and remained in the area between Teshekpuk Lake and the Colville River for the rest of 2007. It was in the ASDP study area several times during the year, moving east of the Colville River into the western periphery of the Colville East survey area in late October, before moving south of Nuiqsut by December.

Caribou 0307 — This adult cow was accompanied by a calf when recollared north of Teshekpuk Lake on 25 June 2007. She stayed northwest of Teshekpuk Lake during the mosquito and oestrid-fly seasons, moved to the upper Meade River during late summer, and then moved south of the NPRA survey area during fall migration. She died about 18 November, approximately 80 km from the coast (Figure 10).

Caribou 0622 — No movement data are available yet for this adult cow because the satellite transmitter on the collar never functioned after she was recollared on 24 June (she was accompanied by a calf at that time). We think that GPS data currently are being acquired and stored in the collar memory and we hope that ADFG will be able to relocate this animal using the VHF transmitter and then retrieve the collar in June 2008, after which we will be able to download the data stored onboard the collar.

<u>Telemetry Summary</u>

The overall patterns of monthly occurrence by both satellite- and GPS-collared animals show that the ASDP study area is used at low to moderate levels by TH caribou throughout most of the year, predominantly in the western half of the study area. Through 2006, the highest use of the ASDP study area by TH caribou occurred in the fall, the only season in which collared TH animals moved east of the Colville River. That pattern mirrored the results of aerial transect surveys (Table 2, Figure 5, Appendices C–H). In 2007, however, the greatest level of use of the ASDP study area by collared TH caribou occurred during the insect season (late July and early August), although extensive movements again were observed in October during fall migration.

In contrast, use of the ASDP study area by CAH caribou is most extensive during the calving and postcalving periods in June, and virtually all of the CAH movements occurred east of the Colville River. Few collared CAH caribou were present in the study area during winter, especially in recent years; previous work found that few CAH caribou winter on the coastal plain (Murphy and Lawhead 2000, Arthur and Del Vecchio 2007). Use of the eastern half of the study area by CAH caribou was sporadic during the mosquito and oestrid-fly seasons, consistent with previous research that documented a strong relationship between local CAH movements on summer range in relation to temperature and prevailing wind conditions (White et al. 1975, Dau 1986, Lawhead 1988, Cameron et al. 1995). During mosquito harassment, CAH caribou typically head north to the coast and then move into the wind, which usually blows from the east–northeast. During less common periods of westerly winds, however, large numbers of CAH caribou occasionally move onto the Colville River delta.

Taken together (using all 3 types of transmitters), the telemetry data reveal little overlap in the summer ranges of the TH and CAH. Most CAH caribou remain east of the Colville River delta, most TH caribou stay west of it, and the existing Alpine facilities (including CD-4) are located between the normal herd ranges (Figures 6–10). Exceptional movements by both herds have been documented, however. The most notable instance occurred in July 2001, when at least 10,700 CAH caribou moved west onto the Colville River delta and at least 6000 of those animals continued across the delta into NPRA, with many remaining there into September (Lawhead and Prichard 2002, Arthur and Del Vecchio 2007). The ranges of the 2 herds overlap more in fall and winter, primarily because of the recent expansion of TH caribou into CAH range. Although most of the TH typically winters on the coastal plain, large numbers recently wintered south of the Brooks Range in areas used by the CAH or WAH (Prichard and Murphy 2004). In a highly unusual movement in 2003–2004, a large proportion of the TH moved east across the Colville River in the fall and wintered in and near ANWR (Carroll et al. 2004). Since that winter, large proportions of the TH have wintered in the traditional range of the CAH.

At least 3 influxes of large numbers of caribou onto the Colville River delta were recorded in July 2007, at least 2 of which comprised TH caribou (based on collared individuals). The first occurred when a fairly large number of caribou (hundreds and perhaps several thousand) were recorded by time-lapse cameras monitoring eider nests in the CD-3 vicinity on the outer delta on 5 July, corresponding with the first significant mosquito harassment of the season (J. Parrett, ABR, pers. comm.). All of the satellite and GPS collars on TH caribou were located 60–170 km away between the Kogru and Chipp rivers that day, so it is possible that the animals in the CD-3 area were from the CAH rather than the TH. Unfortunately, no satellite or GPS telemetry data were available for the CAH in 2007. The second large influx was in mid-July. ADFG biologists attempted a photocensus of the TH on 18 July when thousands of caribou were present on the delta (L. Parrett, ADFG, pers. comm.), including 2 TH satellite collars that remained on or near the delta during 18 July–4 August. Although the census attempt was curtailed by fog farther west in NPRA, good photographs were obtained of an aggregation numbering 3,241 caribou on the outer delta at the confluence of the Tamayayak and Sakoonang channels. The third large influx occurred at the end of July. CPAI personnel reported the presence of thousands of insect-harassed caribou on 26 July around the Alpine facilities on the central and inner delta, including the CD-4 pad and road (C. Rea, J. Blank, and J. Smith, CPAI, pers. comm.). One more satellite collar moved onto the delta that day, 2 GPS collars arrived by 27 July, and 3 more satellite collars arrived by 28 July. In all, 6 satellite collars and 2 GPS collars from the TH, potentially representing several thousand caribou, were present on the Colville delta in the last week of July and first week of August 2007.

Movements by collared TH and CAH caribou into the vicinity of CD-4 (between Nuiqsut and the Alpine processing facilities) have occurred sporadically and infrequently—during calving (early June), mosquito and oestrid-fly seasons (mid- to late July), and fall migration (late September)—since monitoring began in the late 1980s–early 1990s for satellite collars and in 2003–2004 for GPS collars (Figures 6–10). In 2007, 4 satellite-collared TH caribou moved east past Alpine and CD-4 (based on straight-line distances between satellite locations) as they moved to the eastern Colville delta in late July. An additional satellite-collared caribou passed between Nuiqsut and CD-4 as it moved northwest during calving 2007. None of the 102 satellite collars in the TH moved into the immediate vicinity of CD-4 during 1990–2006; the nearest was one female that moved from northwest of CD-4 to south of Nuiqsut on 30 September 2004, remaining west of the Nigliq Channel.

Of the 33 GPS collars on TH animals during 2004–2007, one crossed the delta westward between CD-4 and Alpine on 6 June 2005 en route to Teshekpuk Lake. Caribou 0404 spent 1–6 August 2007 about 2 km south of CD-4 before heading west. Of the sample of 17 satellite collars in the CAH during 1986–1990, one moved into the CD-4 vicinity briefly during 21–23 July 1988 and 4 were nearby during 11–13 July 1989. Of the sample of 17 CAH satellite collars during 2001–2005, 4 moved through the vicinity while heading inland on 28–30 July 2001, evidently after having been collared on the outer Colville delta. One of the 45 CAH GPS collars in the ASDP study area during 2003–2006 moved onto the Colville delta east of CD-4 on 27 September 2004.

A greater proportion of radio-collared caribou movements have occurred across the proposed ASDP road alignment in NPRA since 1990 than near CD-4, although such movements were not frequent. As expected on the basis of herd distribution (Figure 6), most of the crossings of the proposed road alignment were by TH caribou. Of the TH sample of 102 satellite collars (1990–2007), 23 animals crossed the alignment at least 36 times between September 1990 and August 2007. Crossings occurred in winter (February, April), spring (May), calving (June), oestrid-fly season (late July–early August), late summer (August–September), and fall migration (September–November). Of the TH sample of 33 GPS collars (2004–2007), 5 animals crossed the alignment near its western terminus during fall migration between 3 October and 18 November 2004 and another caribou crossed in early June 2005 near Alpine (the same animal mentioned above that passed between CD-4 and Alpine). Caribou 0404 crossed the proposed road corridor at least 25 times in August, September, and December 2007. Caribou 0621 crossed near the western end of the alignment in October 2007. Two of 16 satellite-collared CAH caribou in the late 1980s crossed the alignment near the present location of the Alpine facilities on 12 July 1989 (9 years before construction), the only satellite- or GPS-collared caribou from that herd to do so. Some VHF-collared CAH caribou probably crossed the proposed ASDP road alignments (including the CD-4 alignment before construction) with the aggregation of at least 6000 CAH caribou that moved west across the Colville delta and the NPRA survey area in late July 2001 (Lawhead and Prichard 2002, Arthur and Del Vecchio 2007), but they were not tracked frequently enough to document their route.

REMOTE SENSING

Because MODIS imagery covers large areas at relatively coarse resolution (500-m pixels), we were able to evaluate snow cover and vegetation indices over a much larger region than the ASDP study area at no additional cost. The region evaluated extends from the western edge of Teshekpuk Lake east to the Canadian border and from the Beaufort Sea inland to the northern foothills of the Brooks Range. The ability to examine this large region allowed us to place the ASDP caribou study area into a larger geographic context in terms of snowmelt and chronology of vegetation green-up.

SNOW COVER

Fair weather provided an unusual number of clear, cloud-free days in early June 2007, so we were able to acquire multiple images to calculate snowmelt during the calving period. The progression and pattern of snowmelt in 2007 were depicted and analyzed as a time series (Figure 11, first 6 map tiles), in which white represents complete snow cover, dark green depicts snow-free areas, and intermediate shades of green correspond to intermediate levels of subpixel snow cover. Black indicates unreliable data caused by clouds or sensor malfunction and blue was used for pixels in which >50% of the area (or >50% of one or more underlying 250-m pixels; see Methods) was pond, lake, river, or ice cover. Because the snow fraction is most relevant to caribou habitat conditions and the subpixel snow algorithm was developed for land applications, water-dominated pixels were masked and excluded from analysis.

Although much of the region was obscured by cloud cover on 21 May 2007, the visible portion of the image and our field observations on the aerial transect survey on 15 May indicated that virtually the entire study area was covered by snow. A large proportion of the area was still partially or entirely snow-covered on 2 June, but melt occurred rapidly in the ensuing few days. Very little snow remained in the area on 7 June 2007. A comparison of the dates of snowmelt observed in 2005, 2006 and 2007 (Figure 11) provides insight into the regional pattern of melt. In 2005 and 2007, snowmelt clearly occurred sooner in river valleys at lower elevations. This pattern most likely occurred in 2006 as well, but no cloud-free views of the northern coastal plain were available between 24 May and 9 June that year. The spatial pattern of snowmelt in 2005 and 2007 were similar, albeit with later melt in 2005 (the purple shade in the 2005 tile indicates that snowmelt occurred sometime between 9 June and 15 June 2005).

Comparison of the performance of the MODIS subpixel-scale snow-cover algorithm with aggregated Landsat imagery suggests that the overall performance of the subpixel algorithm is acceptable but that accuracy degrades near the end of snowmelt (Lawhead et al. 2006). Further research comparing Landsat data and oblique aerial photography will improve the accuracy and understanding of errors in subpixel-scale snow-cover mapping.

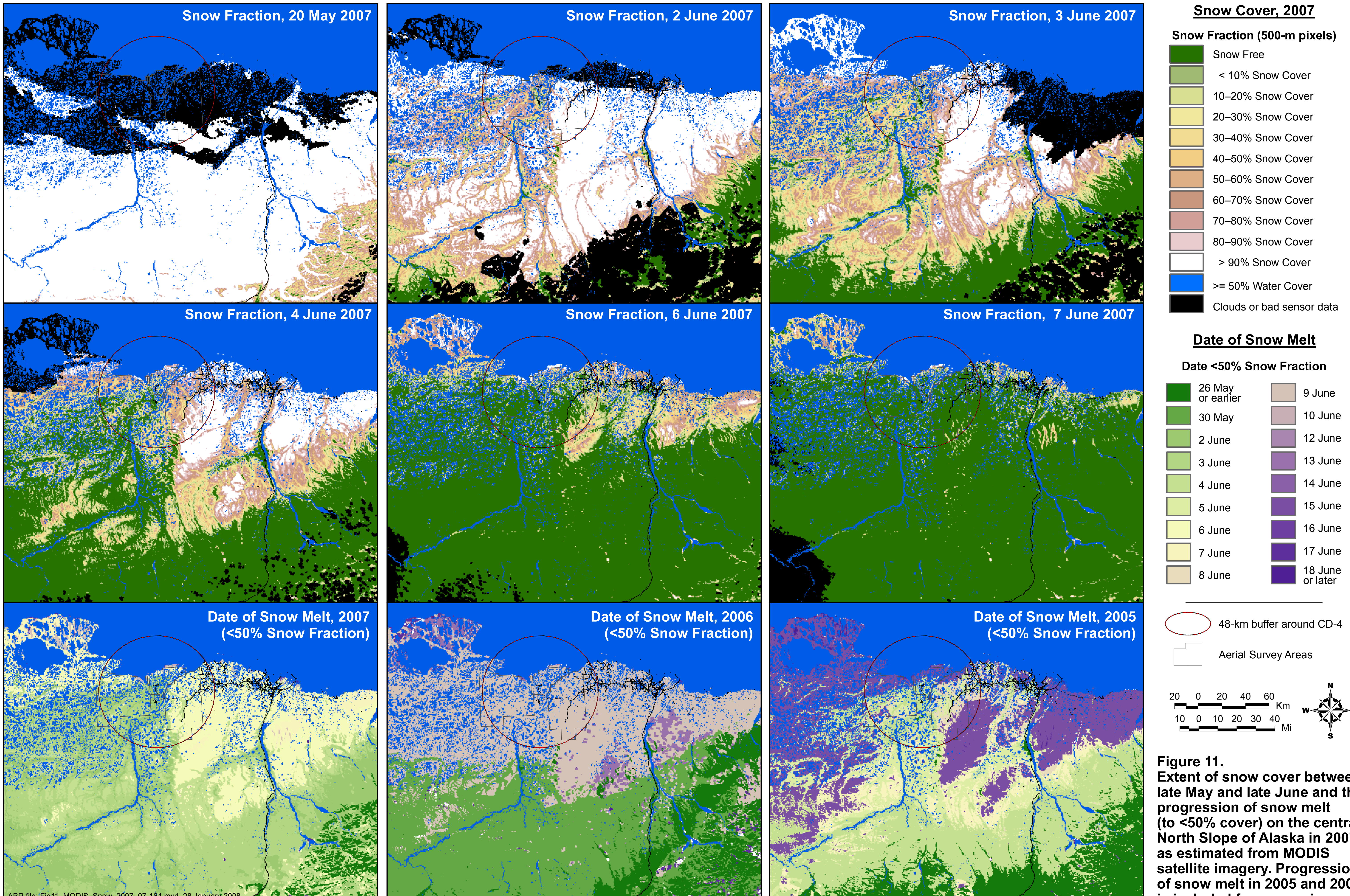


Figure 11.
Extent of snow cover between late May and late June and the progression of snow melt (to <50% cover) on the central North Slope of Alaska in 2007, as estimated from MODIS satellite imagery. Progression of snow melt in 2005 and 2006 is included for comparison.

VEGETATIVE BIOMASS

To examine the chronological dynamics of vegetation green-up, we examined a 6-year time series for the variables NDVI_calving, NDVI_621, and NDVI_rate (2007 data in Figure 12; 2002–2006 data in Lawhead et al. 2006, 2007). Care must be exercised in comparing NDVI values between the 2002–2003 images and the 2004–2007 images because the image-processing approach used with the earlier data differed somewhat. Reprocessing of archived data to the current Version-5 format should be done to facilitate future comparisons of imagery among all years in the data set.

By 21 June, the estimated date of peak lactation (Griffith et al. 2002), the study area is generally free of snow (other than incised valleys) but lake ice remains a prominent feature, particularly in the northern part of the region covered by the MODIS imagery. In previous (2002–2006) calculations of NDVI_621 values, a fringe of lower NDVI values was evident around many lakes on the northern coastal plain even with the water mask applied to pixels containing >50% water. This fringe indicated that the presence of lake ice lowered NDVI values in pixels adjacent to lakes and suggested that removal of the negative bias caused by subpixel-scale lake ice could be accomplished by masking more pixels around waterbodies. Therefore, we applied a larger mask around waterbodies to minimize this negative bias in the 2007 data.

In 2007, we used the late-fall NDVI values (22 September 2007) as the baseline levels of NDVI for each pixel (e.g., NDVI could not be lower than the value of standing dead biomass in late fall just before snowfall). Doing so had the effect of eliminating negative bias in NDVI caused by snow, water, and ice. In 2007, NDVI values in the northern half of the NPRA survey area during calving were equal to or lower than the late fall values, suggesting that little new vegetative growth was detected on the satellite imagery. The first flush of new vegetative growth that occurs in spring among melting patches of snow is valuable to foraging caribou (Klein 1990, Kuropat 1994, Johnstone et al. 2002), but the spectral signal of snow complicates NDVI-based inferences in patchy snow conditions. Variation in dates with clear-sky conditions in early June also can confound interpretation of the effect of snow cover on NDVI values. For example, the dates of imagery in 2002, 2004, and 2006 were a few days later than in 2003 and 2005. Snow cover typically changes rapidly in early June. Studies using a handheld spectrometer (Stow et al. 2004) and spectral-mixture models (Macander 2005) have demonstrated a large increase in NDVI associated solely with snowmelt. Therefore, we think it is more appropriate to infer habitat conditions from the subpixel-scale snow-cover fraction until all detectable snow in a pixel has melted, and then to incorporate NDVI metrics after pixels are snow-free. Combining climate modeling with satellite observations of snow cover offers a promising technique to infer snow cover more precisely, even under cloudy conditions.

Numerous cloud-free days during calving in 2007 allowed us to examine the relationship between snowmelt and NDVI empirically. We calculated the variables NDVI_calving and NDVI_rate using the same method as in previous years (using a baseline of zero) for several different days during the calving period, a time of rapid snowmelt. The resulting estimates of NDVI_calving and NDVI_rate varied widely depending on the date of the calving image (Figure 13), demonstrating the profound influence of snow cover on NDVI estimates at that time of year.

Beck et al. (2006) proposed that the NDVI value of senescent vegetation is more appropriate to use as a baseline for vegetative phenology calculations than are early-season NDVI values affected by snow. The NDVI of senescent vegetation can be calculated from imagery acquired in late fall after vegetation has senesced and before snow accumulation begins, but it cannot be calculated reliably in the spring because snowmelt and vegetation green-up commonly coincide. Late snowfall in 2007 provided an opportunity for the acquisition of suitable baseline images for senescent vegetation. A major tundra fire within the larger study area in late summer and fall 2007 complicated the analysis in 2 ways. First, there was substantial smoke in the air in late September, which tends to depress NDVI estimates. We minimized this effect by creating a winter NDVI composite, using the highest values from 18 and 22 September 2007. Second, the recent fire scar had extremely low NDVI, and so it was not an appropriate baseline for pre-fire images (i.e. early summer 2007) in the burned area. Because the fire scar was outside of our analytical area, however, we did not attempt to correct this bias.

We calculated the NDVI values from late fall (after senescence but before snowfall) as the baseline level for each pixel. The late-fall NDVI values are considered to represent the minimum value of the pixel when snow-free. We removed the effects of snow and ice by choosing the late-fall values if the NDVI_calving value was lower than the late-fall value. Therefore, the values of NDVI_rate calculated in this way better represent new vegetative growth rather than snowmelt.

Using the former method (zero-baseline estimation), the NDVI_calving and NDVI_rate estimates changed rapidly during early June. On 2 June, when the average snow fraction was 73% in the NPRA survey area, the estimated value of NDVI_calving was near zero and NDVI_rate was 0.020/day. On 7 June, when the average snow fraction was just 1%, the estimated value of NDVI_calving was 0.278 and NDVI_rate was 0.008 (Figure 14). The value of NDVI changed rapidly during snowmelt (~0.053/day). When snowmelt was nearly complete, the rate of change in NDVI declined rapidly to about 0.008.

Using the late-fall baseline, estimates of NDVI_calving were much higher than the values calculated using the zero-baseline approach of previous years (Figure 14). The value of NDVI_rate calculated using the late-fall baseline was very small (0.001/day), indicating that very little new vegetative growth had occurred in the study area before 21 June (Figure 15). This conclusion is supported by visual observations in the study on 21 June 2007, when very little green vegetation was visible. Because of the large amount of standing dead vegetation in arctic tundra landscapes, much of the new growth below the existing litter cover is less detectable by satellite. The rate of change in NDVI from 21 June to the peak level (measured on 8–11 August) was greater (0.003/day; Figure 14). We expect that using late-fall baseline estimation of NDVI values will improve among-year comparisons of vegetative phenology early in the growing season.

After snowmelt is complete, the spatial pattern of relative NDVI values in a given area remains remarkably similar. NDVI_621, although lower overall, is highly correlated with NDVI_peak, which was highly correlated and similar in value among years. This pattern suggests that the absolute value of NDVI is influenced by the phenological stage of the vegetation in the early stages of growth and by remnant snow and ice cover, but that the peak value of NDVI relative to surrounding pixels is determined by the proportion of water and type of vegetation in the pixel, factors that change little among years.

CARIBOU DISTRIBUTION ANALYSES

GEOGRAPHIC LOCATION

The distribution of caribou groups during aerial transect surveys was not uniform across the 6 geographic sections analyzed in the NPRA survey area (Figure 2) in most seasons and years (Table 5). In this analysis, habitat availability differed between the 2002–2004 and 2005–2007 survey areas. Variation in NDVI values and in the distribution and abundance of habitat types among geographic sections (Appendix M) influenced the seasonal differences in caribou distribution. We focus here on analytical results using the pooled 6-year transect data set (2002–2007; Table 5); the patterns of significance found within individual years generally were similar but often not significant due to smaller sample sizes.

For the pooled 2002–2007 sample, significantly more groups of caribou occurred in the North, River, and Southwest sections than would be expected if caribou were distributed uniformly among sections (Table 5). The North section contained fewer groups during winter and more groups during spring migration and the mosquito season. The River section contained more groups during the postcalving season and late summer. The Southwest section contained more groups during calving and fall migration, but fewer during the mosquito season. The West section contained more groups during calving and fewer during the oestrid-fly season; this section had the fewest departures from a uniform distribution.

Over all years and seasons except winter, the Southeast section, which includes nearly the entire length of the proposed ASDP road alignment,

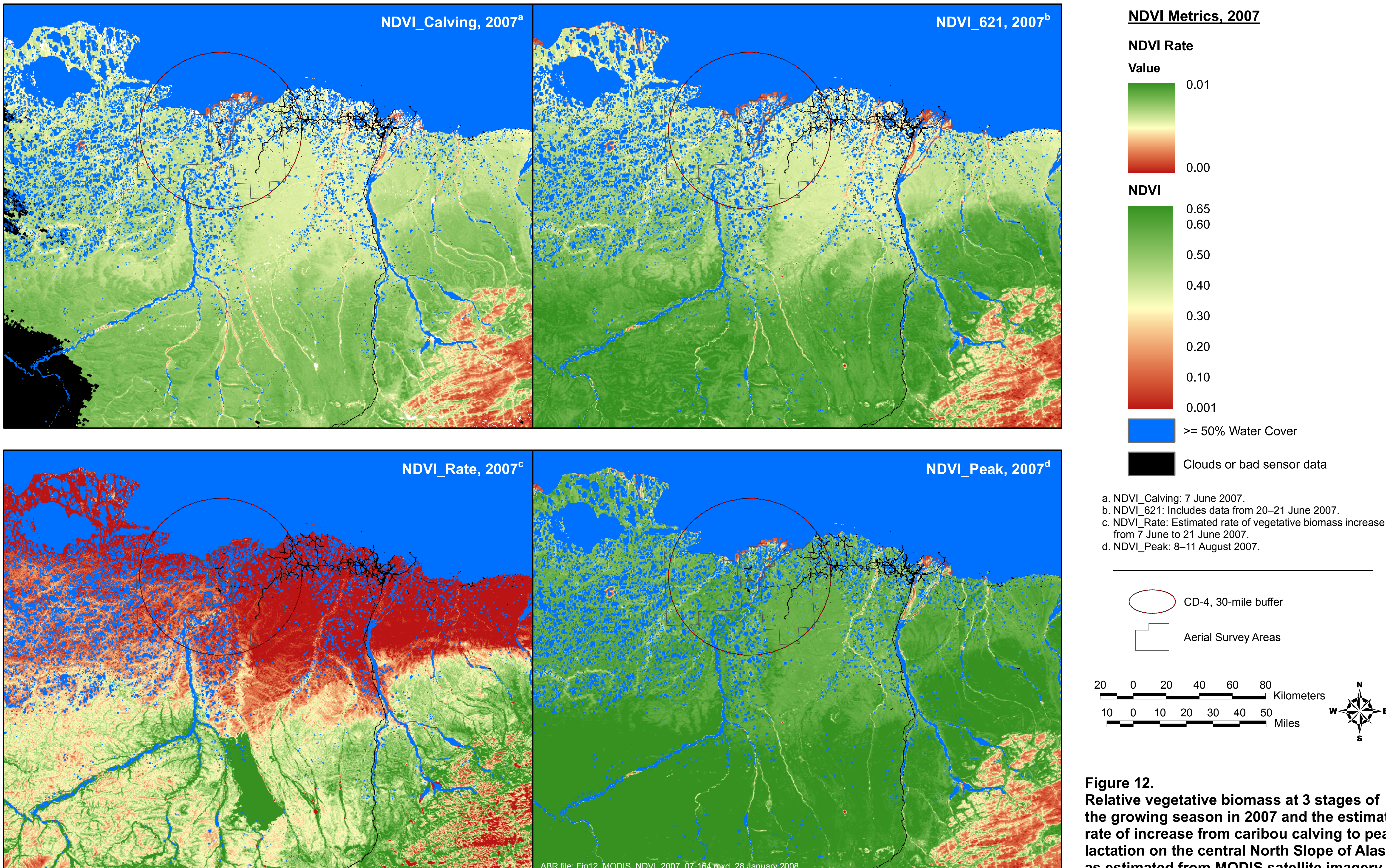


Figure 12.
Relative vegetative biomass at 3 stages of the growing season in 2007 and the estimated rate of increase from caribou calving to peak lactation on the central North Slope of Alaska, as estimated from MODIS satellite imagery.

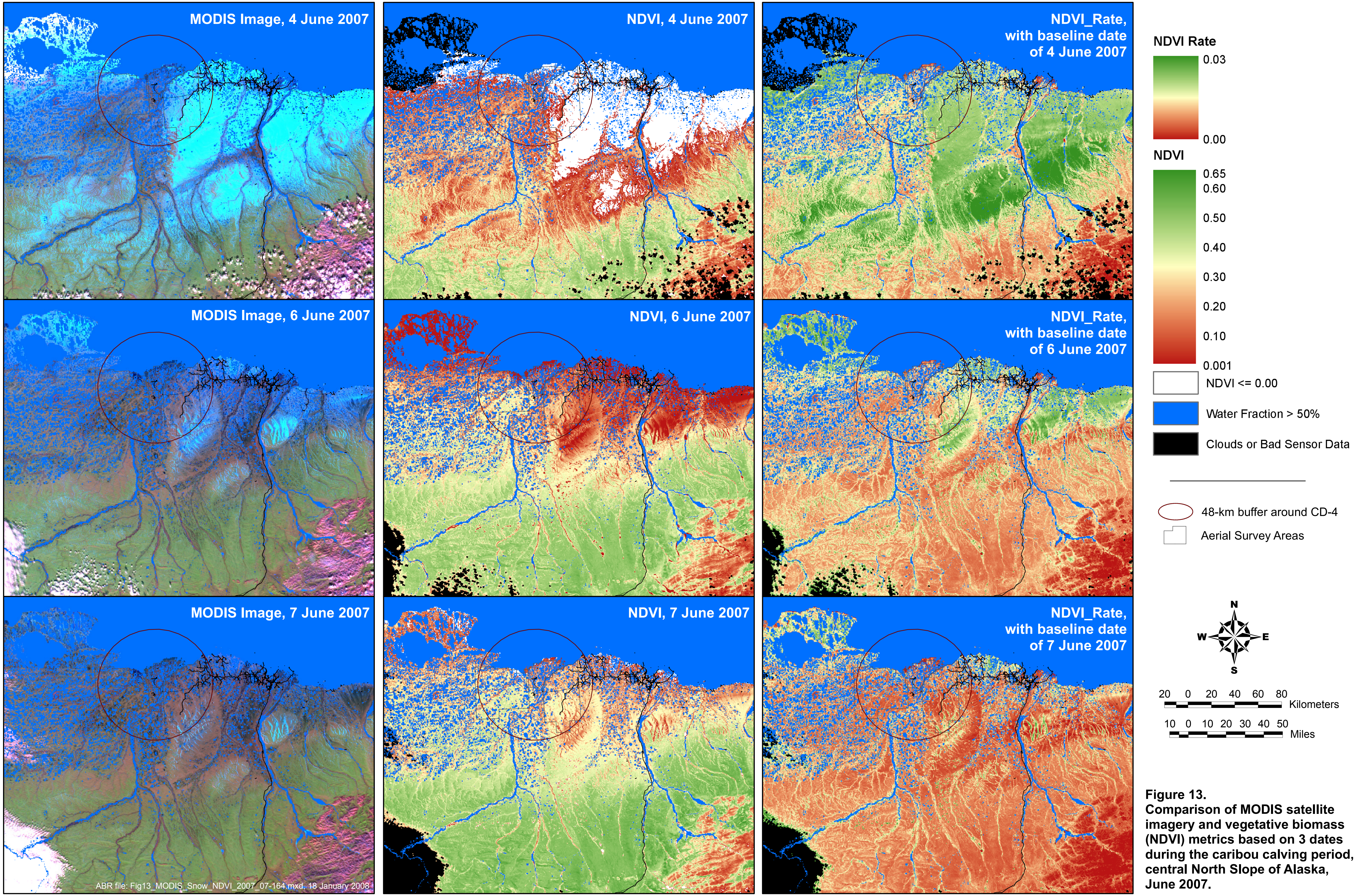


Figure 13.
Comparison of MODIS satellite imagery and vegetative biomass (NDVI) metrics based on 3 dates during the caribou calving period, central North Slope of Alaska, June 2007.

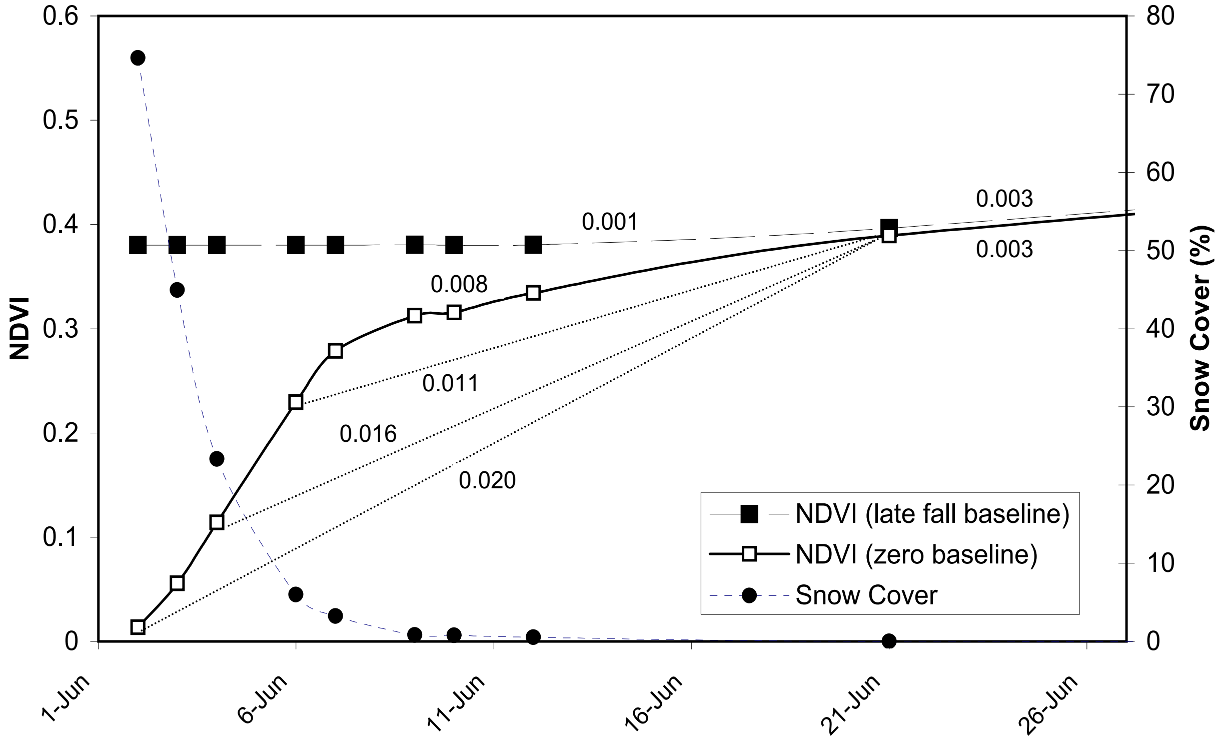


Figure 14. Change in relative vegetative biomass (NDVI, as estimated from MODIS satellite imagery) by date in the NPRA survey area during 2007, illustrating the difference between using zero (solid line) or the late-fall NDVI value (long dashed line) as the baseline for calculating the estimated rate of increase (NDVI_rate) from calving (1–10 June) to peak lactation (21 June). The estimated rate of increase (dotted lines) was influenced substantially by the amount of snow cover remaining at different starting dates during the caribou calving period.

contained fewer groups than would be expected if caribou distribution were uniform (Table 5). The Coast section also tended to contain fewer groups, with the differences being significant during winter, calving, postcalving, late summer, and fall migration (Table 5). During the mosquito season, however, caribou groups were significantly more numerous in the Coast section, which is consistent with the well-documented use of coastal mosquito-relief habitat by caribou. During the oestrid-fly season, the number of groups in the Coast section did not differ from expected values, but this group-based analysis does not reflect the large numbers of caribou found in a few groups in the Coast section on 2 August 2005, a date on which mosquitoes also were active and affecting caribou distribution. The results for 2007 were generally consistent with the patterns observed for all years combined.

These results are interpretable within the context of general patterns of caribou movements on the central Arctic Coastal Plain. During calving, the highest densities of TH females calve near Teshekpuk Lake, so densities decrease farther from the lake (Prichard and Murphy 2004, Carroll et al. 2005); hence, more caribou would be expected in the western portion of the NPRA survey area in that season. When mosquito harassment begins in late June or early July, caribou move toward the coast where lower temperatures and higher wind speeds prevail. When oestrid flies emerge, typically by mid-July, the large groups that formed in response to mosquito harassment break up and caribou disperse, seeking elevated or barren habitats such as sand dunes, mudflats, and river bars (Lawhead 1988, Prichard and Murphy 2004). The riverine habitats along Fish and Judy creeks provide a complex interspersion of barren ground,

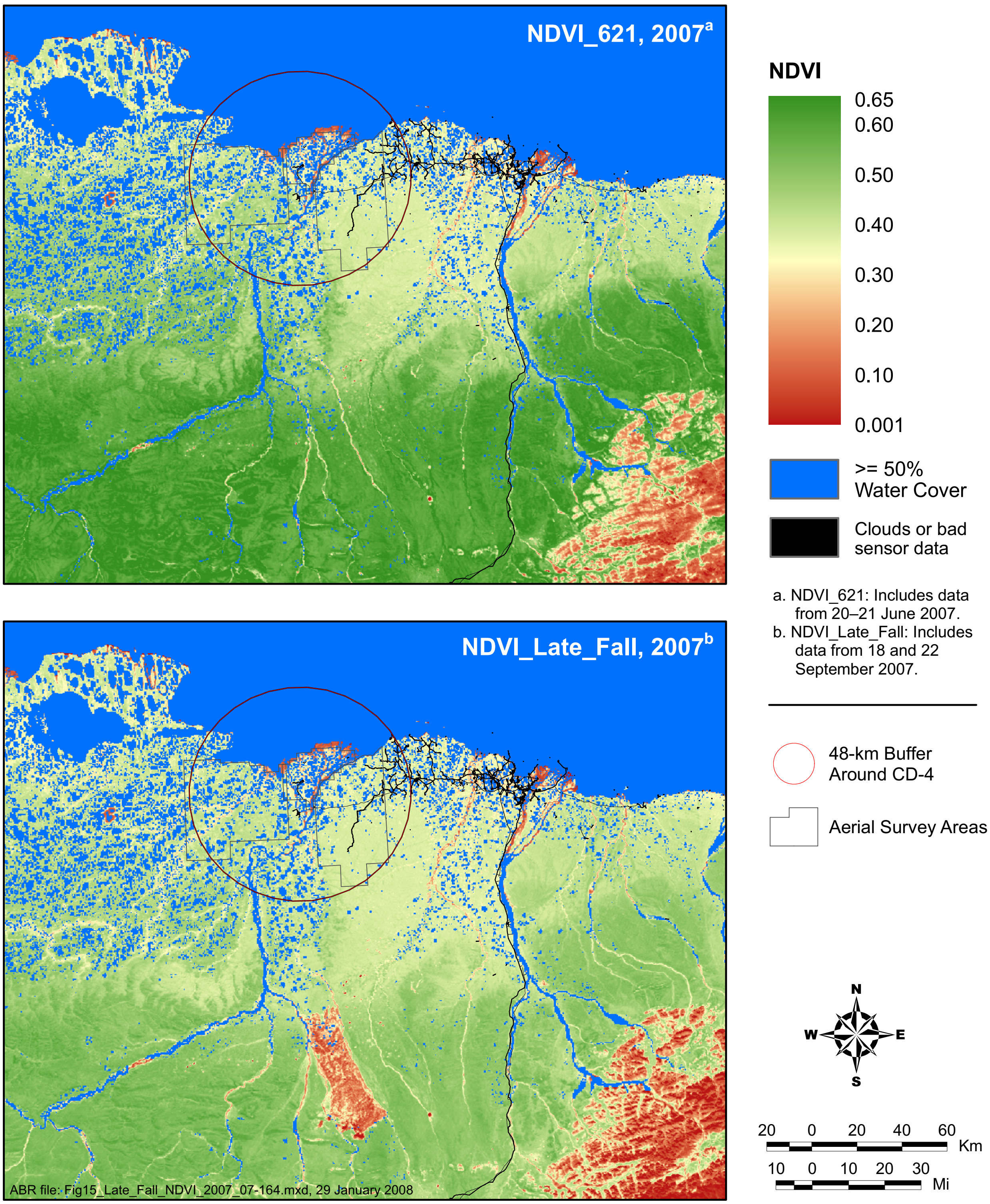


Figure 15. Relative vegetative biomass at peak lactation for caribou (June 21) and late fall (September 22) 2007, as estimated from MODIS satellite imagery.

Table 5. Number of caribou groups in different geographic sections of the NPRA survey area, by year and season, with results of chi-square goodness-of-fit tests (assuming a uniform distribution).

				Geographic Section							
Year(s)	Season	No. of Surveys	Total Groups	Coast	North	River	South east	South west	West	Chi-square	*P*-value
2002	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	2	126	0	26	13--	40	36	11	25.80	<0.001
	Calving	1	116	1	23	42	22--	21	7	22.18	<0.001
	Postcalving	1	82	0	13	45^{++}	12--	3--	9	58.61	<0.001
	Mosquito	1	5	0	4^{++}	1	0	0	0	22.81	<0.001
	Oestrid Fly	3	24	0	0	18^{++}	2--	3	1	34.14	<0.001
	Late Summer	3	201	1	32	82^{++}	42--	35	9	39.71	<0.001
	Fall Migration	3	148	0	7--	33	23--	72^{++}	13	79.44	<0.001
	Total	14	702	2--	105	234^{++}	141--	170	50	85.02	<0.001
2003	Winter	1	313	1--	28	75	97	97^{++}	15	21.64	<0.001
	Spring Migration	1	13	0	3	4	1--	4	1	5.19	0.393
	Calving	2	101	0	12	26	22--	32	9	13.44	0.020
	Postcalving	2	273	1--	37	90^{+}	64^{--}	54	27	29.29	<0.001
	Mosquito	1	1	0	1	0	0	0	0	7.44	0.190
	Oestrid Fly	2	116	1	6--	61^{++}	24--	23	1--	54.15	<0.001
	Late Summer	1	37	0	10	15	7	4	1	16.95	0.005
	Fall Migration	3	431	2--	46	140^{++}	64^{--}	152^{++}	27	105.28	<0.001
	Total	13	1285	5--	143	411^{++}	279^{--}	366^{++}	81	138.82	<0.001
2004	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	1	5	0	1	1	3	0	0	2.66	0.753
	Calving	0	–	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–	–
	Mosquito	1	2	0	0	2	0	0	0	6.18	0.289
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–
	Late Summer	2	75	0	14	34^{++}	9--	16	2	30.14	<0.001
	Fall Migration	1	66	2	9	10	41^{++}	4--	0	28.35	<0.001
	Total	5	148	2	24	47	53	20^{-}	2--	15.05	0.010
2005	Winter	1	98	11	19	15	14--	32^{++}	7	24.46	<0.001
	Spring Migration	0	–	–	–	–	–	–	–	–	–
	Calving	2	98	3--	15	10-	21	43^{++}	6	57.94	<0.001
	Postcalving	1	112	7	29	27	16--	25	8	14.15	0.015
	Mosquito	1	32	10	7	6	4	1--	4	24.81	<0.001
	Oestrid Fly	1	25	8	3	8	5	1--	0	19.44	0.002
	Late Summer	2	29	2	11	3	6	6	1	5.23	0.388
	Fall Migration	1	46	2	11	8	13	10	2	2.40	0.791
	Total	9	440	43	95	77	79--	118^{++}	28	46.44	<0.001
2006	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	1	79	14	40^{++}	8-	9--	7	1	46.85	<0.001
	Calving	1	118	3--	32	13-	23	35^{++}	12	34.87	<0.001
	Postcalving	1	88	3--	22	40^{++}	11--	9	3	44.63	<0.001
	Mosquito	1	0	0	0	0	0	0	0	–	–
	Oestrid Fly	1	32	0	14	11	3--	4	0	18.65	0.002
	Late Summer	2	94	7	26	31^{+}	12--	14	4	18.04	0.003
	Fall Migration	1	5	0	0	1	4^{+}	0	0	7.89	0.163
	Total	8	416	27--	134^{++}	104^{+}	62--	69	20	51.25	<0.001
2007	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	1	159	13	44	44	26--	24	8	15.02	0.010
	Calving	1	198	4--	44	22--	40	72^{++}	16	76.16	<0.001
	Postcalving	1	178	3--	60^{+}	49	37	23	6	32.47	<0.001
	Mosquito	1	62	8	31^{++}	15	7--	1--	0	38.30	<0.001
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–
	Late Summer	2	83	8	19	31^{++}	14	8	3	19.81	0.001
	Fall Migration	3	347	20--	94	63	112	48	10	16.42	0.005
	Total	9	1027	56--	292^{++}	224	236-	176	43	46.10	<0.001

Table 5. Continued.

Year(s)	Season	No. of Surveys	Total Groups	Geographic Section: Coast	North	River	South east	South west	West	Chi-square	*P*-value
2002–2007	Winter	2	411	12--	47--	90	111	129++	22	54.16	<0.001
	Spring Migration	6	382	27	114++	70	79--	71	21	65.92	<0.001
	Calving	7	631	11--	126	113	128--	203++	50+	125.80	<0.001
	Postcalving	6	733	14--	161	251++	140--	114	53	124.98	<0.001
	Mosquito	6	102	18+	43++	24	11--	2--	4	82.12	<0.001
	Oestrid Fly	7	197	9	23	98++	34--	31	2--	87.89	<0.001
	Late Summer	12	519	18--	112	196++	90--	83	20	106.98	<0.001
	Fall Migration	12	1043	26--	167	255	257--	286++	52	76.16	<0.001
	Total	58	4018	135--	793++	1097++	850--	919++	224	272.62	<0.001
Available area, 2002–2004 (km²)				8.9	64.8	133.7	191.0	115.9	32.3		
Available area, 2005–2007 (km²)				70.7	160.9	136.0	191.0	116.1	32.3		

+ Use greater than expected ($P < 0.05$).
++ Use greater than expected ($P < 0.01$).
- Use less than expected ($P < 0.05$).
-- Use less than expected ($P < 0.01$).

dunes, and sparse vegetation (Figure 3, Appendix M) that provide good fly-relief habitat near foraging areas.

The Southwest section consistently contained higher densities of caribou than did the Southeast section. The reasons for this difference are not clear, but possible explanations may include distance from Teshekpuk Lake and location on the fringe of the TH range, differences in habitat quality, or avoidance of human activity (near Nuiqsut or avoidance of infrastructure at a scale not documented). Whatever the reason, it is important to recognize that this pattern of distribution exists before construction of the ASDP pipeline/road corridor.

HABITAT USE

Caribou group locations during transect surveys were significantly related to the distribution of habitat types in the NPRA earth-cover classification (BLM and Ducks Unlimited 2002). The numerous combinations of seasons, years, and habitat classes resulted in a complex matrix of test results (Table 6) with variable data among years. As in the geographic analysis above, the pooled-year samples provided larger sample sizes, so this section focuses primarily on those results.

Across all seasons and years (2002–2007), the proportions of caribou groups using riverine habitats and the moss/lichen and dwarf-shrub types—3 of the 4 least abundant classes—were significantly greater than expected based on the relative availability of those habitats, whereas the proportions of groups using flooded tundra and tussock tundra—the 2 most abundant classes—were significantly less than expected (Table 6). Riverine habitats were used more than expected during postcalving, oestrid-fly season, and fall migration, consistent with the geographic analysis above, and dwarf shrub was used more than expected during late summer. The proportion of caribou groups using tussock tundra was less than expected during summer (mosquito, oestrid-fly, and late summer seasons). *Carex aquatilis* was used more than expected during the mosquito and oestrid-fly seasons but less than expected during postcalving. Flooded tundra was used less during calving, postcalving, and fall migration. Use of sedge/grass meadow was greater than expected during spring migration and calving, but less during oestrid-fly season and late summer. The moss/lichen class was used less in winter and more than expected during the oestrid-fly season, late summer, and fall migration. The moss/lichen class occurred in higher proportions in riverine areas; the reason for avoidance of that type in winter is unknown, but may be related to limited distribution of the type in the survey area or the small sample ($n = 2$) of surveys in that season.

Table 6. Seasonal use of different habitat types by caribou, expressed as use (% of the area within 100 m of each group) divided by availability (% of area, excluding water), in the NPRA survey area, 2002–2007.

				Habitat Type[a]								
Year	Season	No. of Surveys	No. of Groups	*Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine[b]
2002	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	2	126	0.99	0.91	0.89	1.42^{++}	1.03	0.14--	0.83	1.17	0.06--
	Calving	1	116	1.01	0.90	1.04	1.05	0.91	1.31	1.55^{+}	0.29	1.92
	Postcalving	1	82	0.91	0.70--	1.01	1.07	1.03	1.87	0.78	0.29	2.70^{++}
	Mosquito	1	5	0.69	0.98	1.49	1.14	0.75	0.42	1.47	0	2.98
	Oestrid Fly	3	24	1.13	0.79	1.05	0.64	0.69	1.08	1.96	1.00	7.97^{++}
	Late Summer	3	201	1.02	1.02	0.99	0.80--	0.74--	2.18^{++}	1.44^{+}	2.14	4.89^{++}
	Fall Migration	3	148	1.24	1.01	1.15	0.98	0.86	1.34	1.32	0.34	1.25
	Total	14	702	1.05	0.93	1.02	1.02	0.88--	1.41^{+}	1.26^{+}	1.01	2.60^{++}
2003	Winter	1	313	1.01	0.89	0.93	0.93	1.07	0.76	1.35^{+}	0.77	1.06
	Spring Migration	1	13	0.85	1.02	0.83	1.46	0.91	1.68	1.14	0.00	0.46
	Calving	2	101	1.12	0.75-	1.01	0.99	1.00	1.60	1.01	0.62	2.49^{++}
	Postcalving	2	273	0.93	0.91	0.96	1.05	0.95	1.19	1.01	1.05	2.69^{++}
	Mosquito	1	1	2.77	1.57	1.04	2.22	0.07	0	0	0	0
	Oestrid Fly	2	116	1.02	1.05	1.08	0.57--	0.69--	3.34^{++}	1.39	2.56	5.66^{++}
	Late Summer	1	37	0.90	1.00	0.95	1.59^{+}	0.82	1.39	0.77	0.00	1.15
	Fall Migration	3	431	1.08	0.90	1.00	0.94	0.97	1.66^{++}	1.30	1.92	1.49^{+}
	Total	13	1285	1.02	0.91--	0.98	0.96	0.96	1.48^{++}	1.22^{++}	1.33	2.08^{++}
2004	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	5	0.80	1.56	0.87	0.58	0.41	14.20^{++}	0.35	8.29	2.03
	Calving	0	–	–	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–	–	–
	Mosquito	1	2	3.68	2.10	0.61	1.24	0.04	0	0	0	0.70
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	2	75	1.03	0.93	1.14	0.85	0.72--	2.45^{+}	1.45	0.76	4.80^{++}
	Fall Migration	1	66	1.20	0.98	0.86	0.69-	1.08	1.01	1.19	1.39	1.28
	Total	5	148	1.14	0.99	1.00	0.78-	0.86-	2.17^{++}	1.28	1.28	3.08^{++}
2005	Winter	1	98	1.20	1.12	0.90	1.00	1.04	0.42-	0.93	0.32	0.14--
	Spring Migration	0	–	–	–	–	–	–	–	–	–	–
	Calving	2	98	0.64-	0.77-	0.86	1.17	1.23^{+}	0.55	0.99	1.76	0.47
	Postcalving	1	112	0.80	0.73-	0.97	1.24	1.11	1.08	1.19	2.13	0.49
	Mosquito	1	32	2.18^{++}	0.95	0.78	0.96	0.51--	2.88^{+}	1.29	2.39	3.33^{++}
	Oestrid Fly	1	25	3.33^{++}	1.47^{+}	0.72	0.29--	0.25--	2.51	0.30	0	4.86^{++}
	Late Summer	2	29	1.75^{+}	1.00	0.91	0.70	0.93	1.56	1.74	0	0.78
	Fall Migration	1	46	0.97	0.97	0.98	1.20	0.99	0.61	0.72	0	0.98
	Total	9	440	1.18^{+}	0.93	0.90	1.06	1.00	1.01	1.03	1.18	0.93
2006	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	79	1.00	0.89	1.10	1.23	0.97	0.94	0.81	0	0.75
	Calving	1	118	0.96	0.89	0.87	1.33^{++}	1.08	0.64	0.71	0.77	0.08--
	Postcalving	1	88	0.60-	0.93	1.27^{+}	1.00	0.85	1.67	1.24	4.40^{+}	2.35^{++}
	Mosquito	1	0	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	32	1.10	1.15	1.18	1.19	0.73	0.51	1.17	0	1.46
	Late Summer	2	94	0.80	0.79	1.12	1.08	0.87	2.69^{++}	1.47	0.65	2.06^{+}
	Fall Migration	1	5	0.84	0.32	0.51	0.14-	1.39	0.57	3.04	9.56	4.06
	Total	8	416	0.86	0.89	1.08	1.16^{+}	0.94	1.37	1.07	1.41	1.29
2007	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	159	1.21^{+}	1.18	0.99	1.19	0.85-	1.14	0.74	0.68	0.49
	Calving	1	198	0.97	0.92	0.96	1.13	1.12	0.37--	0.77	0.61	0.27--
	Postcalving	1	178	0.86	0.86	1.00	0.99	1.04	1.19	1.10	0.57	1.53
	Mosquito	1	62	1.15	0.94	1.00	1.16	0.85	1.55	0.99	0.00	1.60
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	2	83	1.18	0.98	1.08	0.51--	0.66--	1.17	1.76^{+}	4.14	5.21^{++}
	Fall Migration	3	347	0.93	0.91	0.97	1.06	1.09	1.11	0.91	0.44	0.59
	Total	9	1027	1.00	0.95	0.99	1.04	1.00	1.02	0.96	0.81	1.11

Table 6. Continued.

Year	Season	No. of Surveys	No. of Groups	Habitat Type [a]								
				Carex aquatilis	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2002–2007	Winter	2	411	1.05	0.97	0.94	0.90	1.08	0.67-	1.27	0.73	0.65
	Spring Migration	6	382	1.08	1.01	0.96	1.31^{++}	0.92	0.97	0.78	0.78	0.51
	Calving	7	631	0.95	0.86--	0.95	1.15^{+}	1.07	0.81	0.98	0.73	0.75
	Postcalving	6	733	0.85-	0.85--	1.02	1.05	0.99	1.31	1.06	1.37	1.85^{++}
	Mosquito	6	102	1.52^{++}	0.95	0.93	1.17	0.70-	1.88	1.06	0.67	2.52
	Oestrid Fly	7	197	1.34^{++}	1.09	1.05	0.65--	0.64--	2.49^{++}	1.29	1.75	4.73^{++}
	Late Summer	12	519	1.04	0.97	1.05	0.84-	0.77--	2.05^{++}	1.47^{++}	1.76	3.51^{++}
	Fall Migration	12	1043	1.05	0.93-	1.00	0.97	1.01	1.34^{+}	1.16	1.20	1.01
	Total	58	4018	1.02	0.93--	0.99	1.01	0.96--	1.31^{++}	1.13^{+}	1.16	1.59^{++}
Availability, 2002–2004				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability, 2005–2007				8.4%	18.7%	10.5%	16.5%	37.3%	1.5%	3.2%	0.2%	3.7%

[a] NPRA earth-cover classification (BLM and Ducks Unlimited 2002).
[b] Riverine type comprises Dry Dunes, Sparsely Vegetated, and Barren Ground subtypes.
$^{+}$ Use greater than expected (P < 0.05).
$^{++}$ Use greater than expected (P < 0.01).
\- Use less than expected (P < 0.05).
-- Use less than expected (P < 0.01).

During calving, caribou may seek dry, snow-free areas, but habitat type generally was a poor predictor of group location during calving in the NPRA survey area at the scale of our analysis. Comparison across studies is complicated by the fact that different investigators have used different habitat classifications. Kelleyhouse (2001) reported that TH caribou selected wet graminoid vegetation during calving and Wolfe (2000) reported that CAH caribou selected wet graminoid or moist graminoid classes; both of those studies used the classification by Muller et al. (1998, 1999). Using a classification similar to the ELS scheme developed by Jorgenson et al. (2003), Lawhead et al. (2004) found that CAH caribou in the Meltwater study area in the southwestern Kuparuk Oilfield and the adjacent area of concentrated calving selected moist sedge–shrub tundra, the most abundant type, during calving. Using the NPRA earth-cover classification (BLM and Ducks Unlimited 2002) in the NPRA survey area (which is not an important calving area), we found less evidence for selection for specific habitat types during calving than during other seasons.

After mosquitoes and oestrid flies emerged, caribou distribution was dominated by the profound influences of insect harassment. The selection of coastal and riverine areas by caribou as insect-relief habitat predominated over selection of other classes with greater forage availability. The drainages of Fish and Judy creeks are important landscape features affecting caribou distribution. In addition, the proportions of different habitat types around the proposed ASDP road alignment are strongly influenced by the presence of Fish and Judy creeks to the north of the proposed road (Table 7) and by the generally decreasing proportion of tussock tundra from north to south. The proportions of dunes, sparsely vegetated, and barren-ground types all are higher north of the road alignment, with only small amounts of these habitat types near or south of the alignment. Future evaluations of caribou distribution after construction of the proposed infrastructure will need to incorporate these differences in habitat availability.

SNOW COVER

Comparison of snow cover with the locations of caribou groups during calving showed little evidence of selection for or against snow-cover classes. The mean snow cover at locations used by caribou on the transect survey on 9 June did not differ significantly from availability using the 3 June (use = 45.8%, available = 44.9%; P > 0.05) or 4 June (use = 20.3%, available = 23.3%; P > 0.05) snow-cover data. However, the locations used by caribou on 9 June had significantly less mean snow cover than was available on 6 June (use = 1.9%,

Table 7. Area (percentage) of habitat types within distance-to-road zones north and south of the proposed ASDP road in the NPRA survey area.

Zone	Distance Zone (km)	Water	Habitat Type [a] *Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Dry Dunes	Sparsely Vegetated	Barren Ground
North	6–5	30.0	8.6	18.1	8.8	4.5	13.7	3.0	1.9	0.1	2.7	2.4	6.2
	5–4	26.8	7.1	18.1	9.2	4.5	19.8	2.8	1.9	0.1	2.9	3.8	2.9
	4–3	21.5	6.1	20.6	11.5	5.0	20.4	4.3	2.3	0.6	2.3	3.1	2.2
	3–2	17.0	5.8	20.3	11.0	8.9	30.9	2.2	2.2	0.3	0.3	0.4	0.5
	2–1	14.7	7.0	19.5	8.9	10.9	36.6	0.4	1.9	0.2	0	0	0
	0–1	10.1	9.4	18.9	9.4	9.4	40.2	0.3	2.0	0.1	0	0	0
South	0–1	13.8	8.2	18.8	7.9	8.5	40.2	0.4	2.0	0.2	0	0	0.1
	2–1	19.3	6.4	17.5	8.1	8.8	37.3	0.2	2.1	0.2	0	0	0.1
	3–2	12.9	5.7	18.6	7.7	5.4	47.4	0.2	2.0	0.1	0	0	0
	4–3	11.7	5.4	15.8	7.8	6.2	47.6	0.1	4.6	0.7	0	0	0.1
	5–4	12.6	4.7	14.4	6.9	7.0	49.6	0.4	3.9	0.4	0	0	0
	6–5	9.3	5.0	16.1	8.1	6.8	50.6	0.2	3.7	0.2	0	0	0

[a] NPRA earth-cover classification by BLM and Ducks Unlimited (2002).

available = 6.0%; $P < 0.01$) and 7 June (use = 0.8%, available = 3.3%; $P < 0.01$). This apparent selection for areas that had less-than-average snow cover on 6–7 June may have resulted from lower caribou density in the northeastern portion of the survey area, where snow cover persisted longer.

Previous studies have not provided consistent results concerning the calving distribution of northern Alaska herds in relation snow cover. Kelleyhouse (2001) concluded that calving females in the TH selected areas of low snow cover and Carroll et al. (2005) reported that TH caribou calved farther north in years of early snowmelt. Wolfe (2000) did not find any consistent selection for snow-cover classes during calving by the CAH, whereas Eastland et al. (1989) and Griffith et al. (2002) reported that calving caribou of the Porcupine Herd preferentially used areas with 25–75% snow cover. The presence of patchy snow in calving areas is associated with the emergence of highly nutritious new growth of forage species such as the tussock cottongrass *Eriophorum vaginatum* (Kuropat 1984, Johnstone et al. 2002, Griffith et al. 2002) and it also may disperse caribou and create a complex visual pattern that reduces predation (Bergerud and Page 1987, Eastland 1989). Interpretation of analytical results is complicated by the fact that caribou do not require snow-free areas in which to calve and are able to find nutritious forage in patchy snow cover. Interpretation also is complicated by high annual variability in the extent of snow cover and the timing of melt among years, as well as by variations in our ability to detect melt dates on satellite imagery because of cloud cover.

VEGETATIVE BIOMASS

Among seasons, caribou appeared to select areas with high values of estimated biomass (NDVI_calving, NDVI_621, NDVI_rate, and NDVI_peak) during calving and fall migration but selected areas with low estimated biomass (NDVI_calving, NDVI_621, and NDVI_peak) during late summer (Table 8). In general, the more inland areas (Southeast, Southwest, and West sections of the NPRA survey area) had higher estimated biomass than the Coast, North, and River sections (Appendix M). In 2005, caribou also selected areas of higher estimated biomass during calving. In 2006, however, caribou selected areas with lower biomass (NDVI_calving and NDVI_621) during calving. The reason for the difference in the 2006 results is not readily explainable, because caribou otherwise showed similar patterns of habitat use and geographic distributions in the 3 years of study (Tables 5 and 6).

Table 8. Estimated vegetative biomass (expressed as mean NDVI values) at locations used by caribou groups in the NPRA survey area in 2007, compared with availability using a bootstrap analysis.

Season	n[a]	NDVI_calving	NDVI_621	NDVI_rate	NDVI_peak
Spring Migration	133	0.3830	0.4003	0.0011	0.5505
Calving	174	0.3992++	0.4187++	0.0012++	0.5591++
Postcalving	142	0.3790	0.3959	0.0010	0.5458
Mosquito	47	0.3651	0.3774	0.0007	0.5282-
Late Summer	63	0.3462--	0.3605--	0.0009	0.5123--
Fall Migration	287	0.3892++	0.4071++	0.0011	0.5505++
Total Use	846	0.3840++	0.4014++	0.0011+	0.5462+
Available		0.3802	0.3964	0.00098	0.5428

[a] Caribou groups in pixels with <50% water fraction were not included in analysis.
\+ Use greater than expected ($P < 0.05$).
++ Use greater than expected ($P < 0.01$).
\- Use less than expected ($P < 0.05$).
-- Use less than expected ($P < 0.01$).

NDVI was used in this study to estimate biomass because other researchers have reported significant relationships between caribou distribution and NDVI_calving, NDVI_621, and NDVI_rate during the calving period. Griffith et al. (2002) reported that the annual calving grounds used by the Porcupine Herd during 1985–2001 generally were characterized by a higher daily rate of change in biomass (estimated by NDVI_rate) than was available in the entire calving grounds. In addition, the area of concentrated calving contained higher NDVI_calving and NDVI_621 values than was available in the annual calving grounds. They concluded that caribou used calving areas with high forage quality (inferred from a high daily rate of change) and that, within those areas, caribou selected areas of high biomass. The relationship between annual NDVI_621 and June calf survival for the Porcupine Herd was strongly positive, as was the relationship between NDVI_calving and the percentage of marked females calving on the coastal plain of ANWR (Griffith et al. 2002).

Female caribou of both the CAH and TH have been reported to select areas of high NDVI_rate (Wolfe 2000, Kelleyhouse 2001). In contrast, female caribou of the WAH selected areas with high NDVI_calving and NDVI_621 (Kelleyhouse 2001). Kelleyhouse suggested that geographical differences in spring phenology may account for the differences among herds. The calving grounds of the CAH and TH typically are colder and covered with snow later than are those of the WAH, so the chronology of forage development and selection in early June likely differs accordingly. Caribou select areas of patchy snow cover and high NDVI_rate during calving but select high biomass (NDVI_621) after tussock cottongrass (*E. vaginatum*) flowers are no longer available.

In the eastern portion of the ASDP study area (the Meltwater area studied by Lawhead et al. 2004), use of areas of high NDVI_rate by caribou varied according to the timing of snowmelt during 2001–2003. NDVI_calving and NDVI_rate are inversely correlated, so the values differ greatly between years of early and late melt. In years when snowmelt occurred early, NDVI_calving was high and NDVI_rate was low throughout the region. In years when snow cover lingered through calving, NDVI_calving was low and NDVI_rate was high.

NDVI increases rapidly during snowmelt due to the inherent NDVI value of standing dead biomass (Sellers 1985, cited in Hope et al. 1993; Stow et al. 2004) and the initial flush of new growth (an NDVI value of 0.09 is considered a threshold value indicating "onset of greenness" in arctic tundra; Reed et al. 1994). Following snowmelt (and possibly seasonal runoff flooding), the rate of increase in NDVI value slows. Previous analyses for 2001–2006 (Lawhead et al. 2004, 2006, 2007) used zero-baseline estimation to calculate NDVI_calving and in those reports the results largely were determined by the phenology of snowmelt. Snowmelt typically occurs during calving and can change significantly within just a few days. As a result of changing snow cover, the levels of NDVI_calving vary substantially based on the timing of the calving image relative to snowmelt and the effect of snow and ice masks the effect of new vegetation. To overcome this problem, we adjusted NDVI_calving by using the value of NDVI in late September (late-fall baseline estimation) obtained after plant senescence occurred but before snow began to accumulate. By using this correction, we were able to better estimate the amount and pattern of new vegetation growth in early June. Consequently, the resulting values of NDVI_calving and NDVI_rate are quite different from previous estimates and are more accurate estimates of the actual level of vegetative biomass.

DISTANCE TO PROPOSED ROAD

In most seasons and individual years, the number of caribou groups observed in each distance-to-road zone did not differ significantly from those expected based on a uniform distribution among zones (Table 9). For all years combined (2001–2007), however, fewer caribou groups than expected (based on a uniform distribution) occurred within 2 km of the road alignment and more caribou than expected occurred 4–6 km north of the road alignment during the oestrid-fly season. The area 2–4 km south of the road alignment was used less than expected during the mosquito and oestrid-fly seasons and late summer. The area 2–4 km north of the road was used more than expected during late

Table 9. Number of caribou groups in distance-to-proposed-road zones by year and season, with results of a chi-square goodness-of-fit test (assuming a uniform distribution).

				Distance to Proposed ASDP Road (km)						
Year	Season	No. of Surveys	Total Groups	North 4–6	North 2–4	0–2	South 2–4	South 4–6	Chi-square	*P*-value
2001	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	16	6	3	0 -	2	5	10.18	0.037
	Calving	1	14	0	2	4	4	4	5.20	0.268
	Postcalving	2	105	13	24	39	10	19	5.62	0.229
	Mosquito	1	3	0	0	2	0	1	3.12	0.538
	Oestrid Fly	2	3	1	0	0	1	1	3.08	0.544
	Late Summer	2	42	11	9	11	3	8	4.46	0.347
	Fall Migration	3	86	17	11	39	8	11	7.60	0.107
	Total	12	269	48	49	95	28 -	49	5.33	0.255
2002	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	2	20	0 -	2	5	5	8	10.37	0.035
	Calving	1	32	6	5	12	4	5	0.71	0.950
	Postcalving	1	28	13 +	3	8	2	2	16.51	0.002
	Mosquito	1	1	1	0	0	0	0	–	–
	Oestrid Fly	3	5	4 ++	1	0	0	0	14.14	0.007
	Late Summer	3	49	13	13	12	4	7	9.36	0.053
	Fall Migration	3	16	1	0	6	2	7	9.65	0.047
	Total	14	151	38	24	43	17	29	7.51	0.111
2003	Winter	1	71	11	7	15	18	20	11.66	0.020
	Spring Migration	1	1	1	0	0	0	0	4.57	0.334
	Calving	2	25	7	2	9	3	4	2.75	0.600
	Postcalving	2	70	15	2 --	22	12	19	10.63	0.031
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	2	39	14	10	5 --	2 --	8	17.37	0.002
	Late Summer	1	10	4	1	3	1	1	3.53	0.473
	Fall Migration	3	93	21	17	27	15	13	2.87	0.580
	Total	13	309	73	39	81	51	65	11.72	0.020
2004	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	2	0	1	1	0	0	2.82	0.588
	Calving	0	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	21	9	4	6	0	2	11.85	0.019
	Fall Migration	1	33	4	5	12	6	6	0.87	0.928
	Total	5	56	13	10	19	6	8	2.73	0.605
2005	Winter	1	19	3	3	6	4	3	0.61	0.961
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	2	16	3	0	5	2	6	6.32	0.177
	Postcalving	1	16	7	2	3	3	1	6.21	0.184
	Mosquito	1	5	2	0	1	0	2	4.11	0.391
	Oestrid Fly	1	10	5	3	2	0	0	9.17	0.057
	Late Summer	2	5	0	1	3	1	0	3.43	0.489
	Fall Migration	1	10	2	0	3	1	4	4.69	0.321
	Total	9	81	22	9	23	11	16	3.28	0.512
2006	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	12	3	2	3	1	3	1.05	0.902
	Calving	1	22	2	2	5	4	9	9.54	0.049
	Postcalving	1	22	9	5	4	2	2	7.68	0.104
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	1	3	0	2	0	1	0	7.70	0.103
	Late Summer	2	16	5	6	3	1	1	8.60	0.072
	Fall Migration	1	2	1	0	1	0	0	2.04	0.728
	Total	8	77	20	17	16	9	15	6.57	0.161

Table 9. Continued.

Year	Season	No. of Surveys	Total Groups	Distance to Proposed ASDP Road (km): North 4–6	North 2–4	0–2	South 2–4	South 4–6	Chi-square	*P*-value
2007	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	29	8	9	4 -	6	2	10.16	0.038
	Calving	1	34	5	4	16	4	5	4.32	0.364
	Postcalving	1	48	14	3-	16	6	9	4.80	0.309
	Mosquito	1	11	5	4	2	0	0	10.52	0.033
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	19	2	8	5	2	2	10.50	0.033
	Fall Migration	3	74	10	14	24	13	13	2.63	0.622
	Total	9	215	44	42	67	31	31	3.51	0.477
2001–2007	Winter	2	90	14	10	21	22	23	10.70	0.030
	Spring Migration	7	215	44	42	67	31	31	3.51	0.477
	Calving	8	143	23	15	51	21	33	6.51	0.164
	Postcalving	8	289	71	39	92	35	52	9.05	0.060
	Mosquito	7	20	8	4	5	0 -	3	8.47	0.076
	Oestrid Fly	9	60	24 ++	16	7 --	4 -	9	30.69	<0.001
	Late Summer	14	162	44 +	42 +	43	12 --	21	27.21	<0.001
	Fall Migration	15	314	56	47	112	45	54	2.33	0.676
	Total	70	1158	258 +	190	344	153 -	213	14.06	0.007
Area surveyed, 2002–2004 (km²)				34.5	29.5	61.9	31.4	35.1		
Area surveyed, 2005–2007 (km²)				41.6	31.3	61.9	31.4	35.1		

\+ Use greater than expected ($P < 0.05$).
++ Use greater than expected ($P < 0.01$).
\- Use less than expected ($P < 0.05$).
-- Use less than expected ($P < 0.01$).

summer. Significantly more groups than expected occurred 4–6 km north of the road and fewer groups than expected occurred 2–4 km south of the road during all seasons combined. These results were consistent with greater use of areas near Fish and Judy creeks during those seasons, as was described above for the geographical and habitat-use analyses.

Caribou density did not differ significantly among distance zones (Greenhouse Geisser *P*-value = 0.190; Figure 16), but there was a significant zone-by-season interaction ($P = 0.011$) and significant differences in density were found among seasons ($P < 0.001$). Caribou density in the NPRA survey area within 6 km of the road alignment was significantly lower during the mosquito and oestrid-fly seasons than it was during fall migration, postcalving, and winter (all $P < 0.043$; the 2005 oestrid-fly season was dropped from the analysis to avoid undue influence on test results) and density was significantly lower in late summer than in winter ($P = 0.018$). The only significant zone-by-season interactions were a significantly lower density in the zone within 2 km of the proposed road than in the North 2–4-km zone during postcalving ($P = 0.001$) and a significantly lower density in the zone within 2 km of the proposed road than in the North 4–6-km zone during fall migration ($P = 0.036$).

Because caribou aggregate into large groups when mosquitoes are present and move quickly when harassed by insects, density during the mosquito and early part of the oestrid-fly seasons fluctuates widely. Caribou density in the area of the proposed road generally was low during the mosquito and oestrid-fly seasons, but large groups did occur in the NPRA survey area occasionally, as documented by the aerial survey on 2 August 2005 and the large movement of CAH caribou into the NPRA survey area in July 2001. Caribou density in other seasons was fairly consistent and did not exhibit a pattern with regard to distance from the proposed road alignment.

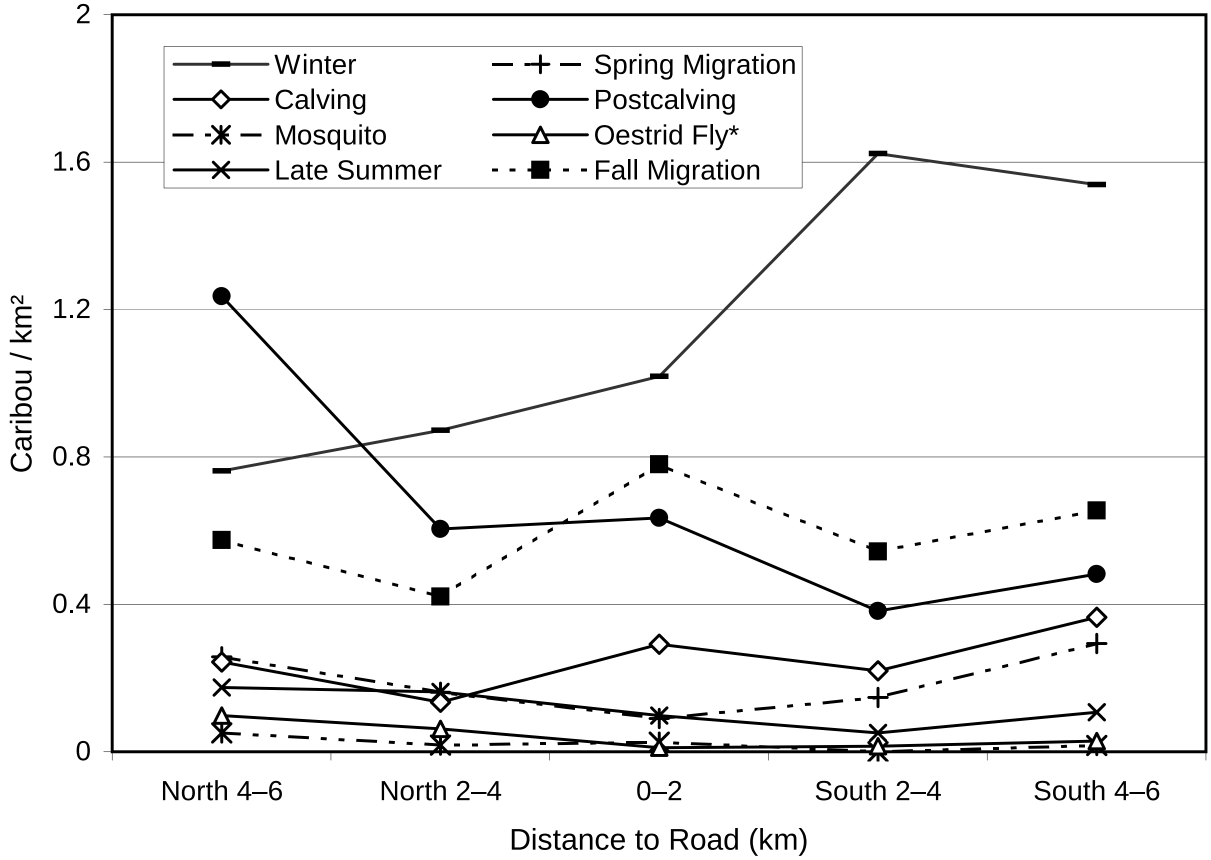


Figure 16. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during 8 different seasons in 2001–2007.

CARIBOU DENSITY ANALYSIS

Grid-cell analysis of the aerial-survey transect data examined the influence of geographic section, snow cover, vegetative biomass, habitat type, and distance to the proposed ASDP road on caribou density during the calving season in 2007 and among all seasons for the years 2002–2007. A number of variables used in the grid-cell analyses were correlated.

After removing one outlier, estimated peak vegetative biomass (NDVI_peak) was highly correlated with NDVI_621 ($r = 0.921$; $P < 0.001$), NDVI_calving ($r = 0.895$; $P < 0.001$), and NDVI_rate ($r = 0.494$; $P < 0.001$). NDVI_peak increased with increasing proportion of tussock tundra ($r = 0.799$; $P < 0.001$) but decreased in wetter habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; $r = -0.445$; $P < 0.001$). Because of the additional masking we did in 2007 to eliminate waterbody margins from NDVI calculations, the correlation between NDVI_peak and the proportion of water ($r = -0.367$; $P < 0.001$) was lower than in previous years.

The proportion of tussock tundra alone explained 63.8% of the variation in NDVI_peak values, and the combination of tussock tundra with the proportion of wet habitat explained 77.9% of the variation. Distance from the coast also had an effect: NDVI_peak values were higher in grid-cells farther from the coast (slope = 0.0010; $P < 0.001$).

The snow-cover fraction on 3 June was highly correlated with NDVI_rate ($r = -0.783$, $P < 0.001$), suggesting that areas with early snowmelt had more advanced vegetative growth by 21 June. The correlation between snow cover on 3 June and NDVI_621 was weak ($r = -0.259$; $P = 0.001$), however, perhaps because the variation in the

NDVI of standing dead vegetation swamps the signal from new growth.

The best model for caribou density in the NPRA survey area during the 2007 calving season included 5 independent variables: presence of Fish or Judy creek (included in all models), presence of the proposed road (included in all models), transect number (west to east), snow cover on 3 June, and NDVI_peak; this model had a 61.5 % chance of being the best model (w_i = 0.615; Appendix N). The second best model was the same as the best model but without snow cover; this model had a 36.7% chance of being the best model (w_i = 0.367) (Appendix N). Caribou density during calving was greater farther inland and in areas with higher NDVI_peak values and was lower near creeks and in the eastern transects. The selection for areas with high NDVI_peak may reflect selection for areas with high biomass, for areas with tussock tundra, and/or against areas of wet habitat.

The model-weighted parameter estimates indicated NDVI_peak, NDVI_rate, proportion of tussock tundra, and transect number were all significantly related to calving density ($P < 0.001$; Table 10). Snow cover ($P = 0.081$) and wet habitat ($P = 0.060$) were nearly significant. Neither the presence of Fish or Judy creeks ($P = 0.913$) nor the presence of the proposed road ($P = 0.671$) were significant factors.

For all years combined (2002–2007), analysis of calving density provided generally similar results as in 2007 alone, albeit with a few differences. The best models included the presence of the creeks and the proposed road (both variables were in all models) and the transect number (west to east), NDVI_peak value, and distance to coast (Appendix O). During calving, the model-weighted parameter estimates indicated that caribou density was greater with increasing NDVI_peak values ($P = 0.002$) and proportion of tussock tundra ($P = 0.006$; Appendix P); that caribou density was lower in the eastern transects ($P < 0.001$); that the proportion of wet habitat (negative relationship, $P = 0.055$) and distance to coast (positive relationship, $P = 0.081$) were moderately significant factors; and that the presence of the creeks ($P = 0.431$) and the proposed road ($P = 0.570$) were not significant (Table 11, Appendix P).

Caribou densities in the NPRA survey area during calving indicate a weak preference for areas with higher NDVI_peak values in most years. Given the high correlation between NDVI and habitat type, it is difficult to distinguish whether caribou were selecting specific habitat types or areas with greater vegetative biomass, or were simply avoiding wet areas and barrens. Vegetation sampling in 2005 indicated that moist tussock tundra had higher biomass than moist sedge–shrub tundra, but that difference disappeared when evergreen shrubs, which are unpalatable caribou forage, were excluded (Lawhead et al. 2006). Tussock tundra does contain higher biomass of plant species that are preferred by caribou, such as *E. vaginatum*, forbs, and lichens, however. The between-year correlations of caribou density during calving were low for 2005, 2006, and 2007

Table 10. Model-weighted parameter estimates for calving caribou density (*ln* [*calving density* + *1/6*]) in the NPRA survey area, 9 June 2007.

Variable	Coefficient	SE	*P*-value
Intercept	–10.145	2.072	<0.001
Presence of creeks	0.035	0.318	0.913
Presence of proposed road	–0.147	0.347	0.671
NDVI_peak	19.493	3.509	<0.001
NDVI_rate	0.110	0.021	<0.001
Snow cover on June 3 (%)	0.008	0.005	0.081
Tussock tundra (%)	2.658	0.660	<0.001
Wet habitat (%)	–1.338	0.711	0.060
Transect number (W to E)	–0.128	0.020	<0.001

Table 11. Significance levels of model-weighted parameter estimates of independent variables used in analyses of caribou density within 124 grid cells in the NPRA survey area, 2002–2007.

Variable	Winter	Spring Migration	Calving	Post-calving	Mosquito	Oestrid Fly	Late Summer	Fall Migration
Intercept				++				
Presence of creeks				++			++	
Presence of proposed road	--							
NDVI_peak	+		++			--	--	
Distance to coast	++			--	--			++
Tussock tundra (%)	+		++			--		
Wet habitats (%)				-				
Transect number (W to E)		--	--	--	--		--	

+ Greater than expected ($P < 0.05$).
++ Greater than expected ($P < 0.01$).
- Less than expected ($P < 0.05$).
-- Less than expected ($P < 0.01$).

(r = 0.186–0.409; natural-log transformed), suggesting that different factors influenced caribou distribution among years.

In the combined sample across all years and seasons, the variables that were significantly related to caribou density in the NPRA survey area varied by season (Table 11, Appendix P). During winter, caribou density was lower near the proposed road and higher farther from the coast, in areas with high NDVI_peak, and in areas with more tussock tundra. During spring migration, caribou density was lower in the eastern than the western portion of the survey area. During postcalving, density was higher near the creeks and decreased inland from the coast, in wet habitat, and from west to east. During the mosquito season, caribou density was higher near the coast and in the western portion of the survey area. During the oestrid-fly season, density was lower in areas with higher vegetative biomass and in the eastern portion of the survey. In late summer, density was higher near the creeks and in the west and was lower in areas with higher biomass values. During fall migration, caribou density was higher inland than near the coast.

Overall, strong seasonal patterns in caribou density were evident. A west-to-east gradient of decreasing density was evident throughout most of the year, probably because the NPRA survey area is located on the eastern edge of the TH range. The riverine area of Fish and Judy creeks had higher densities during postcalving and late summer. The riverine area is characterized by a habitat mosaic of abundant willows and forbs that provide forage during postcalving, and the barrens, dunes, and river bars provide fly-relief habitat. Caribou densities near the coast were lower in winter and fall and higher during postcalving and mosquito season, consistent with increased use of coastal areas during mosquito harassment. Caribou densities during winter and calving were greater in areas with high proportions of tussock tundra. During winter, caribou presumably feed on the abundant lichens in tussock tundra habitat and may select windblown areas with less snow. During calving, tussock tundra provides abundant forage, such as *E. vaginatum*, as well as drier conditions during the seasonal flooding that accompanies snowmelt in wet habitats. Throughout most of the year, there was little evidence that the area around the proposed ASDP road in NPRA was used by caribou to a different degree than adjacent areas, although caribou group density during winter was lower in grid cells containing the road.

CONCLUSIONS

Analysis of the VHF, satellite, and GPS telemetry data sets clearly demonstrates that the Colville River delta and ASDP study area (48-km radius circle centered on CD-4) are at the interface of the annual ranges of the TH and CAH. The CD-4 drill site is located in an area that is used relatively little by caribou from either herd. The TH consistently uses the western half of the ASDP study area to some extent during all seasons of the year; caribou numbers generally are low during calving, vary substantially during the insect season, and then tend to increase in the fall. In contrast, the CAH uses the eastern half of the ASDP study area primarily during calving (including concentrated calving in the southeastern part of the study area) and the insect season. Although caribou from both herds occur on the Colville delta occasionally, large movements onto or across the delta are uncommon for either herd. In general, CAH caribou are more likely to occur on the delta in summer and TH caribou are more likely to occur during fall or spring migration. The movements by large numbers of TH caribou onto the Colville delta in July 2007 were a notable exception to this generalization, however.

Movements by satellite- and GPS-collared TH and CAH caribou into the vicinity of CD-4 (between Nuiqsut and the Alpine processing facilities) have occurred sporadically and infrequently during the calving, mosquito and oestrid-fly seasons and fall migration since monitoring began. In 2007, 4 satellite-collared TH caribou moved east past Alpine and CD-4 in late July and another satellite-collared animal passed between Nuiqsut and CD-4 during calving 2007. None of the 102 satellite collars in the TH moved into the immediate vicinity of CD-4 during 1990–2006. Of the 33 GPS collars on TH animals during 2004–2007, one crossed the delta between CD-4 and Alpine in June 2005 and another spent several days in August 2007 about 2 km south of CD-4. One satellite-collared CAH caribou moved into the CD-4 vicinity briefly in July 1988 and 4 others were nearby briefly in July 1989. Four CAH satellite collars moved through the CD-4 vicinity while heading inland in late July 2001 and one CAH GPS collar moved onto the Colville delta east of CD-4 in late September 2004.

Radio-collared TH caribou occasionally crossed the proposed ASDP pipeline/road-corridor alignment extending from Alpine CD-2 to the proposed CD-7 drill site in NPRA, primarily during fall migration, but the road alignment is located in a geographic area with low-density use by caribou. Collared CAH caribou crossed the alignment very rarely and the proposed corridor would have little or no effect on the CAH unless movement patterns change substantially in the future. Because TH caribou use the western half of the ASDP study area year-round, however, our detailed analyses of caribou distribution and density focused primarily on the NPRA survey area, which encompasses the proposed ASDP road alignment.

Use of the NPRA survey area by TH caribou varies widely among seasons. These differences can be described in part by snow cover, vegetative biomass, habitat distribution, and distance to the coast. During calving, caribou generally use areas of higher plant biomass (estimated from NDVI values), higher proportions of tussock tundra, and lower proportions of wet habitats. Calving tends to occur in areas of patchy snow cover, although calving habitat selection appears to vary depending on snow-melt timing and plant phenology, and may vary between adjacent herds.

The riverine habitats along Fish and Judy creeks were selected by caribou in the postcalving, oestrid fly, and late summer seasons. The complex mosaic of riverine habitats provides opportunities both for foraging and for relief from oestrid-fly harassment. The presence of these streams was a significant variable explaining the distribution and density of caribou in the NPRA survey area, affecting the geographic-section and distance-zone analyses.

Because the NPRA survey area is on the eastern edge of the TH range, a natural west-to-east gradient of decreasing density occurs during much of the year. Caribou density is typically lowest in the southeastern section of the NPRA survey area, in which the proposed road alignment is located, than in other sections of the survey area. We found little evidence for selection or avoidance of specific distance zones within 6 km of the proposed road alignment.

The current emphasis of this study is to monitor caribou movements in relation to the existing facilities in the ASDP study area and to compile predevelopment baseline data on caribou density and movements in the portion of the NPRA survey area where further development is planned. Detailed analyses of the existing patterns of seasonal distribution, density, and movements are providing a useful record of the way in which caribou use the study area. The data reported here provide an important record for evaluating and mitigating the potential impacts of ASDP development on caribou distribution and movements, as well as providing ongoing results to refine the study effort in future years of the program.

LITERATURE CITED

Anderson, D. R., K. P. Burnham, and W. L. Thompson. 2000. Null hypothesis testing: Problems, prevalence, and an alternative. Journal of Wildlife Management 64: 912–923.

Arthur, S. M., and P. A. Del Vecchio. 2007. Effects of oil field development on calf production and survival in the Central Arctic Herd. Alaska Department of Fish and Game, Interim Research Technical Report, June 2001–March 2006. Project 3.46. Division of Wildlife Conservation, Juneau. 40 pp.

Beck, P. S. A., C. Atzberger, K. A. Høgda, B. Johansen, A. K. Skidmore. 2006. Improved monitoring of vegetation dynamics at very high latitudes: A new method using MODIS NDVI. Remote Sensing of the Environment 100: 321–334.

Bee, J. W., and E. R. Hall. 1956. Mammals of northern Alaska on the Arctic Slope. University of Kansas, Museum of Natural History, Miscellaneous Publication No. 8. 309 pp.

Bergerud, A. T. and R. E. Page. 1987. Displacement and dispersion of parturient caribou as antipredator tactics. Canadian Journal of Zoology 65: 1597–1606.

BLM (Bureau of Land Management) and MMS (Minerals Management Service). 1998. Northeast National Petroleum Reserve–Alaska: Final Integrated Activity Plan / Environmental Impact Statement. U.S. Department of the Interior, Anchorage.

BLM. 2004. Alpine Satellite Development Plan Final Environmental Impact Statement. Volumes 1–3. U.S. Department of the Interior, Bureau of Land Management, Anchorage.

BLM. 2005. Northeast National Petroleum Reserve–Alaska: Final Amended Integrated Activity Plan / Environmental Impact Statement. Volumes 1–3. U.S. Department of the Interior, Bureau of Land Management, Anchorage.

BLM and Ducks Unlimited. 2002. National Petroleum Reserve–Alaska Earth Cover Classification. BLM Alaska Technical Report 40. U.S. Department of the Interior. 81 pp.

Brower, H. K., and R. T. Opie. 1997. North Slope Borough Subsistence Harvest Documentation Project: data for Nuiqsut, Alaska for the period July 1, 1994 to June 30, 1995. North Slope Borough Department of Wildlife Management, Barrow.

Brown, J., R. K. Haugen, and S. Parrish. 1975. Selected climatic and soil thermal characteristics of the Prudhoe Bay region. Pages 3–11 *in* J. Brown, ed. Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biological Papers of the University of Alaska, Special Report No. 2, Fairbanks.

Burgess, R. M., C. B. Johnson, P. E. Seiser, A. A. Stickney, A. M. Wildman, and B. E. Lawhead. 2002. Wildlife studies in the Northeast Planning Area of the National Petroleum Reserve–Alaska, 2001. Report prepared for Phillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 71 pp.

Burgess, R. M., C. B. Johnson, A. M. Wildman, P. E. Seiser, J. R. Rose, A.K. Prichard, T. J. Mabee, A. A. Stickney, and B. E. Lawhead. 2003. Wildlife studies in the Northeast

Planning Area of the National Petroleum Reserve–Alaska, 2002. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 126 pp.

Burnham, K. P., and D. R. Anderson. 1998. Model Selection and Inference: A Practical Information–Theoretic Approach. Springer–Verlag, New York. 353 pp.

Byers, C. R., R. K. Steinhorst, and P. R. Krausman. 1984. Clarification of a technique for analysis of utilization–availability data. Journal of Wildlife Management 48: 1050–1053.

Cameron, R. D. 1983. Issue: Caribou and petroleum development in arctic Alaska. Arctic 36: 227–231.

Cameron, R. D., W. T. Smith, and S. G. Fancy. 1989. Distribution and productivity of the Central Arctic Caribou Herd in relationship to petroleum development. Alaska Department of Fish and Game, research progress report, Federal Aid in Wildlife Restoration Projects W-23-1 and W-23-2, Study 3.35, Juneau. 52 pp.

Cameron, R. D., W. T. Smith, S. G. Fancy, K. L. Gerhart, and R. G. White. 1993. Calving success of female caribou in relation to body weight. Canadian Journal of Zoology 71: 480–486.

Cameron, R. D., E. Lenart, D. J. Reed, K. R. Whitten, and W. T. Smith. 1995. Abundance and movements of caribou in the oilfield complex near Prudhoe Bay, Alaska. Rangifer 15: 3–7.

Carroll, G. 2003. Unit 26A: Teshekpuk Herd. Pages 280–303 *in* C. Healy, editor. Caribou management report of survey and inventory activities, 1 July 2000–30 June 2002. Alaska Department of Fish and Game, Juneau.

Carroll, G. M., A. K. Prichard, R. S. Suydam, L. S. Parrett, and D. A. Yokel. 2004. Unexpected movements of the Teshekpuk Caribou Herd. Paper presented at the 10th North American Caribou Workshop, 4–6 May 2004, Girdwood, AK. [abstract]

Carroll, G. M., L. S. Parrett, J. C. George, and D. A. Yokel. 2005. Calving distribution of the Teshekpuk caribou herd, 1994–2003. Rangifer, Special Issue 16: 27–35.

Danks, F. S. 2000. Potential muskox habitat in the National Petroleum Reserve–Alaska: A GIS analysis. M.S. thesis, University of Alaska, Fairbanks. 133 pp.

Dau, J. R. 1986. Distribution and behavior of barren-ground caribou in relation to weather and parasitic insects. M.S. thesis, University of Alaska, Fairbanks. 149 pp.

Dau, J. 2005. Two caribou mortality events in northwestern Alaska: Possible causes and management implications. Rangifer, Special Issue 16: 37–50.

Déry, S. J., V. V. Salomonson, M. Stieglitz, D. K. Hall, and I. Appel. 2005. An approach to using snow areal depletion curves inferred from MODIS and its application to land surface modelling in Alaska. Hydrological Processes 19: 2755–2774.

Eastland, W. G., R. T. Bowyer, and S. G. Fancy. 1989. Caribou calving sites relative to snow cover. Journal of Mammalogy 70: 824–828.

Fancy, S. G. 1986. Daily energy budgets of caribou: a simulation approach. Ph.D. thesis, University of Alaska, Fairbanks. 226 pp.

Fancy, S. G., K. R. Whitten, N. E. Walsh, and R. D. Cameron. 1992. Population dynamics and demographics of caribou in developed and undeveloped areas of the Arctic Coastal Plain. Pages 1–21 *in* T. R. McCabe, B. Griffith, N. E. Walsh, and D. D. Young, editors. Terrestrial research: 1002 Area, Arctic National Wildlife Refuge. Interim report, 1988–1990. U.S. Fish and Wildlife Service, Anchorage.

Fancy, S. G., and R. G. White. 1985. Energy expenditure by caribou while cratering in snow. Journal of Wildlife Management 49: 987–993.

Finstad, G. L., and A. K. Prichard. 2000. Climatic influence on forage quality, growth and reproduction of reindeer on the Seward Peninsula, II: Reindeer growth and reproduction. Rangifer, Special Issue 12: 144.

Fuller, A. S., and J. C. George. 1997. Evaluation of subsistence harvest data from the North Slope Borough 1993 census for eight North Slope villages: for calendar year 1992. North Slope Borough Department of Wildlife Management, Barrow.

Gasaway, W. C., S. D. DuBois, D. J. Reed, and S. J. Harbo. 1986. Estimating moose population parameters from aerial surveys. Biological Papers of the University of Alaska, No. 22, Fairbanks. 108 pp.

Griffith, B., D. C. Douglas, N. E. Walsh, D. D. Young, T. R. McCabe, D. E. Russell, R. G. White, R. D. Cameron, and K. R. Whitten. 2002. Section 3: The Porcupine Caribou Herd. Pages 8–37 *in* D. C. Douglas, P. E. Reynolds, and E. B. Rhode, editors. Arctic Refuge coastal plain terrestrial wildlife research summaries. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-2002-0001.

Gumley, L., J. Descloitres, and J. Schmaltz. 2003. Creating reprojected true-color MODIS images: a tutorial. Version 1.0, 14 November 2003. MODIS Rapid Response System, Goddard Space Flight Center, Greenbelt, MD. 19 pp. http://rapidfire.sci.gsfc.nasa.gov/faq/MODIS_True_Color.pdf (accessed 15 January 2006).

Hays, G. C., S. Akesson, B. J. Godley, P. Luschi, and P. Santidrian. 2001. The implications of location accuracy for the interpretation of satellite-tracking data. Animal Behavior 61: 1035–1040.

Hope, A. S., J. S. Kimball, and D. A. Stow. 1993. The relationship between tussock tundra spectral properties and biomass and vegetation composition. International Journal of Remote Sensing 14: 1861–1874.

Jensen, P. G., and L. E. Noel. 2002. Caribou distribution in the northeast National Petroleum Reserve–Alaska, summer 2001. Chapter 3 *in* M. A. Cronin, editor. Arctic Coastal Plain caribou distribution, summer 2001. Report prepared for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage.

Johnson, C. B., B. E. Lawhead, J. R. Rose, M. D. Smith, A. A. Stickney, and A. M. Wildman. 1998. Wildlife studies on the Colville River delta, Alaska, 1997. Sixth annual report prepared for ARCO Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 144 pp.

Johnson, C. B., R. M. Burgess, A. M. Wildman, A. A. Stickney, P. E. Seiser, B. E. Lawhead, T. J Mabee, J. R. Rose, and J. E. Shook. 2004. Wildlife studies for the Alpine Satellite Development Project, 2003. Annual report prepared for ConocoPhillips Alaska, Inc., and Anadarko Petroleum Corporation, Anchorage, by ABR, Inc., Fairbanks. 155 pp.

Johnson, C. B., R. M. Burgess, A. M. Wildman, A. A. Stickney, P. E. Seiser, B. E. Lawhead, T. J Mabee, A. K. Prichard, and J. R. Rose. 2005. Wildlife studies for the Alpine Satellite Development Project, 2004. Annual report prepared for ConocoPhillips Alaska, Inc., and Anadarko Petroleum Corporation, Anchorage, by ABR, Inc., Fairbanks. 129 pp.

Johnson, C. B., A. M. Wildman, J. P. Parrett, J. R. Rose, T. Obritschkewitsch, and J. E. Shook. 2008. Avian studies for the Alpine Satellite Development Project, 2007. Fifth annual report prepared for ConocoPhillips Alaska, Inc., and Anadarko Petroleum Corporation, Anchorage, by ABR, Inc., Fairbanks.

Johnstone, J., D. E. Russell, and B. Griffith. 2002. Variations in plant forage quality in the range of the Porcupine caribou herd. Rangifer 22: 83–91.

Jorgenson, M. T., J. E. Roth, E. R. Pullman, R. M. Burgess, M. Raynolds, A. A. Stickney, M. D. Smith, and T. Zimmer. 1997. An ecological land survey for the Colville River delta, Alaska, 1996. Report prepared for ARCO Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 160 pp.

Jorgenson, M. T., J. E. Roth, M. Emers, S. Schlentner, D. K. Swanson, E.R. Pullman, J. Mitchell, and A. A. Stickney. 2003. An ecological land survey for the Northeast

Planning Area of the National Petroleum Reserve–Alaska, 2002. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 84 pp.

Jorgenson, M. T., J. E. Roth, M. Emers, W. Davis, E.R. Pullman, and G. J. Frost. 2004. An ecological land survey for the Northeast Planning Area of the National Petroleum Reserve–Alaska, 2003. Addendum to 2002 report prepared for ConocoPhillips Alaska, Inc., Anchorage, and Anadarko Petroleum Corporation, Anchorage, by ABR, Inc., Fairbanks. 40 pp.

Keating, K. A. 1994. An alternative index of satellite telemetry location error. Journal of Wildlife Management 58: 414–421.

Kelleyhouse, R. A. 2001. Calving-ground selection and fidelity: Teshekpuk Lake and Western Arctic herds. M.S. thesis, University of Alaska, Fairbanks. 124 pp.

Klein, D. R. 1990. Variation in quality of caribou and reindeer forage plants associated with season, plant part, and phenology. Rangifer, Special Issue 3: 123–130.

Kuropat, P. J. 1984. Foraging behavior of caribou on a calving ground in northwestern Alaska. M.S. thesis, University of Alaska, Fairbanks. 95 pp.

L1B EV 500m File Specification–Terra. 2005. V5.0.4, 2005-01-12. http://www.mcst.ssai.biz/L1B/L1B_docs/V5_LATEST_L1B_DOCUMENTS/L1B_Terra_File_Specs/MOD02HKM_File_Specs.txt (accessed 15 January 2006).

Lair, H. 1987. Estimating the location of the focal center in red squirrel home ranges. Ecology 68: 1092–1101.

Lawhead, B. E. 1988. Distribution and movements of Central Arctic Herd caribou during the calving and insect seasons. Pp. 8–13 *in* R. Cameron and J. Davis, editors. Reproduction and calf survival: Proceedings of the Third North American Caribou Workshop. Wildlife Technical Bulletin No. 8, Alaska Department of Fish and Game, Juneau.

Lawhead, B. E and A. K. Prichard. 2002. Surveys of caribou and muskoxen in the Kuparuk–Colville region, Alaska, 2001. Report prepared for Phillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 37 pp.

Lawhead, B. E and A. K. Prichard. 2003a. Surveys of caribou and muskoxen in the Kuparuk–Colville region, Alaska, 2002. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 38 pp.

Lawhead, B. E, and A. K. Prichard. 2003b. Mammal surveys in the Greater Kuparuk Area, northern Alaska, 2003. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 45 pp.

Lawhead, B. E, and A. K. Prichard. 2005. Mammal surveys in the Greater Kuparuk Area, northern Alaska, 2004. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 39 pp.

Lawhead, B. E, and A. K. Prichard. 2006. Mammal surveys in the Greater Kuparuk Area, northern Alaska, 2005. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 33 pp.

Lawhead, B. E, and A. K. Prichard. 2007. Mammal surveys in the Greater Kuparuk Area, northern Alaska, 2006. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 33 pp.

Lawhead, B. E, and A. K. Prichard. 2008. Mammal surveys in the Greater Kuparuk Area, northern Alaska, 2007. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks.

Lawhead, B. E., A. K. Prichard, M. J. Macander, and M. Emers. 2004. Caribou mitigation monitoring study for the Meltwater Project, 2003. Third annual report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 104 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2006. Caribou monitoring study for the Alpine Satellite Development Program, 2005. First annual report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 102 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2007. Caribou monitoring study for the Alpine Satellite Development Program, 2006. Second annual report prepared for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 75 pp.

Lawhead, B. E., C. B. Johnson, and L. C. Byrne. 1994. Caribou surveys in the Kuparuk Oilfield during the 1993 calving and insect seasons. Report prepared for ARCO Alaska, Inc. and the Kuparuk River Unit, Anchorage, by Alaska Biological Research, Inc., Fairbanks. 38 pp.

Lenart, E. A. 2003. GMU 26B and 26C, Central Arctic. Pages 304–326 *in* C. Healy, editor. Caribou management report of survey and inventory activities, 1 July 2000–30 June 2002. Alaska Department of Fish and Game, Division of Wildlife Conservation, Juneau.

Macander, M. J. 2005. MODIS satellite vegetation indices over partially vegetated pixels on the Arctic Coastal Plain of Alaska. M.S. thesis, University of Alaska, Fairbanks. 113 pp.

McNay, R. S., J. A. Morgan, and F. L. Bunnell. 1994. Characterizing independence of observations in movements of Columbian black-tailed deer. Journal of Wildlife Management 58: 422–429.

Mosteller, F., and J. W. Tukey. 1977. Data Analysis and Regression: A Second Course in Statistics. Addison–Wesley, Reading, MA.

Muller, S. V., D. A. Walker, F. E. Nelson, N. A. Auerbach, J. G. Bockheim, S. Guyer, and D. Sherba. 1998. Accuracy assessment of a land-cover map of the Kuparuk River basin, Alaska: Considerations for remote regions. Photogrammetric Engineering and Remote Sensing 64: 619–628.

Muller, S. V., A. E. Racoviteanu, and D. A. Walker. 1999. Landsat-MSS-derived land-cover map of northern Alaska: Extrapolation methods and a comparison with photo-interpreted and AVHRR-derived maps. International Journal of Remote Sensing 20: 2921–2946.

Murphy, S. M., and B. E. Lawhead. 2000. Caribou. Chapter 4, pp. 59–84 *in* J. Truett and S. R. Johnson, editors. The Natural History of an Arctic Oil Field: Development and the Biota. Academic Press, San Diego, CA.

Neter, J., W. Wasserman, and M.H. Kutner. 1990. Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Design. Irwin, Boston, MA. 547 pp.

Neu, C. W., C. R. Byers, J. M. Peek, and V. Boy. 1974. A technique for analysis of utilization–availability data. Journal of Wildlife Management 38: 541–545.

Noel, L. E. 1999. Calving caribou distribution in the Teshekpuk Lake area, June 1998. Final data report for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage. 31 pp.

Noel, L. E. 2000. Calving caribou distribution in the Teshekpuk Lake area, June 1999. Report for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage. 29 pp.

Noel, L. E. and J. C. George. 2003. Caribou distribution during calving in the northeast National Petroleum Reserve–Alaska, June 1998 to 2000. Rangifer, Special Issue 14: 283–292.

Noel, L. E., K. Parker, and M. A. Cronin. 2004. Caribou distribution near an oilfield road on Alaska's North Slope, 1978–2001. Wildlife Society Bulletin 32: 757–771.

North, M. R. 1986. Breeding biology of Yellow-billed Loons on the Colville River Delta, arctic Alaska. M.S. thesis, North Dakota State University, Fargo. 109 pp.

NRC (National Research Council). 2003. Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. National Academies Press, Washington, D.C. 288 pp.

Pedersen, S. 1995. Nuiqsut. Chapter 22 *in* J. A. Fall and C. J. Utermohle, editors. An investigation of the sociocultural consequences of Outer Continental Shelf development in Alaska. Vol. V, Alaska Peninsula and Arctic. Technical Report No. 160, OCS Study MMS 95-014, Minerals Management Service, Anchorage.

Pennycuick, C. J., and D. Western. 1972. An investigation of some sources of bias in aerial transect sampling of large mammal populations. East African Wildlife Journal 10: 175–191.

Person, B. T., A. K. Prichard, G. M. Carroll, D. A. Yokel, R. S. Suydam, and J. C. George. 2007. Distribution and movements of the Teshekpuk caribou herd 1990–2005: prior to oil and gas development. Arctic 60: 238–250.

Philo, L. M., G. M. Carroll, and D. A. Yokel. 1993. Movements of caribou in the Teshekpuk Lake Herd as determined by satellite tracking, 1990–1993. Unpublished report, North Slope Borough Department of Wildlife Management, Barrow; Alaska Department of Fish and Game, Barrow; and U.S. Department of Interior, Bureau of Land Management, Fairbanks. 60 pp.

Prichard, A. K., and S. M. Murphy. 2004. Analysis and mapping of satellite telemetry data for the Teshekpuk Caribou Herd, 1990–2002. Final report prepared for North Slope Borough, Barrow, by ABR Inc., Fairbanks. 110 pp.

Reed, B. C., J. F. Brown, D. VanderZee, T. R. Loveland, J. W. Merchant, and D. O. Ohlen. 1994. Measuring phenological variability from satellite imagery. Journal of Vegetation Science 5: 703–714.

Reynolds, T. D., and J. W. Laundre. 1990. Time intervals for estimating pronghorn and coyote home ranges and daily movements. Journal of Wildlife Management 54: 316–322.

Rouse, J. W., R. H. Haas, J. A. Schell, and D. W. Deering. 1973. Monitoring vegetation systems in the Great Plains with ERTS. Third ERTS Symposium, Greenbelt, Maryland, NASA (SP-351) 1: 309–317.

Russell, D. E., A. M. Martell, and W. A. C. Nixon. 1993. Range ecology of the Porcupine caribou herd in Canada. Rangifer, Special Issue 8. 167 pp.

Salomonson, V. V., and I. Appel. 2004. Estimating fractional snow cover from MODIS using the normalized difference snow index. Remote Sensing of the Environment 89: 351–360.

Schoener, T. W. 1981. An empirically based estimate of home range. Theoretical Population Biology 20: 281–325.

Sellers, P. J. 1985. Canopy reflectance, photosynthesis, and transpiration. International Journal of Remote Sensing 21: 143–183.

Service ARGOS. 1988. Users manual. Service ARGOS, Landover, MD.

Shideler, R. T. 1986. Impacts of human developments and land use on caribou: A literature review. Volume II—Impacts of oil and gas development on the Central Arctic Herd. Technical Report No. 86-3. Alaska Department of Fish and Game, Juneau. 128 pp.

Solow, A. R. 1989. A randomization test for independence of animal locations. Ecology 70: 1546–1549.

Stow, D. A., A. Hope, D. McGuire, D. Verbyla, J. Gamon, F. Huemmrich, S. Houston, C. Racine, M. Sturm, K. Tape, L. Hinzman, K. Yoshikawa, C. Tweedie, B. Noyle, C. Silapaswan, D. Douglas, B. Griffith, G. Jia, H. Epstein, D. Walker, S. Daeschner, A. Pertersen, L. Zhou and R. Myneni. 2004. Remote sensing of vegetation and land-cover change in arctic tundra ecosystems. Remote Sensing of the Environment 89: 281–308.

Swihart, R. K., and N. A. Slade. 1985. Testing for independence of observations in animal movements. Ecology 66: 1176–1184.

Vincent, C., B. J. McConnell, V. Ridoux, and M. A. Fedak. 2002. Assessment of Argos location error from satellite tags deployed on captive gray seals. Marine Mammal Science 18: 156–166.

Walker, H. J. 1983. Guidebook to permafrost and related features of the Colville River delta, Alaska. Guidebook 2. Alaska Division of Geological and Geophysical Surveys, Anchorage. 34 pp.

Walker, H. J., and H. H. Morgan. 1964. Unusual weather and river bank erosion in the delta of the Colville River, Alaska. Arctic 17: 41–47.

Weladji, R. B., G. Steinheim, Ø. Holand, S. R Moe, T. Almøy, and T. Ådnøy. 2003. Use of climatic data to assess the effect of insect harassment on the autumn weight of reindeer (*Rangifer tarandus*) calves. Journal of Zoology 260: 79–85.

White, G. C., and R. A. Garrott. 1990. Analysis of Wildlife Radio-tracking Data. Academic Press, San Diego, California. 383 pp.

White, R. G., B. R. Thomson, T. Skogland, S. J. Person, D. E. Russell, D. F. Holleman, and J. R. Luick. 1975. Ecology of caribou at Prudhoe Bay, Alaska. Pages 151–201 in J. Brown, editor. Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biological Papers of the University of Alaska, Special Report No. 2, Fairbanks.

Wolfe, S. A. 2000. Habitat selection by calving caribou of the Central Arctic Herd, 1980–95. M.S. thesis, University of Alaska, Fairbanks. 83 pp.

Appendix A. Cover-class descriptions of the NPRA earth-cover classification (BLM and Ducks Unlimited 2002).

Cover Class	Description
Clear Water	Fresh or saline waters with little or no particulate matter. Clear-water areas are typically deep (greater than 1 meter). The clear-water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage by these species.
Turbid Water	Waters that contain particulate matter or shallow (<1 m), clear waterbodies that are spectrally different from clear water. This class typically occurs in shallow lake shelves, deltaic plumes, and rivers and lakes with high sediment loads. The turbid-water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage by these species.
Carex aquatilis	Associated with lake or pond shorelines and composed of 50–80% clear or turbid water >10 cm deep. The dominant species is *Carex aquatilis*. A small percentage of *Arctophila fulva, Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris* may be present.
Arctophila fulva	Associated with lake or pond shorelines and composed of 50–80% clear or turbid water >10 cm deep. The dominant species is *Arctophila fulva*. A small percentage of *Carex aquatilis, Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris* may also be present.
Flooded Tundra–Low-centered Polygons	Polygon features that retain water throughout the summer. This class is composed of 25–50% water; *Carex aquatilis* is the dominant species in permanently flooded areas. The drier ridges of polygons are composed mostly of *Eriophorum russeolum, Eriophorum vaginatum, Sphagnum* spp., *Salix* spp., *Betula nana, Arctostaphylos* spp., and *Ledum palustre*.
Flooded Tundra–Non-pattern	Continuously flooded areas composed of 25–50% water. *Carex aquatilis* is the dominant species. Other species may include *Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris*. Non-pattern is distinguished from low-centered polygons by the lack of polygon features and associated shrub species that grow on dry ridges of low-centered polygons.
Wet Tundra	Associated with areas of super-saturated soils and standing water. Wet tundra often floods in early summer and generally drains of excess water during dry periods, but remains saturated throughout the summer. It is composed of 10–25% water; *Carex aquatilis* is the dominant species. Other species may include *Eriophorum angustifolium*, and other sedges, grasses, and forbs.
Sedge/Grass Meadow	Dominated by the sedge family. This class commonly consists of a continuous mat of sedges and grasses with a moss and lichen understory. The dominant species are *Carex aquatilis, Eriophorum angustifolium, Eriophorum russeolum, Arctagrostis latifolia,* and *Poa arctica*. Associated genera include *Cassiope* spp., *Ledum* spp., and *Vaccinium* spp.
Tussock Tundra	Dominated by the tussock-forming sedge *Eriophorum vaginatum*. Tussock tundra is common throughout the Arctic Foothills and may be found on well-drained sites in all areas of the NPRA. Cottongrass tussocks are the dominant landscape elements and moss is the common understory. Lichen, forbs, and shrubs are also present in varying densities. Associated genera include *Salix* spp., *Betula nana*, *Ledum palustre*, and *Carex* spp.
Moss/Lichen	Associated with low-lying lakeshores and dry sandy ridges dominated by moss and lichen species. As this type grades into a sedge type, graminoids such as *Carex aquatilis* may increase in cover, forming an intermediate zone.
Dwarf Shrub	Associated with ridges and well-drained soils and dominated by shrubs less than 30 cm in height. Because of the relative dryness of the sites on which this cover type occurs, it is the most species-diverse. Major species include *Salix* spp., *Betula nana*, *Ledum palustre, Dryas* spp.*, Vaccinium* spp.*, Arctostaphylos* spp.*, Eriophorum vaginatum, and Carex aquatilis.* This class frequently occurs over a substrate of tussocks.

Appendix A. Continued.

Cover Class	Description
Low Shrub	Associated with small streams and rivers, but also occurs on hillsides in the southern portion of the NPRA. This class is dominated by shrubs between 30 cm and 1.5 m in height. Major species included *Salix* spp., *Betula nana*, *Alnus crispa*, and *Ledum palustre.*
Dunes/Dry Sand	Associated with streams, rivers, lakes and coastal beaches. Dominated by dry sand with less than 10% vegetation. Plant species may include *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.
Sparsely Vegetated	Occurs primarily along the coast in areas affected by high or storm tides, in recently drained lake or pond basins, and where there is bare mineral soil that is being recolonized with vegetation. Dominated by non-vegetated material with 10–30% vegetation. The vegetation in these areas may include rare plants, but the more commonly found species include *Stellaria* spp., *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes.*
Barren Ground/Other	Associated with river and stream gravel bars, mountainous areas and urban areas. Includes less than 10% vegetation. May incorporate dead vegetation associated with salt burn from ocean water.

Appendix B. Snow depth (cm; 1 April–31 May) and cumulative thawing degree-days (° C above freezing; 1 May –15 August) at the Kuparuk airstrip, 1983–2007.

	Snow Depth (cm)			Cumulative Thawing Degree-days (° C)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
1983	10	5	0	0	3.6	53.8	73.4	74.7	103.8	100.3
1984	18	15	0	0	0	55.6	75.3	122.8	146.4	99.5
1985	10	8	0	0	10.3	18.6	92.8	84.7	99.4	100.0
1986	33	20	10	0	0	5.0	100.8	112.2	124.7	109.4
1987	15	8	3	0	0.6	6.7	61.4	112.2	127.8	93.1
1988	10	5	5	0	0	16.7	78.1	108.3	143.1	137.5
1989	33	–	10 [a]	0	5.6	20.6	109.4	214.7	168.1	215.8
1990	8	3	0	0	16.1	39.7	132.2	145.0	150.0	82.5
1991	23	8	3	0	7.8	14.4	125.0	73.3	115.0	70.6
1992	13	8	0	0.3	20.3	55.0	85.3	113.9	166.1	104.2
1993	13	5	0	0	8.6	33.6	94.4	175.8	149.7	96.1
1994	20	18	8	0	4.4	49.2	51.7	149.7	175.8	222.2
1995	18	5	0	0	1.1	59.4	87.5	162.8	106.9	83.3
1996	23	5	0	8.1	41.7	86.1	121.1	138.9	168.1	95.8
1997	28	18	8	0	20.8	36.1	109.7	101.7	177.8	194.2
1998	25	8	0	3.6	45.8	74.2	135.0	158.9	184.4	174.4
1999	28	15	10	0	1.4	30.3	67.8	173.3	81.1	177.5
2000	30	23	13	0	0	36.7	173.3	115.0	130.0	120.6
2001	23	30	5	0	1.1	53.3	75.0	82.2	185.6	135.0
2002	30	trace	0	4.4	31.1	59.4	72.8	93.9	136.1	106.1
2003	28	13	trace	0	10.8	23.6	77.5	140.0	144.7	91.9
2004	36	10	5	0	10.0	27.8	188.3	150.0	153.3	155.0
2005	23	13	0	0	3.3	16.1	80.0	69.4	81.7	178.9
2006	23	5	0	0	23.3	93.3	153.1	82.2	186.1	109.7
2007	25	46	5	0	0	46.4	81.7	115.0	138.9	134.4
Mean	22	12	3	0.7	10.7	40.5	100.1	122.8	141.7	127.5

[a] Value for June 1

Appendix C. Number and density of caribou in the NPRA and Colville East survey areas, May–October 2001.

Survey Area (Size) and Date	Large Caribou [a,b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (906–988 km²) [f]							
May 20 [g]	319	0	319	638	87.9	0.65	5.8
June 9 [h]	117	6	123	246	49.2	0.26	3.6
June 17 [h]	447	12	459	908	77.3	0.97	3.5
June 23 [h]	654	43	697	1394	117.0	1.47	4.3
July 12 [i]	302	24	326	652	150.9	0.72	8.4
July 23 [i]	nr	nr	636	1272	614.2	1.40	127.2
August 4 [g]	10	0	10	20	10.0	0.02	2.0
August 14 [g]	59	3	62	124	20.7	0.13	2.1
August 28 & 30 [g]	139	8	147	294	34.6	0.30	1.7
September 29 [g]	652	36	688	1376	214.8	1.39	10.6
October 12 [g]	826	30	856	1712	353.2	1.73	10.7
October 24 [g]	377	35	412	824	99.7	0.83	5.7
Total	4538	197	4735			0.82	6.2
COLVILLE EAST (1700 km²) [f]							
August 4–5	10	1	11	22	7.5	0.01	2.75
August 15	7	0	7	14	4.4	0.01	1.17
August 28 & 30	132	3	135	270	72.7	0.16	2.60
September 30 [j]	64	5	69	138	41.2	0.09	6.27
October 12–13	71	6	77	154	23.9	0.09	5.13
October 24 & 26	139	8	147	294	61.3	0.17	5.07
Total	423	23	446			0.09	3.81

[a] Adults + yearlings.
[b] nr = not recorded.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (453–494 km² in NPRA and 850 km² in Colville East).
[g] Total area = 988 km².
[h] Total area = 948 km².
[i] Total area = 906 km².
[j] Part of transects not flown due to fog.

Appendix D. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2002.

Survey Area (Size) and Date	Large Caribou [a]	Calves	Total Caribou	Estimated Total [b]	SE [c]	Density (caribou/km²) [d]	Mean Group Size
NPRA (1310 km²) [e]							
May 3	190	0	190	380	36.1	0.29	3.1
May 25–26	215	0	215	430	72.6	0.33	3.3
June 8	422	8	430	860	129.2	0.66	3.7
June 18	536	4	540	1080	170.6	0.83	6.6
June 27	17	0	17	34	12.0	0.03	3.4
July 18	0	0	0	0	–	0	–
July 26	9	0	9	18	5.3	0.01	1.5
August 3	239	31	270	540	329.0	0.41	15.0
August 14	170	36	206	412	89.5	0.31	2.3
August 26	63	1	64	128	19.3	0.10	1.3
September 9	231	20	251	502	104.7	0.38	4.0
September 24	48	2	50	100	34.0	0.08	6.3
October 6	29	0	29	58	15.9	0.04	2.6
October 24	959	42	1001	2002	345.3	1.53	7.8
Total	3128	144	3272	6544		0.38	4.7
COLVILLE R. DELTA (494 km²) [e]							
July 13	74	0	74	148	49.2	0.30	9.25
July 18	0	0	0	0	–	–	–
July 25	0	0	0	0	–	–	–
August 3	0	0	0	0	–	–	–
August 14	6	0	6	12	3.7	0.02	1.20
August 26	4	0	4	8	3.1	0.02	1.33
September 9	0	0	0	0	–	–	–
Total	84	0	84	168	–	0.05	5.25
COLVILLE EAST (1700 km²) [e]							
May 3	26	0	26	52	13.4	0.03	1.73
August 3–4	6	2	8	16	4.6	0.01	1.33
August 14–15	5	0	5	10	4.3	0.01	1.67
August 27	18	1	19	38	9.5	0.02	2.71
September 9–10	244	11	255	510	76.0	0.30	3.23
September 24 [f]	7	0	7	19	9.9	0.01	7.00
October 6–7	64	0	64	128	32.7	0.08	5.82
October 25–26	66	8	74	148	45.1	0.09	4.93
Total	436	22	458	921		0.07	3.34

[a] Adults + yearlings.
[b] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[c] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[d] Density = Estimated Total / Survey Area Size.
[e] Survey coverage was 50% (654 km² in NPRA, 247 km² on the Colville R. Delta, and 850 km² in Colville East).
[f] Part of area not flown due to fog.

Appendix E. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2003.

Survey Area (Size) and Date	Large Caribou [a,b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1310 km²) [f]							
April 24	1565	0	1565	3130	263.0	2.39	5.0
May 20	46	0	46	92	25.5	0.07	3.5
May 30 [g]	81	2	83	166	53.1	0.13	2.3
June 8	225	0	225	450	78.1	0.34	2.7
June 16	401	7	408	816	129.9	0.62	3.0
June 24	521	9	530	1060	130.6	0.81	3.8
July 7	1	1	2	4	2.8	<0.01	2.0
July 20	0	0	0	0	–	0	–
August 4	296	23	319	638	144.4	0.49	2.8
September 3	nr	nr	108	216	39.5	0.17	2.9
September 16	nr	nr	565	1130	204.8	0.86	6.7
September 29	nr	nr	2262	4524	756.9	3.46	7.0
October 28	nr	nr	176	352	75.4	0.27	7.0
Total			6289	12,578	–	0.74	4.9
COLVILLE R. DELTA (494 km²) [f]							
June 28	31	0	31	62	22.4	0.13	4.4
July 7	1	1	2	4	2.8	0.01	2.0
July 20	3	0	3	6	2.2	0.01	1.0
September 16	nr	nr	13	26	14.2	0.05	6.5
Total			49	98	–	0.05	3.8
COLVILLE EAST (1700 km²) [f]							
April 24	314	0	314	628	172.4	0.37	5.5
May 14	121	0	121	242	79.1	0.16	3.6
October 28–29	nr	nr	426	852	182.3	0.50	7.0
Total			861	1722	–	0.34	5.7

[a] Adults + yearlings.
[b] nr = not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (654 km² in NPRA, 247 km² on the Colville R. Delta, and 850 km² in Colville East were surveyed).
[g] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994).

Appendix F. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2004.

Survey Area (Size) and Date	Large Caribou [a]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1310 km²) [f]							
May 18	29	0	29	58	17.0	0.04	5.8
June 25	2	0	2	4	2.8	<0.01	1.0
August 10	45	0	45	90	11.0	0.07	1.1
September 15	183	27	210	420	81.9	0.32	6.0
October 18	802	nr	802	1604	229.3	1.23	12.2
Total	1061	27	1088	2176	–	0.33	7.4
COLVILLE R. DELTA (494 km²) [f]							
June 25	316	13	329	658	418.7	1.33	82.3
August 11	4	0	4	8	3.1	0.02	1.0
Total	320	13	333	666	–	0.67	41.6
COLVILLE EAST (1700 km²) [f]							
August 11	22	1	23	46	13.0	0.03	1.5
September 16	193	19	212	424	76.9	0.25	4.9
October 19	1335	nr	1335	2670	743.7	1.57	17.8
Total	1550	20	1570	3140	–	0.62	11.8

[a] Adults + yearlings.
[b] nr = not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% sampling coverage.
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (654 km² in NPRA, 247 km² on the Colville R. Delta, and 850 km² in Colville East were surveyed).

Appendix G. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2005.

Survey Area (Size) and Date	Large Caribou [a,b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1720 km²) [f]							
April 23	590	0	590	1180	184.6	0.686	6.0
June 6 [g]	64	6	70	263	54.5	0.149	2.6
June 13 [h]	279	45	324	648	296.9	0.753	4.6
June 20	476	69	545	1090	151.8	0.634	4.9
June 28	47	0	47	94	17.2	0.055	1.5
August 3 [i]	nr	nr	8947	9015	51.5	5.241	357.9
August 17	16	2	18	36	7.3	0.021	2.0
August 31	41	0	41	82	14.0	0.048	2.1
October 21	144	14	158	316	54.6	0.184	3.4
COLVILLE R. DELTA (494 km²) [f]							
April 24	4	0	4	8	4.3	0.02	2
June 11 [h]	1	0	1	2	3.4	0.01	1
June 20	9	0	9	18	10.0	0.04	4.5
June 28	170	12	182	364	85.0	0.74	6.1
August 2	nr	nr	881	994	71.0	2.01	55.1
August 17	22	1	23	46	18.7	0.09	5.8
August 31	9	1	10	20	8.4	0.04	2.5
October 21 & 23	0	0	0	0	–	0	–
COLVILLE EAST (1696 km²) [f]							
April 24	39	0	39	78	20.9	0.05	3.0
June 5–6 [g,i]	290	79	369	1387	164.4	0.97	2.18
June 10–11 [j]	1010	363	1373	2746	332.3	1.92	5.12
June 21	2172	842	3014	6028	624.1	3.55	10.3
June 29 [k]	366	34	400	800	867.7	0.82	15.4
August 2–3	nr	nr	1915	1962	74.1	1.16	95.8
August 15–16	34	4	38	76	19.8	0.05	3.8
August 31 [k]	19	1	20	40	18.4	0.05	2.0
October 4 [k]	32	3	35	70	116.3	0.20	4.4
October 21 & 23 [k]	82	4	86	172	59.3	0.12	5.7

[a] Adults + yearlings.
[b] nr = not recorded (calves not differentiated).
[c] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage) or × 4 (for 25% sampling coverage).
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Typical survey coverage was 50% (860 km² in NPRA, 247 km² on the Colville R. Delta, and 848 km² in Colville East).
[g] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994).
[h] Flown at 90-m altitude and 25% coverage due to low cloud ceiling.
[i] Assumes all large groups along the coast were found.
[j] Survey of calving transects (1.6-km spacing) at 90-m altitude and 50% coverage (Lawhead and Prichard 2006).
[k] Survey shortened due to poor weather.

Appendix H. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2006.

Survey Area (Size) and Date	Large Caribou [a]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1720 km²) [f]							
May 3	288	0	288	576	74.1	0.33	3.6
June 9	275	21	296	592	76.6	0.34	2.5
June 19	440	75	515	1030	169.9	0.60	5.9
June 26	0	0	0	0	–	0	–
August 4	35	1	36	72	15.4	0.04	1.1
August 15	36	2	38	76	10.7	0.04	1.1
August 30	122	4	126	252	35.9	0.15	2.2
October 10	11	nr	11	22	12.7	0.01	2.2
COLVILLE R. DELTA (494 km²) [f]							
May 3	16	0	16	32	9.2	0.06	2.3
June 9	13	1	14	28	14.6	0.06	2.3
June 19	10	0	10	20	11.2	0.04	2.5
June 26	1	0	1	2	1.4	<0.01	1.0
August 3	3	0	3	6	2.2	0.01	1.0
August 15	3	0	3	6	3.0	0.01	1.5
August 29	7	0	7	14	4.7	0.03	1.4
October 10	1	nr	1	2	1.4	<0.01	1.0
COLVILLE EAST (1696 km²) [f]							
May 3–4	49	0	49	98	19.9	0.06	2.6
June 3–5 [g,h]	91	14	105	395	84.8	0.28	1.8
June 11–12 [h]	1517	511	2028	4056	309.2	2.83	6.4
June 20	998	208	1206	2412	398.2	1.42	11.9
June 26–27	0	0	0	0	–	0	–
August 3	1	0	1	2	1.4	<0.01	1
August 15–16	7	0	7	14	5.6	0.01	1
August 29	60	3	63	126	18.0	0.07	2.6
October 11	593	nr	593	1186	335.9	0.70	15.2

[a] Adults + yearlings.
[b] nr = not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage).
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (860 km² were surveyed in NPRA, 247 km² on the Colville R. Delta, and 848 km² in Colville East).
[g] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994).
[h] Survey of calving-season transects (1.6-km-spacing) at 90-m altitude for 50% coverage; SE calculated based on 3.2-km-long transect segments (Lawhead and Prichard 2006).

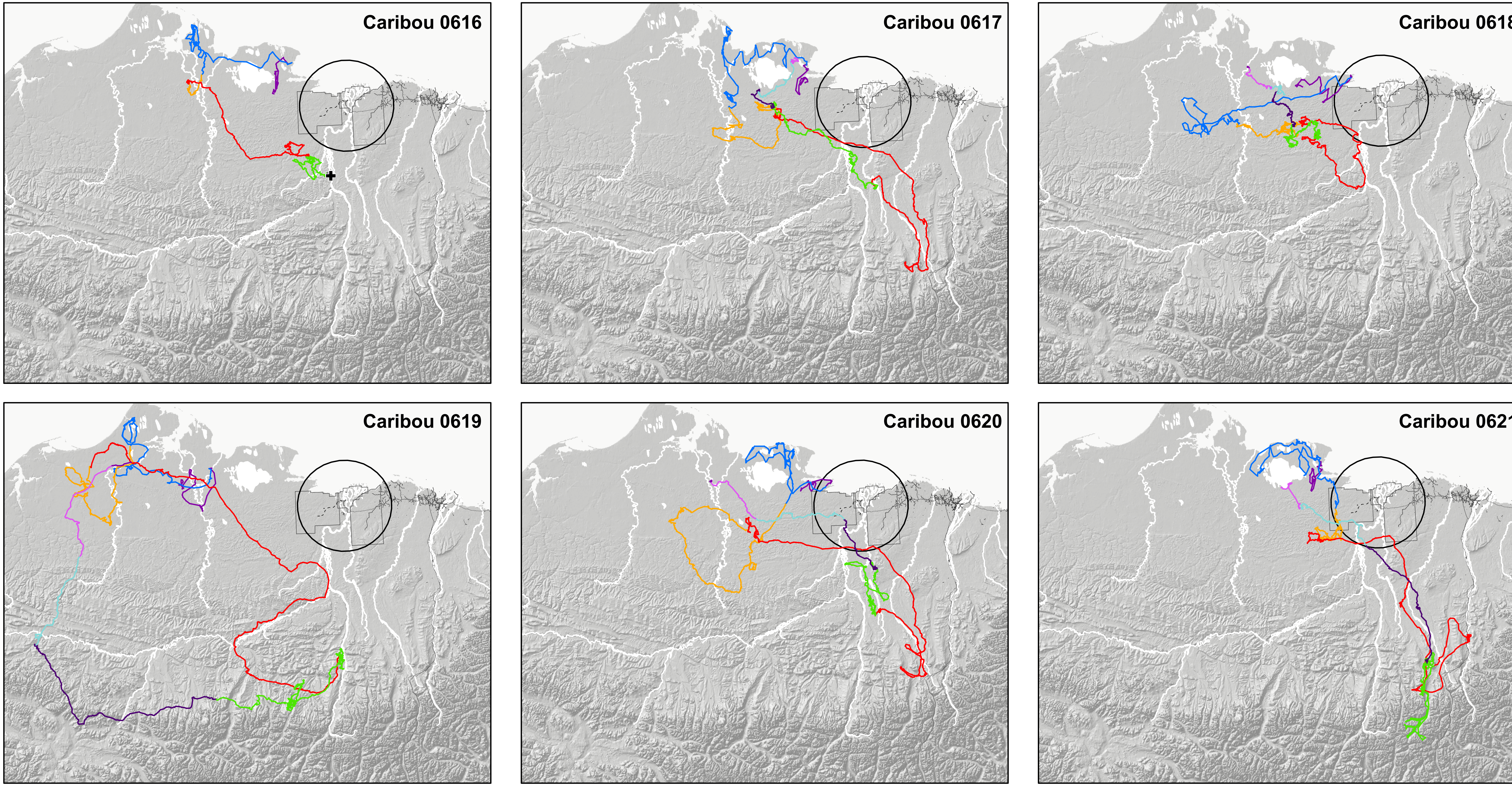
Appendix I. Estimated numbers and densities of caribou in the Colville East and Colville River Delta calving survey areas, June 1993 and 1995–2007 (from Lawhead and Prichard 2008).

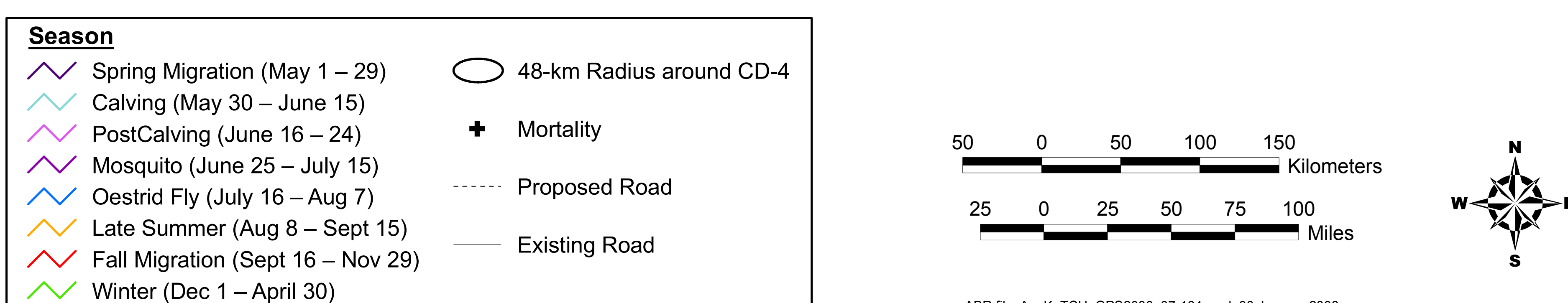
Survey Area	Date	Total Area (km²)	Estimated Total Caribou [a]	Total Density (per km²)	Estimated Total Calves [a]	Calf Density (per km²)	Snow Cover
Colville East [b,c,d,e,f]	26 May 1993	650	60	0.09	0	0	High; SCF not used
	27 May 1993	1050	87	0.08	0	0	High; SCF not used
	3 June 1993	1050	542	0.52	0	0	Patchy; SCF used
	8 June 1993	709	914	1.29	148	0.21	Low; SCF not used
	11 June 1993	910	2181	2.40	558	0.61	None
	4–5 June 1995	1057	315	0.30	41	0.04	Patchy; SCF used
	12–13 June 1995	1349	2057	1.52	305	0.23	None
	3–4 June 1996	1362	800	0.59	159	0.12	None
	12–13 June 1996	1358	2670	1.97	786	0.58	None
	1–2 June 1997	1362	555	0.41	60	0.04	Patchy; SCF used
	10–12 June 1997	1321	4035	3.05	1214	0.92	Patchy; SCF used
	3 June 1998	1370	1840	1.34	284	0.21	None
	11–12 June 1998	1370	1902	1.39	310	0.23	None
	11 June 1999	1478	2166	1.47	544	0.37	Low; SCF not used
	11–12 June 2000	1478	966	0.65	192	0.13	Patchy; SCF used
	5–6 June 2001	1478	169	0.11	0	0	Patchy; SCF used
	10–11 June 2001	1478	1148	0.78	192	0.13	Patchy; SCF not used
	6–7 June 2002	1432	5584	3.90	830	0.58	None
	10–11 June 2002	1432	6232	4.35	1034	0.72	None
	3–4 June 2003	1432	1162	0.81	120	0.08	Patchy; SCF used
	10 & 12 June 2003	1432	2790	1.95	614	0.43	Low; SCF not used
	5 June 2004	1262	1092	0.61	350	0.28	Patchy; SCF used
	16 June 2004	1323	6982	5.28	2286	1.73	None
	5–6 June 2005	1432	1387	0.97	297	0.21	Patchy; SCF used
	10–11 June 2005	1432	2746	1.92	726	0.51	Low; SCF not used
	3–5 June 2006	1432	395	0.28	53	0.04	Patchy, SCF used
	11–12 June 2006	1432	4056	2.83	1022	0.71	None
	2, 4–5 June 2007	1432	2290	1.60	192	0.13	Patchy; SCF used
	11–12 June 2007	1432	10,624	7.42	2596	1.81	None
Colville R. Delta	28 May 1993	637	27	0.04	0	0	High; SCF not used
	10 June 1993	637	0	0	0	0	Low; SCF not used
	3 June 1995	637	18	0.03	0	0	Low; SCF not used
	2 June 1996	637	58	0.09	0	0	None
	13 June 1996	637	10	0.02	1	<0.01	None
	1 June 1997	637	0	0	0	0	High; SCF not used
	12 & 20 June 1997	637	0	0	0	0	Patchy; SCF used
	9 June 2006	637	6	0.01	1	<0.01	None

[a] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994) where indicated.
[b] Extended south to 70° N latitude in 1995, thus incorporating much of 1993 Colville Inland survey area.
[c] Extended south in 1999 to incorporate Meltwater South study area.
[d] Dropped westernmost transect in 2002.
[e] Unable to survey 3 westernmost transects on 5 June 2004.

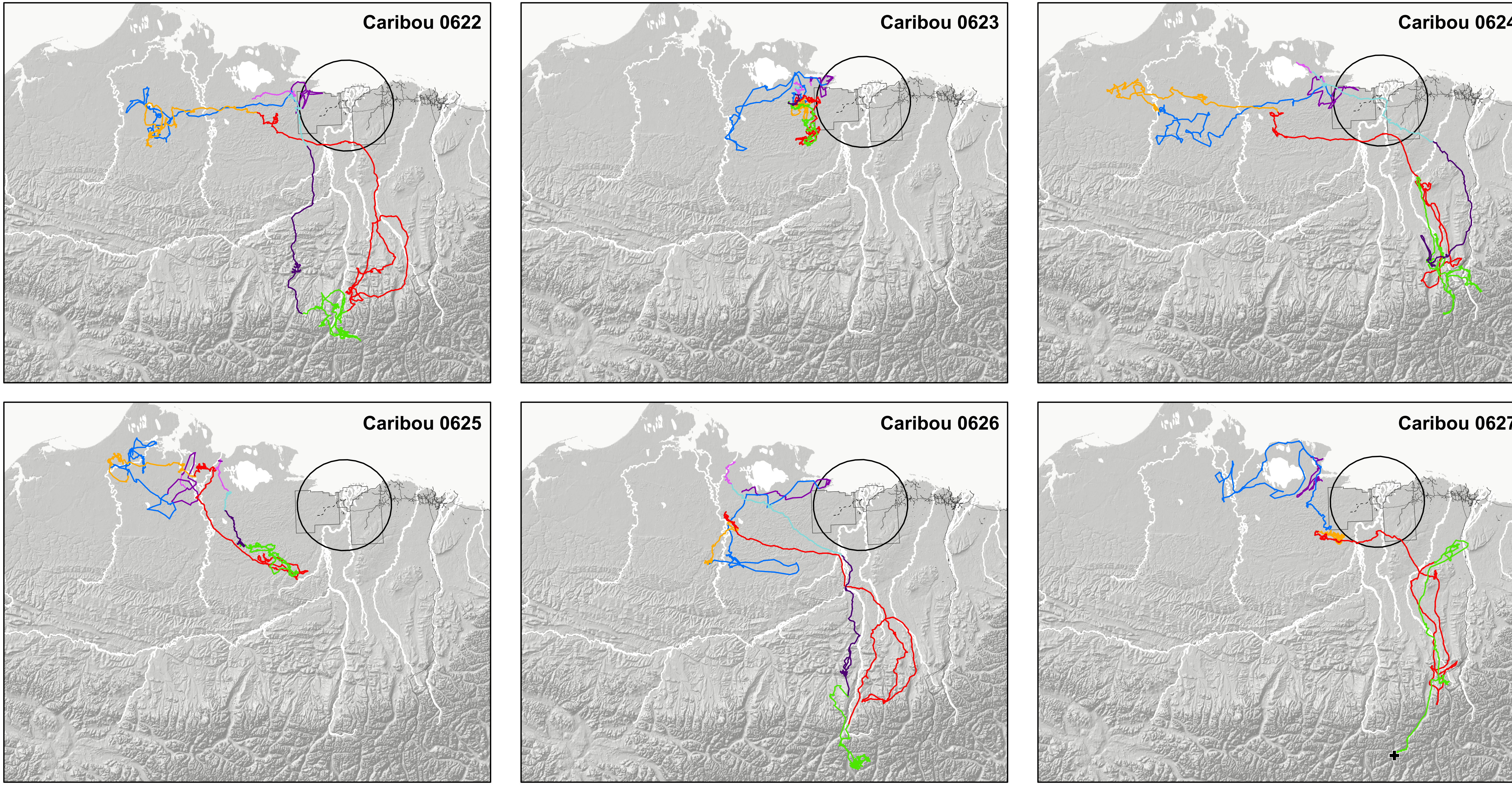
Appendix J. Location and number of muskoxen and grizzly bears observed in the NPRA survey area, May–October 2007.

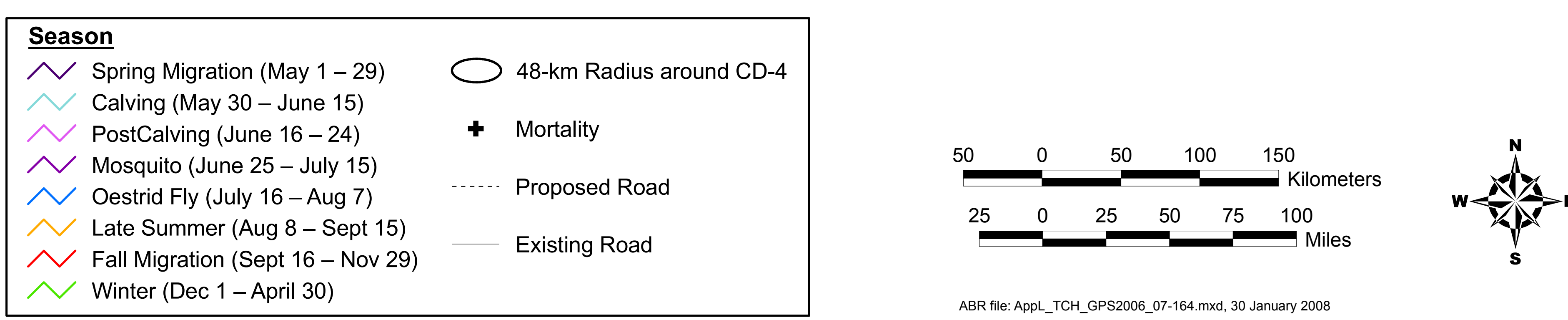
Species	Date	Total Number	Number of Adults	Number of Young	General Location
Muskox	May 14	25	21	4	Fish Creek Delta
Grizzly bear	May 14	3	1	2	Western portion
	June 25	3	1	2	Fish Creek Delta
	August 12	3	1	2	Western portion
	September 21	3	1	2	North of Nuiqsut
	October 8	1	1	0	Southern portion
	October 22	3	1	2	Northwestern portion
	October 22	1	1	0	Southern portion





Appendix K.
Movements of individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, July 2006–June 2007.





Appendix L.
Movements of individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, July 2006–June 2007.

Appendix M. Descriptive statistics for snow cover and vegetative biomass (NDVI) in 2007 and for habitat type (BLM and Ducks Unlimited 2002) within different geographic sections of the 2002–2004 and 2005–2007 NPRA survey areas.

Survey Area	Variable	Statistic	Coast	North	Rivers	Southeast	Southwest	West
2002–2004	Area	km²	9.8	88.2	156.1	232.2	130.9	36.4
	Vegetative Biomass	NDVI_calving	0.3739	0.3833	0.3576	0.3962	0.4033	0.4036
		NDVI_621	0.3863	0.3938	0.3787	0.4175	0.4241	0.4290
		NDVI_rate	0.0007	0.0006	0.0013	0.0013	0.0013	0.0015
		NDVI_peak	0.5474	0.5376	0.5256	0.5694	0.5611	0.5666
	Snow Cover 4 June	Mean %	17.5	38.0	8.6	11.0	15.8	5.5
	Snow Cover 6 June	Mean %	3.0	5.7	2.1	1.6	1.9	0.3
	Snow Cover 7 June	Mean %	1.8	2.7	1.1	1.0	1.3	0.2
	Habitat Type (% area)	Water	9.7	26.5	14.4	17.7	11.4	11.3
		Carex aquatilis	11.5	6.4	6.4	6.2	9.3	5.1
		Flooded Tundra	33.2	11.6	14.9	18.3	19.9	12.2
		Wet Tundra	12.4	7.6	11.5	7.3	10.7	9.0
		Sedge/Grass Meadow	7.3	21.9	14.2	5.4	9.3	28.7
		Tussock Tundra	23.8	22.0	25.0	41.3	35.1	31.1
		Moss/Lichen	1.4	0.9	3.3	0.3	0.7	0.5
		Dwarf Shrub	0.2	1.9	3.2	2.9	3.1	1.8
		Low Shrub	0	<0.1	0.1	0.3	0.3	0.1
		Dry Dunes	0.1	0.1	2.1	0.1	0	0
		Sparsely Vegetated	<0.1	0.5	2.9	0.1	<0.1	<0.1
		Barren Ground	0.4	0.7	2.1	0.1	0.1	0.1
2005–2007	Area	km²	93.2	206.6	160.7	232.2	130.9	36.4
	Vegetative Biomass	NDVI_calving	0.3316	0.3802	0.3571	0.3963	0.4033	0.4036
		NDVI_621	0.3342	0.3866	0.3782	0.4177	0.4241	0.4290
		NDVI_rate	0.0002	0.0004	0.0013	0.0013	0.0013	0.0015
		NDVI_peak	0.4835	0.5334	0.5251	0.5695	0.5612	0.5666
	Snow Cover 4 June	Mean %	58.9	44.6	8.7	11.0	15.8	5.5
	Snow Cover 6 June	Mean %	34.6	5.8	2.1	1.6	1.9	0.3
	Snow Cover 7 June	Mean %	20.6	1.8	1.1	1.0	1.4	0.2
	Habitat Type (% area)	Water	24.1	22.1	15.4	17.7	11.4	11.3
		Carex aquatilis	8.3	6.3	6.4	6.2	9.3	5.1
		Flooded Tundra	15.1	10.1	14.9	18.3	19.9	12.2
		Wet Tundra	6.9	7.6	11.3	7.3	10.7	9.0
		Sedge/Grass Meadow	11.8	23.3	13.9	5.4	9.3	28.7
		Tussock Tundra	19.6	25.5	24.8	41.3	35.1	31.1
		Moss/Lichen	1.0	1.2	3.2	0.3	0.7	0.5
		Dwarf Shrub	1.3	2.3	3.1	2.9	3.1	1.8
		Low Shrub	<0.1	<0.1	0.1	0.3	0.3	0.1
		Dry Dunes	3.2	0.3	2.0	0.1	0	0
		Sparsely Vegetated	0.7	0.5	2.8	0.1	<0.1	<0.1
		Barren Ground	8.0	0.8	2.1	0.1	0.1	0.1

Appendix N. Model selection results for ANCOVA tests of caribou density during calving 2007 in the NPRA survey area (163 grid cells). The best model (bold type) contained the variables indicating the presence or absence of Fish or Judy creeks (Creek), presence or absence of the proposed ASDP road (Road), transect number west to east (W to E), percent snow cover on June 3 (Snow Cover), and peak NDVI value (NDVI_peak).

Model [a]	RSS [b]	*n* [c]	K [d]	AIC_c [e]	ΔAIC_c [f]	w_i [g]
Creek, Road, W to E, Snow Cover, NDVI_peak	**144.06**	**163**	**7**	**-5.41**	**0.00**	**0.615**
Creek, Road, W to E, NDVI_peak	146.94	163	6	-4.37	1.04	0.367
Creek, Road, W to E, Snow Cover, NDVI_rate	150.45	163	7	1.67	7.08	0.018
Creek, Road, W to E, NDVI_rate	160.41	163	6	9.93	15.33	0.000
Creek, Road, W to E, Tussock	163.79	163	6	13.33	18.74	0.000
Creek, Road, W to E, Snow Cover, Tussock	163.56	163	7	15.29	20.69	0.000
Creek, Road, W to E, Wet Habitat	176.75	163	6	25.74	31.14	0.000
Creek, Road, Snow Cover, NDVI_rate	177.79	163	6	26.69	32.10	0.000
Creek, Road, W to E, Snow Cover, Wet Habitat	176.36	163	7	27.56	32.97	0.000
Creek, Road, W to E, Snow Cover	178.98	163	6	27.78	33.19	0.000
Creek, Road, W to E	181.53	163	5	27.94	33.35	0.000
Creek, Road, Snow Cover, NDVI_peak	181.97	163	6	30.49	35.90	0.000
Creek, Road, NDVI_peak	186.45	163	5	32.29	37.70	0.000
Creek, Road, NDVI_rate	194.50	163	5	39.18	44.59	0.000
Creek, Road, Tussock	208.34	163	5	50.38	55.79	0.000
Creek, Road, Snow Cover, Tussock	208.17	163	6	52.41	57.82	0.000
Creek, Road, Snow Cover	215.74	163	5	56.07	61.48	0.000
Creek, Road, Wet Habitat	215.90	163	5	56.20	61.61	0.000
Creek, Road, Snow Cover, Wet Habitat	215.45	163	6	58.02	63.42	0.000

[a] Coast = distance from coast; Tussock = proportion of tussock tundra; Wet Habitat = combined proportions of 4 types; see text).
[b] Residual Sum of Squares.
[c] Sample size.
[d] Number of estimable parameters in the approximating model.
[e] Akaike's Information Criterion corrected for small sample size.
[f] Difference in value between the AIC_c of the current model and that of the best approximating model.
[g] Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix O. Model selection results for ANCOVA tests of caribou density in different seasons during 2002–2007 in the NPRA survey area (124 grid cells). Bold type denotes the best model for each season.

Season	Value	Model [a] C,R,NP	C,R,DC	C,R,TT	C,R,WH	C,R,TR	C,R,DC,NP	C,R,DC,TT	C,R,DC,WH	C,R,TR,DC	C,R,TR,NP	C,R,TR,TT	C,R,TR,WH	C,R,TR,DC,NP	C,R,TR,DC,TT	C,R,TR,DC,WH
All Seasons	*n* [b]	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124
	K [c]	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7
Winter	RSS [d]	106.4	85.9	107.4	108.3	98.9	83.6	83.7	84.3	84.9	91.3	88.3	90.1	81.7	**80.7**	81.7
	AIC_c [e]	-8.5	-35.0	-7.3	-6.3	-17.5	-36.1	-36.0	-35.1	-34.2	-25.2	-29.3	-26.9	-36.7	**-38.3**	-36.8
	w_i [f]	0.00	0.06	0.00	0.00	0.00	0.11	0.10	0.06	0.04	0.00	0.00	0.00	0.14	**0.33**	0.15
Spring	RSS	41.5	41.4	41.6	41.6	**39.1**	41.3	41.3	41.4	38.9	38.7	38.6	38.9	38.4	38.1	38.5
	AIC_c	-125.3	-125.6	-125.0	-124.8	**-132.7**	-123.8	-123.5	-123.4	-131.1	-131.5	-131.9	-131.2	-130.5	-131.3	-130.2
	w_i	0.01	0.01	0.00	0.00	**0.23**	0.00	0.00	0.00	0.10	0.13	0.16	0.11	0.07	0.11	0.06
Calving	RSS	51.9	40.6	53.8	53.9	32.6	40.0	40.6	40.5	30.8	29.4	29.9	30.9	**28.6**	29.2	30.0
	AIC_c	-97.4	-127.9	-93.1	-92.7	-155.1	-127.5	-125.7	-126.2	-159.9	-165.9	-163.8	-159.4	**-166.9**	-164.3	-160.9
	w_i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.28	0.10	0.01	**0.46**	0.12	0.02
Postcalving	RSS	62.0	61.7	60.7	61.1	45.5	61.7	60.2	60.8	**41.0**	45.1	45.5	45.5	41.0	40.6	40.4
	AIC_c	-75.5	-76.0	-78.2	-77.2	-113.9	-73.8	-76.8	-75.7	**-124.4**	-112.6	-111.7	-111.7	-122.3	-123.5	-124.2
	w_i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.34**	0.00	0.00	0.00	0.12	0.22	0.31
Mosquito	RSS	17.2	16.1	17.3	17.6	17.8	15.7	15.7	16.0	**14.4**	17.1	17.2	17.5	14.3	14.4	14.4
	AIC_c	-234.6	-242.3	-234.1	-231.8	-230.2	-243.2	-243.2	-241.4	**-254.0**	-232.9	-232.0	-229.9	-252.8	-251.9	-251.9
	w_i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.45**	0.00	0.00	0.00	0.24	0.15	0.15
Oestrid Fly	RSS	**91.44**	96.77	92.25	97.24	97.73	90.87	91.48	96.06	96.76	90.54	90.27	96.23	90.47	90.27	95.87
	AIC_c	**-27.26**	-20.24	-26.17	-19.63	-19.01	-25.82	-25.00	-18.95	-18.04	-26.28	-26.65	-18.72	-24.12	-24.40	-16.94
	w_i	**0.23**	0.01	0.13	0.01	0.00	0.11	0.08	0.00	0.00	0.14	0.17	0.00	0.05	0.06	0.00
Late	RSS	17.0	18.2	17.2	17.7	14.3	16.5	16.8	17.4	13.6	**13.2**	13.9	14.1	12.9	13.5	13.6
Summer	AIC_c	-236.2	-227.5	-234.7	-230.6	-257.7	-237.4	-235.1	-230.6	-261.4	**-265.2**	-258.7	-256.4	-265.8	-260.2	-259.2
	w_i	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.06	**0.37**	0.01	0.00	0.50	0.03	0.02
Fall	RSS	36.5	29.5	36.5	36.5	32.2	29.2	29.2	29.2	**28.9**	32.2	32.0	32.0	28.8	28.9	28.9
Migration	AIC_c	-141.1	-167.6	-141.2	-141.2	-156.8	-166.5	-166.7	-166.5	**-167.7**	-154.7	-155.1	-155.1	-166.1	-165.8	-165.8
	w_i	0.00	0.19	0.00	0.00	0.00	0.11	0.12	0.11	**0.21**	0.00	0.00	0.00	0.09	0.08	0.08

[a] C = presence or absence of Fish or Judy creeks, R = presence or absence of proposed road, NP = NDVI_peak, DC = distance to coast, TT = proportion of tussock tundra, WH = proportion of wet habitat (4 types combined; see text), and TR = transect number (west to east).
[b] *n* = sample size.
[c] K = number of estimable parameters in the approximating model.
[d] RSS = Residual Sum of Squares.
[e] AIC_c = Akaike's Information Criterion corrected for small sample size.
[f] w_i = Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix P. Model-weighted parameter estimates, standard error (SE), and *P*-value of variables included in the grid-cell analyses of caribou densities in the NPRA survey area, 2002–2007. Asterisks denote significance of *P*-value (* < 0.05, ** <0.01, *** <0.001).

Season	Variable	Mean	SE	*P*-value
Winter	Intercept	-2.480	1.696	0.144
	Presence of Creek	-0.141	0.242	0.561
	Includes Proposed Road	-1.009	0.308	0.001**
	NDVI_peak	0.0007	0.0003	0.049*
	Distance to Coast (km)	0.041	0.012	<0.001***
	Tussock Tundra (%)	1.427	0.650	0.028*
	Wet Habitat (%)	-1.182	0.634	0.062
	Transect Number (West to East)	-0.049	0.026	0.065
Spring Migration	Intercept	-0.850	0.693	0.220
	Presence of Creek	-0.085	0.150	0.571
	Includes Proposed Road	0.002	0.210	0.993
	NDVI_peak	0.0003	0.0002	0.292
	Distance to Coast (km)	-0.007	0.007	0.357
	Tussock Tundra (%)	0.535	0.423	0.206
	Wet Habitat (%)	-0.357	0.413	0.387
	Transect Number (West to East)	-0.043	0.016	0.006**
Calving	Intercept	-2.711	1.762	0.124
	Presence of Creek	0.123	0.156	0.431
	Includes Proposed Road	0.105	0.185	0.570
	NDVI_peak	0.0007	0.0003	0.002**
	Distance to Coast (km)	0.011	0.006	0.081
	Tussock Tundra (%)	1.039	0.377	0.006**
	Wet Habitat (%)	-0.729	0.380	0.055
	Transect Number (West to East)	-0.104	0.016	<0.001***
Postcalving	Intercept	1.897	0.506	<0.001***
	Presence of Creek	0.826	0.135	<0.001***
	Includes Proposed Road	-0.094	0.192	0.624
	NDVI_peak	-0.00004	0.0002	0.848
	Distance to Coast (km)	-0.026	0.007	<0.001***
	Tussock Tundra (%)	0.586	0.390	0.132
	Wet Habitat (%)	-0.769	0.378	0.042*
	Transect Number (West to East)	-0.129	0.017	<0.001***
Mosquito	Intercept	-0.571	0.442	0.196
	Presence of Creek	0.083	0.091	0.365
	Includes Proposed Road	0.043	0.128	0.736
	NDVI_peak	-0.0002	0.0002	0.328
	Distance to Coast (km)	-0.021	0.004	<0.001***
	Tussock Tundra (%)	-0.089	0.263	0.736
	Wet Habitat (%)	-0.079	0.257	0.758
	Transect Number (West to East)	-0.036	0.010	<0.001***
Oestrid Fly	Intercept	2.205	3.053	0.470
	Presence of Creek	0.330	0.262	0.207
	Includes Proposed Road	-0.231	0.319	0.470
	NDVI_peak	-0.001	0.0004	0.003**
	Distance to Coast (km)	-0.006	0.010	0.550
	Tussock Tundra (%)	-1.772	0.624	0.005**
	Wet Habitat (%)	0.689	0.620	0.267
	Transect Number (West to East)	0.028	0.023	0.228
Late Summer	Intercept	1.598	0.933	0.087
	Presence of Creek	0.309	0.101	0.002**
	Includes Proposed Road	0.172	0.124	0.165
	NDVI_peak	-0.0004	0.0001	0.007**
	Distance to Coast (km)	-0.007	0.004	0.086
	Tussock Tundra (%)	-0.309	0.260	0.235
	Wet Habitat (%)	0.079	0.257	0.758
	Transect Number (West to East)	-0.052	0.010	<0.001***

Appendix P. Continued.

Season	Variable	Mean	SE	*P*-value
Fall Migration	Intercept	-0.158	0.569	0.781
	Presence of Creek	0.210	0.129	0.103
	Includes Proposed Road	-0.180	0.182	0.322
	NDVI_peak	-0.0002	0.0002	0.362
	Distance to Coast (km)	0.025	0.006	<0.001***
	Tussock Tundra (%)	0.351	0.433	0.418
	Wet Habitat (%)	0.283	0.356	0.426
	Transect Number (West to East)	-0.020	0.015	0.177