CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2005

ANNUAL REPORT

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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 Plan (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-mile) 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 first year of the ASDP caribou monitoring study, combining aerial transect survey data with analysis of telemetry data. We conducted strip-transect aerial surveys of caribou distribution within three adjacent survey areas (NPRA, Colville River Delta, and Colville East) during April to October 2001–2005. The telemetry analyses used location data from VHF, satellite, and GPS radio-collars in the Central Arctic Herd (CAH) and the Teshekpuk Caribou Herd (TCH) 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 1990–2005 for the TCH and 1986–1990 and 2001–2005 for the CAH; and GPS-collar data were collected during 2004–2005 for the TCH and 2003–2005 for the CAH.

Above-ground vegetative biomass of vascular plants was sampled in the NPRA survey area within the two dominant habitat types (moist sedge–shrub tundra and moist tussock tundra) in three different distance categories from the planned ASDP road. Normalized Difference Vegetation Index (NDVI) estimates were derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery from 2002–2005 for the study area during calving (1–10 June), peak lactation (21 June), the rate of NDVI change between calving and peak lactation, and during the peak of the vegetative growing season (2005 only). Snow cover (subpixel-scale snow fraction) was calculated for the ASDP study area from MODIS satellite imagery for spring 2005. The feasibility of using remote sensing was evaluated to identify and map caribou trails on tundra landscapes.

Caribou were present in the survey areas during all seasons in which surveys were conducted. The highest densities of caribou west of the Colville River typically occurred in fall, with erratically occurring large groups of caribou present during mosquito and oestrid fly seasons. The highest densities east of the Colville River occurred during the calving and postcalving seasons. The mean proportion of collared CAH caribou within the study area during each month varied between 13 and 51% for satellite collars and 0 and 58% for GPS collars. The mean proportion of collared TCH caribou within the ASDP study area during each month varied between 8 and 20% for satellite collars and 0 and 70% for GPS collars.

Analysis of the VHF, satellite, and GPS telemetry data sets demonstrated clearly that the Colville River delta and ASDP study area is at the interface of the annual ranges of the TCH and CAH. Although caribou from both herds occur on the delta occasionally, large movements across the delta are unusual for both herds. 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. TCH caribou use the NPRA survey area year-round, however, so our detailed analyses focused primarily on the NPRA survey area in the western half of the ASDP study area, in which the proposed road alignment is located.

Significantly more live above-ground vegetative biomass was recorded in moist tussock tundra than in moist sedge–shrub tundra. Moist tussock tundra contained more lichens, *Eriophorum vaginatum*, forbs, evergreen shrubs, and *Betula nana* than did moist sedge–shrub tundra. The relationship between estimates of vegetative biomass based on direct sampling and NDVI estimates from satellite images was weak. Biomass estimates did not differ significantly among the three distance-to-proposed-road categories.

Caribou trails on the tundra were visible during low-level aerial surveys but could not be distinguished reliably on 1–2-ft digital orthophoto mosaic photography. Although often faint, trails were generally visible on digital orthophoto-mosaic photography scanned at a resolution of 8 microns (0.5-ft resolution).

Spatial analysis of caribou distribution in the NPRA survey area during 2002–2005 showed that the area near the sea coast contained significantly more caribou groups during the mosquito season than did other parts of the survey area. Riparian areas along Fish and Judy Creeks contained significantly more caribou groups during postcalving, the oestrid fly season, and late summer. The southeast portion of the NPRA survey area, in which the planned ASDP road will be constructed, contained significantly fewer groups in all seasons except winter and spring migration.

For the years 2002–2005 combined, caribou in NPRA used tussock tundra significantly more than expected in winter and less than expected in the mosquito and oestrid fly seasons and late summer. Riverine habitats were used more than expected from postcalving through fall migration.

High-density calving areas occurred east of the Colville River for the CAH (including our Colville East survey area) and around Teshekpuk Lake for the TCH (west of our NPRA survey area). Although some calving does occur in the western half of the ASDP study area, it is not an area of concentrated calving for the TCH. The high-density calving areas of both herds in 2005 contained greater snow cover than was generally available in the region, but there was little evidence of selection for specific snow cover classes by caribou. During the 2005 calving season in the NPRA survey area, caribou tended to use areas that had high rates of increase in plant biomass and high peak levels of vegetative biomass. The mean value of plant biomass at caribou locations was not significantly different from expected.

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 TCH 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 TCH 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 planned road alignment is located, tends to have lower caribou densities than do other sections of the area. Within 6 km of the road alignment, there was little evidence for selection or avoidance of the area around the planned road corridor. Fewer groups than expected occurred around the road corridor during the oestrid fly season and late summer, probably because of increased use of riparian habitats along Fish and Judy creeks by caribou when oestrid flies were present. Radio-collared TCH caribou moved across the planned ASDP road alignment, primarily during fall migration, but the data collected thus far indicate that the road alignment is in an area of low-density use.

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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 two adjacent herds of barren-ground caribou (*Rangifer tarandus*)—the Teshekpuk Caribou Herd (TCH) and the Central Arctic Herd (CAH). The TCH generally ranges to the west and the CAH to the east of the Colville River delta.

The TCH 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). Most TCH animals 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). In recent years a substantial portion of the TCH has wintered well east of normal range in the Arctic National Wildlife Refuge (ANWR, in 2003–2004; Carroll et al. 2004) and southeast in the winter range of the CAH (in 2004–2005; G. Carroll and L. Parrett, personal communications).

The most concentrated calving by the CAH tends to occur in two areas of the coastal plain, one located south–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 2004, Lawhead and Prichard 2006). 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 2004).

This caribou monitoring study for the Alpine Satellite Development Program (ASDP) builds on research, funded by ConocoPhillips Alaska, Inc. (CPAI) and its predecessors (ARCO Alaska, Inc., and PHILLIPS Alaska, Inc.), 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. 2005 for complete listing of CPAI studies). 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 provide descriptions and mapping 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.

Contemporaneous studies of caribou in the region west of the Colville River include research by the Alaska Department of Fish and Game (ADFG), North Slope Borough (NSB), and Bureau of Land Management (BLM) since 1990, relying primarily on radio telemetry (very-high frequency [VHF], satellite, and, since 2004, GPS transmitters) (Philo et al. 1993, Carroll 2003, Prichard and Murphy 2004, Carroll et al. 2005). A third-party consultant working for BP Exploration (Alaska), Inc. conducted aerial transect surveys over much of the calving grounds of the TCH 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 1980s using VHF, satellite, and, since 2003, GPS telemetry, as well as periodic transect surveys (Cameron et al. 1995, Lenart 2003, Arthur and Del Vecchio 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 Record of Decision (ROD) in 1998. Discoveries of oil-bearing formations in northeastern NPRA since the late 1990s led to strong industry interest in the area and a proposal by CPAI—known as the Alpine Satellite Development Plan (BLM 2004)—to extend development westward from the

Alpine project facilities into NPRA. In January 2006, additional leasing in parts of the northeastern NPRA that were placed off-limits in the 1998 IAP/EIS recently was approved by the Secretary of the Interior after issuance of the Northeast NPRA Planning Area Amended IAP/EIS (BLM 2005).

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. NSB development permit NSB04-117 for the CD-4 project, issued 30 September 2004, stipulated that a 10-year study of the effects of development on caribou be conducted by a third-party contractor hired by CPAI (ABR, Inc. was hired to conduct the study). The study area was specified as the area within a 48-km (30-mile) radius of CD-4 and the study was to include all other satellite drill sites and infrastructure planned for construction within this 10-year time-frame. Therefore, the scope of study also includes the new CD-3 pad constructed in winter 2004–2005 and the planned CD-5, CD-6, and CD-7 pads and 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 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 this 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 governing the sharing of telemetry data for use in the ASDP caribou monitoring study.

The study formulates and 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 and traditional knowledge. The accumulated body of scientific knowledge on the TCH and CAH provides a starting point and framework for structuring the study to address the issues identified since North Slope oil development began ~35 years ago. The extensive knowledge of local residents, most of whom are Iñupiat, 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 three 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 not dealt with in the CAH range east of the Colville River 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 two 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 two. Information on the potential effects of development on caribou distribution can be collected using a variety of methods, including aerial transect surveys, radio telemetry (VHF, satellite, and GPS), and observations by local subsistence users. Information on 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:

- 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 two herds?
  c) How often do caribou cross the proposed corridor and does this differ by herd?
- Characterize important habitat conditions, such as snow cover, spatial pattern and timing of snow melt, 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.
- 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 zones, 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?
- 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.

STUDY AREA

The climate in the region is arctic maritime (Walker and Morgan 1964). Winter lasts ~8 months and is cold and windy. The thaw period lasts only about 90 days during summer (June–August) and the mean summer air temperature is 5° C (43° F) (Kuparuk Oilfield records: National Oceanic and Atmospheric Administration, unpublished data), ranging from –10° C in mid-May to 15° C in July and August (North 1986), with a strong inland gradient of temperatures increasing with distance 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 (32°–50° F) during the growing season. Spring is brief, lasting ~3 weeks from late May to mid-June, and is characterized by the flooding and breakup of rivers. 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). Breakup 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). 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 general study area was defined as the area within the 48-km radius around the CD-4 drill site, as specified by the NSB permit (Figure 1). Aerial surveys were conducted in three survey areas, most of which were within the 48-km circle: Colville East (1696 km²), Colville River Delta (494 km²), and NPRA (1720 km²). The Colville East survey area includes the westernmost portion of the Kuparuk oilfield. The Colville River Delta survey area encompasses the entire delta and includes the Alpine Development Project facilities: CD-1 and CD-2, constructed in 1998–2001, and CD-3 (previously called Fiord or CD-North) and CD-4 (previously 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 accessed only by aircraft in summer, but an elevated pipeline connects it to CD-1. A road and adjacent elevated pipeline connects the CD-4 drill site to CD-1. Three more 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) are planned for NPRA. A road is planned to connect these sites to the Alpine project facilities at CD-2, requiring a new bridge across the Nigliq (Nechelik) Channel of the Colville River.

METHODS

To evaluate the distribution and movements of TCH and CAH caribou in the study area, we conducted aerial transect surveys in 2005, adding to the transect data from 2001–2004, and analyzed several telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS). The aerial surveys provided information on caribou density within the study area. The satellite and GPS collars provided accurate location data for a small number of caribou 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 locations and densities with respect to vegetative biomass and snow cover values derived from remote sensing, as well as an existing habitat map.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Caribou surveys of the NPRA, Colville Delta, and Colville East areas (Figure 1) were conducted during April–October 2001–2005 by two observers viewing out opposite sides of a Cessna 206 airplane (Burgess et al. 2002, 2003; Johnson et al. 2004, 2005; this study). We also conducted additional surveys of the Colville East area during calving season in 2001–2005 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006). 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 agl or ~90 m 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 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 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. 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

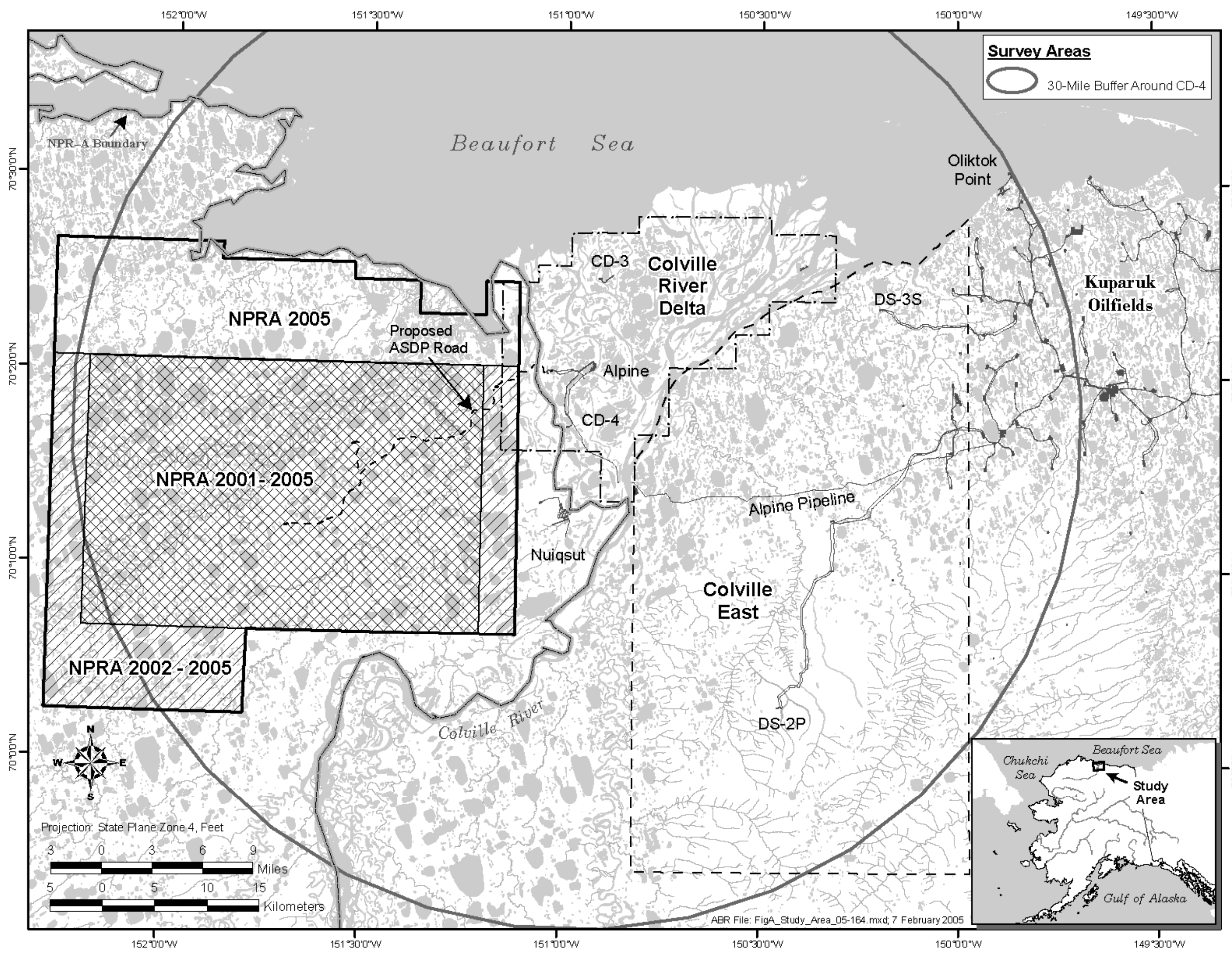

Figure 1. ASDP caribou monitoring study area (30-mile radius around Drill Site CD-4) and locations of NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2005.

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 using a standard-error formula modified from Gasaway et al. (1986) and using transects as the sample units.

RADIO TELEMETRY

VHF Collars

We received location data from ADFG for all VHF collars in the CAH and TCH during the years 1980–2005 (Table 1). These locations ranged over much of northern Alaska and data on the individual areas covered on each survey 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. 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 is the only way to obtain data on group size and behavior. On some surveys, however, the aircraft remained above the clouds, making visual confirmation impossible; locational accuracy was much lower on those surveys. The sex, age, and reproductive status of collared animals were unknown, although most were adult females. Location error was estimated to be 500–1000 m (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 TCH animals for the period July 1990–July 2005 and for CAH caribou during the periods October 1986–July 1990 and July 2001–September 2004 (Table 1). In the TCH sample, 87 caribou (69 females, 18 males) transmitted signals for a mean duration of 501 days. In the CAH, the early sample included 17 caribou (16 females, 1 male) and the later sample included 11 caribou (9 females, 2 males) that transmitted for a mean duration of 587 days. A few caribou moved between herds after collaring (four TCH animals joined the CAH and five TCH animals joined the WAH); a caribou was assumed to have switched herds if it was in the calving area of another herd during the calving period.

Data from satellite transmitters were received by polar-orbiting satellites, transmitted through Command and Acquisition Stations to data-processing centers operated by Service

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	na	na	212
Satellite collars	1990–2005	69	18	87
GPS collars	2004–2005	10	0	10
Central Arctic Herd				
VHF collars	1980–2005	na	na	412
Satellite collars, early	1986–1990	16	1	17
Satellite collars, recent	2001–2004	9	2	12
GPS collars	2003–2005	38[b]	0	38[b]

[a] na = Not available.

[b] Number of different collared caribou within 48 km of CD-4 at least once.

ARGOS (Landover, Maryland), and then transferred monthly to the NSB for data archival (Prichard and Murphy 2004). In 1990 and 1991, the TCH satellite transmitters were programmed to transmit for 6 hours every day for one month after deployment, then 6 hours every second day 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 collars deployed in 2000 malfunctioned and only transmitted data sporadically. Details of the programming of the CAH collars from 1986–1990 were not available, although the data contained multiple locations for each day.

Satellite telemetry locations are considered to be accurate to within 0.5–1 km (Service ARGOS 1988), but the data also require screening to remove spurious locations. Data-screening methods followed Prichard and Murphy (2004), removing locations obtained before and after collaring, after mortality occurred, to remove duplicate data, and to remove locations for which the ARGOS-designated location quality scores (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 three consecutive points. Any three locations with an intervening angle of <20 degrees and both “legs” with speeds greater than 10 km/h (6.2 mi/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 likely to be accurate. We removed any locations that clearly were inaccurate based on previous and subsequent locations.

A concern for mapping and analyses based on frequent telemetry relocations is the introduction of bias caused by autocorrelation of data points collected very close in time (Schoener 1981, Swihart and Slade 1985, Solow 1989). Due to the directional movement of caribou during much of the year, caribou movement data often do not meet the requirements for 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, time between samples should approximate the time necessary to travel anywhere else in a seasonal range (Lair 1987, McNay et al. 1994). In addition, sampling locations systematically over a given time period can remove bias due to dependent data (White and Garrott 1990).

For the TCH and recent CAH data, we selected one location during each duty cycle, defined as a period of transmission of location data, which typically was 6 h every 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 (Keating 1994). ξ is similar to our DRA filter, because it is calculated based on three subsequent locations and is a measure of the distance between locations, the angle formed by the three locations, and the similarity of length between the two legs (Keating 1994). The CAH satellite-collar data from October 1986–July 1990 had been screened before we acquired it; however, it was screened further to select the first location each day with the highest NQ score.

GPS Collars

Ten female caribou from the TCH were fitted with GPS collars in July 2004 (Table 1) and the collars were removed in July 2005; all 10 caribou survived for the entire period. Of these 10 caribou, 7 had calves in 2005, 2 did not, and 1 had a calf that died soon after calving. The GPS collars recorded locations every 4 h throughout the year.

Data were screened to remove any locations obtained prior to collaring or after collars were removed and locations that obviously were incorrect because they were far offshore or far from previous and subsequent locations. For each animal we selected the location closest to noon UT (Universal Time, or 04:00 local time) and used those single daily locations in analyses.

For CAH animals outfitted with GPS collars by ADFG during 2003–2005 (Table 1), we received location data that were within 48 km of CD-4. 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 within 30 miles of CD-4. Most of the CAH locations were obtained at 5-h intervals, but two locations occasionally were recorded over a short time period. In most of those cases, one of the locations appeared to be wrong. We plotted each of these 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 snow melt and vegetation green-up over the ASDP study area. At least one satellite image over the study area was acquired daily between 20:00 and 24:00 UT (12:00 and 16:00 local time). Browse images were reviewed and those with substantial cloud-free views of the study area were identified. For each date, the following data products were obtained from the Land Processes Distributed Active Archive Center (LPDAAC, Sioux Falls, SD):

- 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 non-ocean 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:

$$NDSI = (Band\ 4 - Band\ 6) \div (Band\ 4 + Band\ 6).$$

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 much finer scales than 500-m pixels. Several algorithms have been proposed to infer subpixel-scale snow cover using MODIS data, including two 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 two additional Landsat-7 images and added a ninth-order polynomial correction term to the linear model to address underestimation of snow cover at low snow-cover fractions.

We calculated subpixel-scale snow cover during late winter and spring 2005 using the Déry et al. (2005) algorithm. 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

$$Snow\ Fraction = 0.06 + (1.21 * NDSI) + E,$$

where $E = a_0 + a_1 f + a_2 f^2 + a_3 f^3 + a_4 f^4 + a_5 f^5 + a_6 f^6 + a_7 f^7 + a_8 f^8 + a_9 f^9$ (see Table 2 for these coefficients).

Missing or otherwise bad data were flagged by the occurrence of DN values over 32,767 (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, this 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 26 April–25 June 2005 was processed in this manner. A composite also was compiled to identify the first date with 50% or lower snow cover for each pixel.

The performance of the subpixel-scale snow-cover model was evaluated independently using a Landsat-5 satellite image acquired on 15 June 2005. The binary snow-map algorithm was applied to the 30-m Landsat image and a “ground truth” subpixel-scale snow fraction then was calculated by aggregating the binary snow mask to 500-m resolution. The Landsat-derived snow fraction was then compared to the MODIS-derived snow fraction from the same date. The correlation coefficient, absolute error, and the error at different levels of MODIS-derived subpixel-scale snow fraction then were calculated. For this comparison, both the simple linear subpixel-scale snow algorithm (Salomonson and Appel 2004) and the version with the addition of a ninth-order polynomial correction (Déry et al. 2005) were evaluated.

Table 2. Error-correction parameters (Déry et al. 2005) for the MODIS subpixel snow-cover algorithm.

Coefficient	Value
a_0	6.307560210E-01
a_1	5.901470180E+00
a_2	–1.147429940E+00
a_3	9.455817938E-02
a_4	–4.226271529E-03
a_5	1.108089855E-04
a_6	–1.749119974E-06
a_7	1.635070035E-08
a_8	–8.340111241E-11
a_9	1.789230249E-13

VEGETATIVE BIOMASS

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

$$NDVI = (NIR–VIS) \div (NIR + VIS)$$

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 was calculated using satellite imagery acquired in June during the calving period (June 1–10), again during the presumed period of peak lactation for parturient females (June 21), and finally in late July near the peak of the growing season. The image-processing methods used for the 2004 and 2005 imagery were different than those for the 2002 and 2003 imagery because several improvements were implemented. Because of this difference, some caution should be used in interannual comparisons of absolute values.

Our processing improvements include correcting reflectance for some atmospheric effects, weighted-average resampling, per-pixel cloud masking, and improved compositing (merging data from multiple acquisitions to minimize the effects of cloud cover). Each imaging swath was atmospherically corrected using the MODIS Rapid-Response corrected-reflectance algorithm (*crefl*; Gumley 2003), which removes gross atmospheric effects (2002 and 2003 analyses were based on uncorrected, top-of-atmosphere reflectance). The corrected reflectance swath granules were gridded to 50-m resolution, and then aggregated to 250-m resolution. This procedure is similar to the weighted-average resampling scheme implemented in the MOD13 16-day vegetation index composite products, and it maintained a high level of geolocation accuracy so that no further manual adjustment was necessary. In contrast, the 2002 and 2003 analyses were done using bilinear resampling to 250-m. The geolocation quality of the resulting products was not as precise, so a 3×3-pixel mean smoothing filter was applied to all of the outputs in those years.

Negative NDVI values are an indication of water, snow, ice, or cloud contamination rather than vegetation conditions, so all negative NDVI values were set to zero. NDVI values near the peak of calving (NDVI_calving) were estimated using imagery from 4–5 June 2005, 4–8 June 2004, 5 June 2003, and 7 June 2002. A compositing approach was used to minimize the effects of cloud cover in 2004 and 2005. For example, the 2005 calving NDVI value was the maximum NDVI from the 4 June and 5 June images (after applying cloud and bad pixel masks). In this way the best data from two scenes with partial cloud cover were merged. The 2002 and 2003 analyses were based on single acquisitions, which was sufficient for the smaller study area analyzed at that time (Lawhead et al. 2004). When extended to the full satellite-image study area, however, the cloud-covered area was substantial.

NDVI values near peak lactation for caribou, which occurs around 21 June (NDVI_621) (Griffith et al. 2002), were interpolated from images obtained before and after 21 June, because the sky was not clear on 21 June in any of the 4 years. 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. Finally, NDVI_peak was calculated from the late July imagery (2005 only).

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). This correction lessened, but did not eliminate, the negative bias from open water and ice.

VEGETATION SAMPLING

Vegetation was sampled in plots along the proposed ASDP road in NPRA during 21–26 July 2005. Nine 500×500-m sampling areas were selected in three distance-to-proposed-road categories (0–1 km, 2–3 km, 4–5 km) and three east–west zones (Figure 2). The wildlife habitat map developed from the ecological land survey (ELS) for the study area (Jorgenson et al. 1997, 2003, 2004) was used to characterize the habitat composition of each sampling area. The ELS described terrain units (surficial geology, geomorphology), surface-forms (primarily ice-related features), and vegetation throughout the study area. In each sampling area, we selected five random locations in each of the two dominant habitat types—moist tussock tundra and moist sedge–shrub tundra. Vegetation was sampled in three or four plots in each of these two habitat types in each sampling area.

GPS receivers were used to find random locations selected previously (using a GIS spatial database) and a random-number table then was used to select a compass heading (0–359 degrees) and a distance (1–25 m). We moved that distance on the randomly selected heading to locate the southwest corner of each 5×2-m sampling plot. If the selected location was not in the appropriate habitat type, we moved the plot to the nearest location with the appropriate habitat type. Vegetation was sampled in five randomly selected 20×20-cm quadrats within each plot. In each quadrat, we recorded the presence of species and the presence of grazing evidence (clipped leaves or

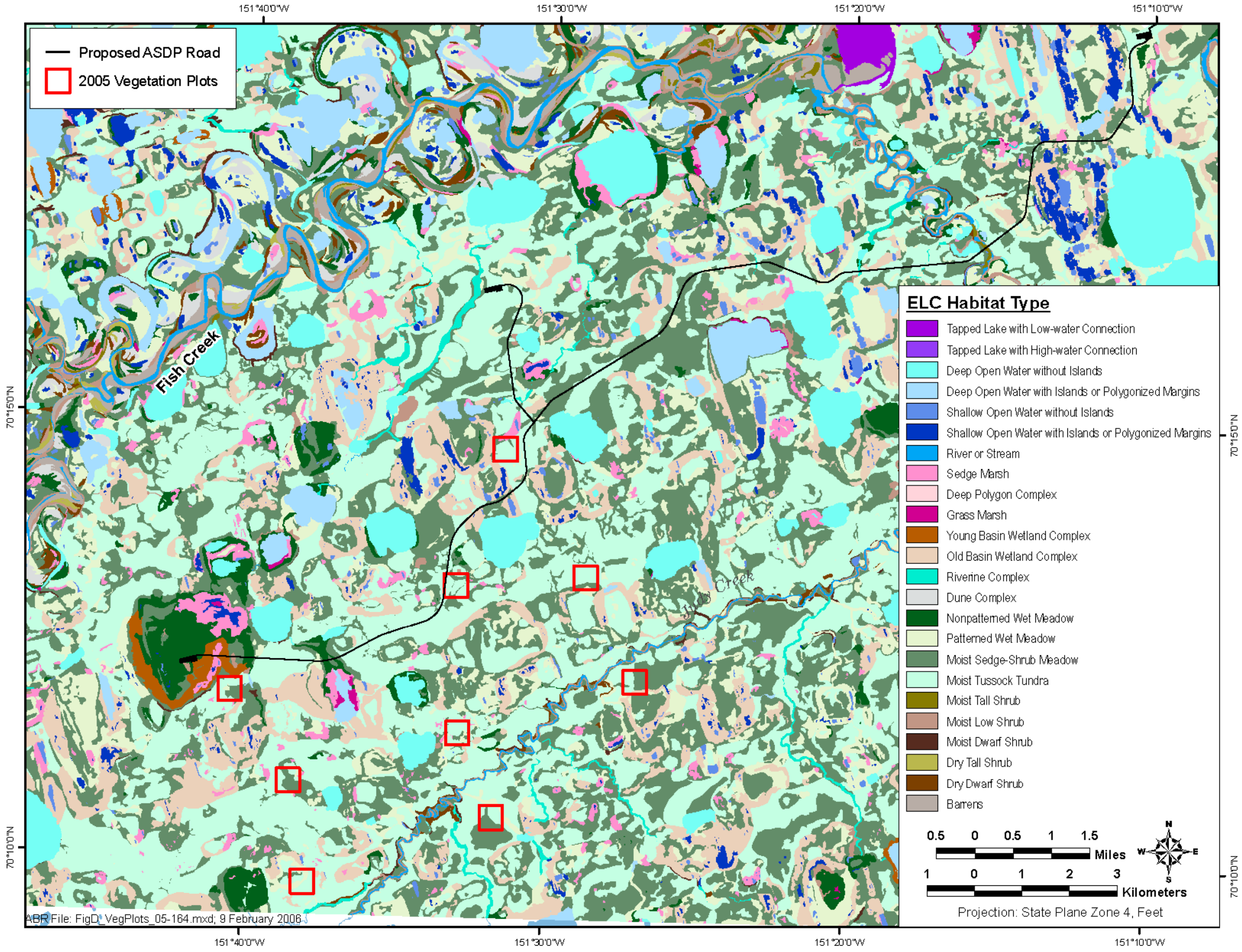

Figure 2. Location of nine vegetation sampling plots in relation to the proposed ASDP road and wildlife habitat types mapped for the northeastern NPRA Ecological Land Survey (ELS; Jorgenson et al. 2003).

stems stripped of leaves) for each species. We then clipped all vegetation in the quadrat down to the moss layer and transported it to the field office at Alpine for processing.

We sorted clipped vegetation into the following groups: *Eriophorum vaginatum*, other graminoids, *Salix pulchra*, other *Salix*, *Betula nana*, evergreen shrubs (including *Arctostaphylos* spp.), forbs (flowering herbaceous plants), and lichens. Dead plant material was separated and discarded because we were measuring only above-ground live biomass. We clipped *Cassiope tetragona* to only include green portions and excluded stems of *Betula nana*. Only annual growth of *Salix* stems was included. Dead tips of graminoids were removed. Preliminary drying of samples was done in a drying oven in the Alpine field office and final drying to a constant weight (nearest mg) was done in Fairbanks. Plant names follow Hultén (1968).

We tested for differences in both total biomass and biomass of all plants except evergreen shrubs, because they are not preferred caribou forage but were abundant in tussock-tundra plots. We used a three-level hierarchical model to test for differences in biomass among the three distance-to-proposed-road categories, between habitat types (moist tussock tundra and moist sedge–shrub tundra), and an interaction between habitat type and distance-to-road category. The 500×500-m sampling areas and 5×2-m plots were included as random variables. Each combination of area and plot was considered a subject. This analysis method estimates the correlation among quadrats in a plot and among plots within a given area and adjusts the results accordingly.

As another indicator of caribou use, groups of fecal pellets were counted within 1 m on each side of a 25-m line stretched north from the northern edge of each vegetation plot (50 m^2). A pellet group was defined as having a minimum of five pellets. We recorded the number of summer (clumped, irregularly shaped) and winter (round, distinct) pellet groups. We used a two-level hierarchical model to test for differences in the number of pellet groups between habitat types. The 500×500-m sampling areas were included as a random variable and each area was considered a separate subject; habitat class was a fixed effect.

TRAIL MAPPING

This pilot effort attempted to ascertain whether caribou trails could be mapped using remote-sensing data from satellite and detailed aerial photographic coverage of the study area. Prominent caribou trails were marked opportunistically as GPS waypoints during aerial transect surveys and were photographed if conditions allowed (trails were accorded secondary priority after caribou groups on transect). The oblique photographs were compared with digital orthophoto base-maps (Aeromap U.S., Anchorage) covering the Colville River delta and adjacent areas to the east (1-ft resolution, acquired in 2004) and the northeastern portion of NPRA, including the Fish Creek delta (2-ft resolution, acquired in 1999 and 2001). Six areas of interest—three on each side of the Colville River—were selected for more detailed evaluation. The objective was to determine whether the spatial resolution and spectral characteristics of the available orthophoto base-maps were sufficient to identify and map perennial caribou trails.

For each of the six areas of interest, the location of trails visible on the oblique photos was digitized on the orthophoto base-map based on the location of corresponding lakes, polygons, and other features that could be identified on both photographs. Preliminary comparisons of the oblique photographs and the orthophoto base-maps suggested that the resolution was too grainy to reliably identify trails. We therefore investigated the specifications of the original aerial photographs and determined that a substantial improvement in resolution and quality could be obtained by rescanning the original negatives at a higher resolution. Scans at a resolution of 8 microns (compared to the 16–24-micron resolution of the original scans) were obtained and the trails on the oblique photographs were digitized on these images.

The detectability of caribou trails was rated for the three different image formats—oblique photograph, orthophoto base-map, and 8-micron scanned photograph—and the feasibility, costs, and limitations of systematically mapping perennial caribou trails were compared.

CARIBOU DISTRIBUTION ANALYSES

We compared caribou group locations from our aerial transects in the NPRA survey area to a habitat map, vegetative biomass levels, snow cover, and various geographic zones. We tried to determine which factors were influencing caribou distribution in the absence of oil development in the NPRA area. We also compared group locations and density within several 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 eight 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 of the NPRA survey area, so we tested whether caribou locations varied among different geographic zones. We divided the 2002–2004 and 2005 survey area into six zones: (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) (Figure 3). The proposed ASDP road will be constructed in the Southeast area. We determined how many caribou groups were in each zone for every season in each year 2002–2005. We used a chi-square goodness-of-fit test to determine if the number of groups in each geographic area differed significantly from expected values, assuming a uniform distribution (Neu et al. 1974, Byers et al. 1984). If significant differences were found, we compared individual zones using Bonferroni multiple comparison tests (Neu et al. 1974, Byers et al. 1984).

HABITAT USE

To compare habitat use with availability, we used the earth-cover classification previously created for NPRA by BLM and Ducks Unlimited (2002; Figure 4) and the aerial-transect data from surveys flown in the expanded 2005 NPRA survey area. We used the NPRA earth-cover classification for these analyses 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 characteristics important to caribou. The ELS habitat map (Jorgenson et al. 1997, 2003, 2004) did not cover the entire NPRA survey area.

The NPRA survey area contained 15 different cover classes (Appendix A). The clear water, turbid water, and *Arctophila fulva* classes were combined into a single water class and the two different flooded-tundra classes were combined. For analysis of habitat use, we also combined barren ground/other, dunes/dry sand, and sparsely vegetated classes into one “riverine” class.

The use of vegetation types by caribou was calculated by selecting all pixels within a 100-m radius of each group location, 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 vegetation type used for 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 NPRA survey area using *ArcView 3.2a* GIS software. Locations in lakes were removed, leaving a total of 8268 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. We repeated this process 5000 times. If the proportion of a habitat type for a caribou group location was more extreme than the

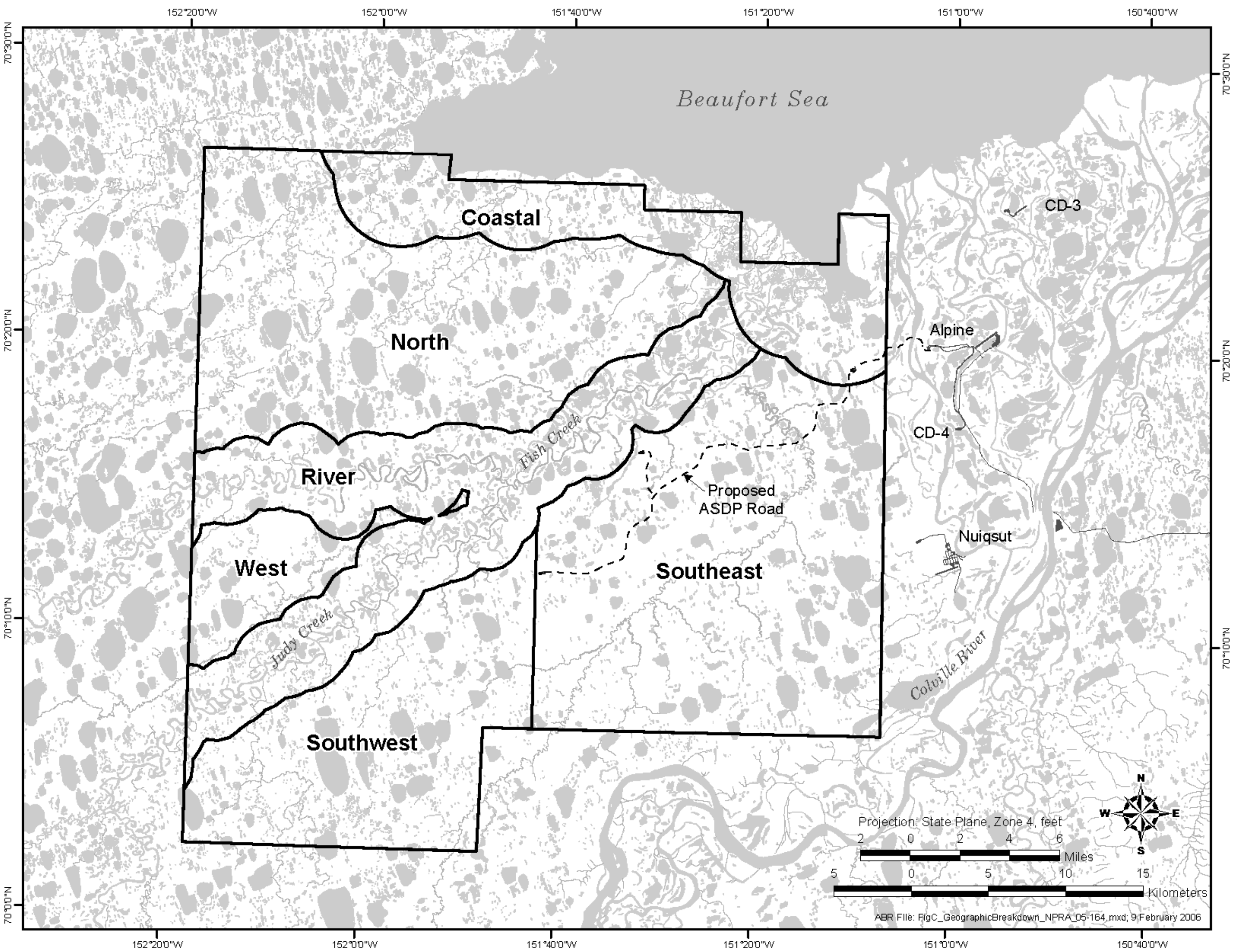

Figure 3. Location of geographic zones used in spatial analyses of caribou distribution in northeastern NPRA, 2002–2005.

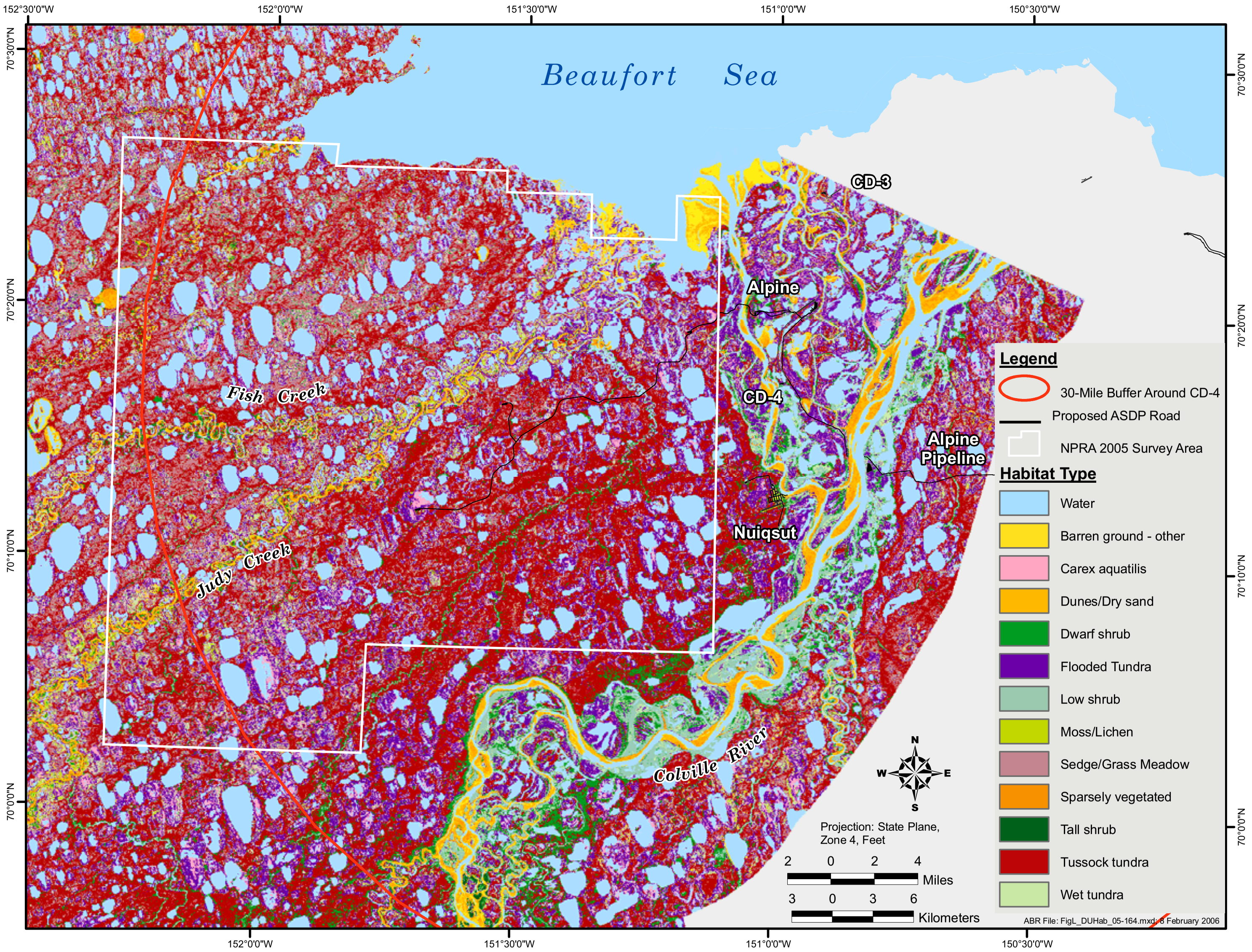

Figure 4. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2005.

average of 95% of resampled random locations, we concluded that the observed proportion was significantly different from random at $P = 0.05$.

SNOW COVER

We compared caribou group locations from aerial surveys in 2005 with snow cover estimated by remote sensing on 5 June 2005. The percentage of snow cover was determined for each caribou group location in the NPRA survey area during the 2005 calving season (6 and 13 June surveys; $n = 98$) and for all caribou groups observed during a calving survey flown in the Colville East survey area on 5–6 June 2005 ($n = 169$). Snow-cover percentages were lumped into four classes (0–25, 26–50, 51–76, 76–100%). We compared use by caribou with availability in survey transects using a chi-square goodness-of-fit test (Neu et al. 1974, Byers et al. 1984). If significant differences were found, individual snow-cover categories were compared using Bonferroni multiple-comparison tests (Neu et al. 1974, Byers et al. 1984).

We also used telemetry locations to compare caribou distribution during calving in 2005 with snow-cover estimates. We selected all caribou locations, taken at least one day apart, from VHF-, satellite-, and GPS-collared caribou during the calving period (defined as 1–15 June) in 2005. We used the Animal Movement Extension for *ArcView GIS 3.2a* (Hooge and Eichenlaub 1997) to calculate 50% and 95% kernel-density estimates of the herd range using least-squares cross-validation. The 50% kernel contour defines the minimum area containing 50% of the herd based on estimated caribou density. We compared use (pixels containing caribou locations) with the availability of snow cover (area within the 95% kernel density estimate) as described above. We compared snow cover at caribou locations with the availability of snow within the 95% contour interval using a chi-square goodness-of-fit, as described above. This analysis was conducted for both CAH and TCH caribou.

VEGETATIVE BIOMASS

We compared caribou group locations in the NPRA survey area in 2005 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 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 $P = 0.05$.

DISTANCE TO PROPOSED ROAD

The group locations from aerial transect surveys in the NPRA survey area constitute the baseline data set on caribou density in the area prior to construction of the proposed ASDP road. 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 five distance-to-proposed-road categories: 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, and used a chi-square goodness-of-fit test to determine if the observed number of groups in each category differed significantly from expected, 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 2–6-km zones differed significantly from the 0–2-km zone containing the proposed road alignment. We used Tukey's post-hoc multiple-comparison test for significant differences among seasons. A natural-log transformation (*ln* [*density +1/6*]) was applied to the density data to better meet the assumptions 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, we subdivided the transect strips in the 2002–2004 and 2005 NPRA survey areas 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 5). Within each cell we calculated the caribou density by season, mean NDVI values from 2005, mean percentage of snow cover on 5 June 2005, 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), transect number (a measure of a west-to-east density gradient), presence or absence of Fish 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 assumptions of normality. The spatial pattern of NDVI_peak was assumed to be similar across years (Lawhead et al. 2004), so we used NDVI_peak in multi-year analyses. Other measures of NDVI and snow cover were used only in analyses of calving densities in 2005.

We tested various models for calving density in 2005 and the density for each season for the years 2002–2005 combined. Data from 2001 were not included in this analysis because the NPRA transect-survey area that year was smaller than those used in subsequent years. We used a series of models (analysis of covariance, or ANCOVA; Neter et al. 1990) 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 (AICc) and used the Akaike weights (Burnham and Anderson 1998, 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 2005. The different models had various combinations of NDVI_peak, NDVI_rate, snow-cover fraction, 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 was used. We removed one grid cell located on the Colville River delta because it contained little suitable habitat and was an outlier in most analyses, leaving a total of 163 grid cells included in the analysis.

A total of 15 candidate models were used for seasonal tests over all years (2002–2005) combined. For these models we dropped the year-specific variables (snow-cover fraction and NDVI rate) and added the distance-to-coast variable, and included only those grid cells surveyed in all four years ($n = 123$).

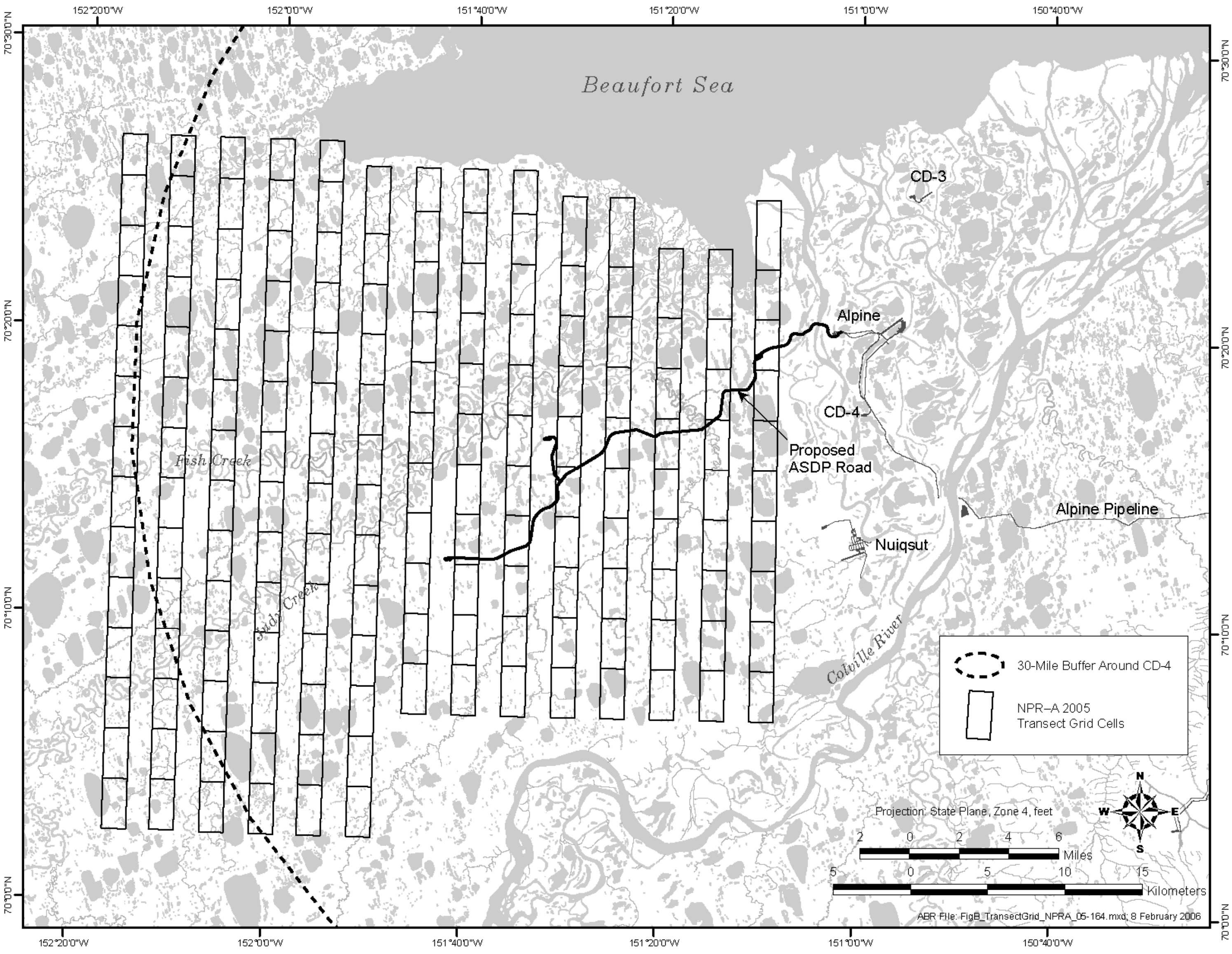

Figure 5. Locations of transect grid-cells ($n = 164$) used to analyze caribou density in the NPRA survey area, 2005.

RESULTS AND DISCUSSION

WEATHER CONDITIONS

The timing of snow melt and the severity of insect seasons varied considerably during the years in which aerial surveys were conducted in the ASDP study area (Appendix B). Snow melt was later than normal in 2001, earlier than normal in 2002, and about average in 2003, 2004, and 2005. Although snow-melt timing was close to average in 2005, air temperatures were well below average during the spring and early summer in 2005. July temperatures were the lowest during the period of record (1983–2005 at the Kuparuk airstrip), making for a milder-than-expected insect season, but temperatures in early August were much higher than average. In contrast, 2004 was a very warm summer (Appendix B).

Weather conditions can exert strong effects on caribou population dynamics. Deep winter snow and icing events can make travel difficult, decrease forage availability, and increase susceptibility to predation (Fancy and White 1985, Griffith et al. 2002). Severe cold and wind also can kill caribou directly (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 lower future reproductive success (Finstad and Prichard 2000). In contrast, hot weather in the summer may decrease weight gain and subsequent reproductive success in caribou through increased insect harassment at an energetically stressful time of year, especially for lactating females (Cameron et al. 1993, Russell et al. 1993, Fancy 1986, Weladji et al. 2003).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Nine surveys of the NPRA survey area were flown between 23 April and 21 October 2005. The estimated density of caribou ranged from a low of 0.02 caribou/km² on 17 August to a high of 5.2 caribou/km² on 3 August (Table 3). The high density on 3 August resulted from the occurrence of large groups near the coast in and between transect strips (Figure 6). Those groups contained the highest number of caribou recorded on all of our NPRA surveys to date (Appendices C–J), although coastal areas were not previously included in our survey area, so large insect-harassed groups during the mosquito and oestrid fly seasons would have been missed. The large groups that form in response to mosquito harassment result in high variability among surveys during the insect season. During April–October surveys in previous years, the highest densities in the NPRA survey area occurred in late September or October (1.2–3.5 caribou/km² annual maxima, 2001–2004), although relatively high densities were recorded occasionally in late winter (2.4 caribou/km² in April 2003) and postcalving (1.5 caribou/km² in late June 2001) (Appendices C–J).

Eight surveys of the Colville River Delta survey area were flown between 24 April and 23 October 2005 (Table 3, Figure 6). The estimated density of caribou ranged from 0 on 21 and 23 October to 2.0 caribou/km² on 2 August, the highest density recorded on our transect surveys in this area during 2001–2005 (Appendices C–J). Large numbers of caribou have been recorded on the delta at other times during past summers (such as 1992 and 1996), however, as large aggregations moved onto or across the delta during or after periods of insect harassment (Johnson et al. 1998). The most notable such instance in recent years 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 2004), through the area of the proposed ASDP road.

Ten surveys of the Colville East survey area were flown between 24 April and 23 October 2005. Several Colville East surveys were only partially completed due to inclement weather. The estimated density of caribou ranged from a low of 0.05 caribou/km² on three different dates and the high of 3.6 caribou/km² on 21 June (Table 3; Figure 6). The postcalving density on 21 June 2005 was more than double that observed on all previous surveys in the Colville East survey area outside of the calving season (range 0.01–1.57 caribou/km², 2001–2004; Appendices C–J). No previous surveys were conducted in that area during the June postcalving period, however; the previous

Table 3. Number and density of caribou in the NPRA, Colville River Delta, and Colville East aerial-survey areas, April–October 2005.

Survey Area Date	Large Caribou [a, b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km^2) [e]	Mean Group Size
NPRA (1310 km^2) [f]							
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 km^2) [f]							
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 km^2) [f]							
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 [g]	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] nr = Not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[d] Standard Error of Total Caribou calculated as described by Gasaway et al. (1986), using transects as sample units
[e] Density = Estimated Total / survey area.
[f] Survey coverage was 50% (654 km^2 in NPRA, 247 km^2 on the Colville R. Delta, and 850 km^2 in Colville East were surveyed).
[g] Part of area not flown due to fog.

Figure 6. Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2005.

11x17

high density was recorded on 19 October 2004 during fall migration by TCH animals through the area (Lawhead and Prichard 2005). The 21 June density was within the range of previous calving surveys in the area (Appendix K). The postcalving density on 21 June 2005 was greater than during the calving survey on 10–11 June 2005 (Lawhead and Prichard 2006), indicating that more caribou moved into the area following calving, presumably from the south as mosquitoes emerged farther inland. This postcalving pattern of slow northward movement by gathering numbers of CAH caribou before mosquito emergence is well-documented (Lawhead et al. 2004).

Annual surveys of the NPRA survey area since 2001 indicate that it is not a high-density calving area, in contrast to the Colville East survey area (Appendices C–K; Lawhead and Prichard 2006). This conclusion is supported by analyses of telemetry data (Prichard and Murphy 2004, Carroll et al. 2005), which demonstrate clearly that most TCH females calve around Teshekpuk Lake, west of the ASDP study area. Although a few CAH caribou have been reported to calve west of the Colville River in certain years (most notably 2001), it is a rare occurrence (Lenart 2003, Arthur and Del Vecchio 2004).

During our NPRA aerial surveys in 2005, one group of muskoxen was recorded repeatedly near the mouth of Kalikpik River and once on the Fish Creek Delta (Appendix L). The size of this group varied between 8 and 18 muskoxen and included up to 6 calves. A female in this group was ear-tagged in ANWR in 1995 and has been seen previously on the Colville River delta and in northeastern NPRA (G. Carroll, ADFG, pers. comm.). These muskoxen were the first we have observed in our NPRA aerial survey area since 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) and historical records of the species exist for northeastern NPRA (Bee and Hall 1956, Danks 2000). A single moose was seen once near Fish Creek in late April, but no grizzly bears were seen in the NPRA survey area in 2005. Observations of muskoxen, moose, and grizzly bears on the Colville River delta and east of the Colville River in 2005 were reported by Lawhead and Prichard (2006).

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 TCH and CAH ranges (Figure 7); GPS collar movements for the CAH sample are not depicted in the map figure because they were available only inside the ASDP study area. The large majority of collar locations for the TCH and CAH were west and east of the center of our study area (CD-4), 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. Although it is not warranted to consider each collared caribou as representing a certain number of unmarked caribou in the herds, the monthly percentages do provide estimates of the relative abundance of each herd 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 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 movements between successive flights. In 2005, the timing of tracking flights was limited to seven surveys between 24–25 June and 13 October (Table 4, Figure 8). The percentage of TCH collars in the ASDP study area rose from zero in late June and early July to 18–29 percent in late July to early August, then dropped to zero by 10 August and 6 percent on 13 October (Table 4). The percentage of collared CAH caribou in the study area was highest (25 percent) on the first survey in late June, ≤12 percent in July and August, and zero in mid-October (Table 4). No TCH collars and only one CAH collar (on 2 August) were found on the Colville River delta during the seven tracking flights in 2005 (Figure 8).

In the NPRA survey area, the closest approach of collared caribou to the proposed ASDP road during the 2005 tracking flights was noted on 26 July, when four TCH collars were found along Fish Creek within 5–16 km northwest of the alignment.

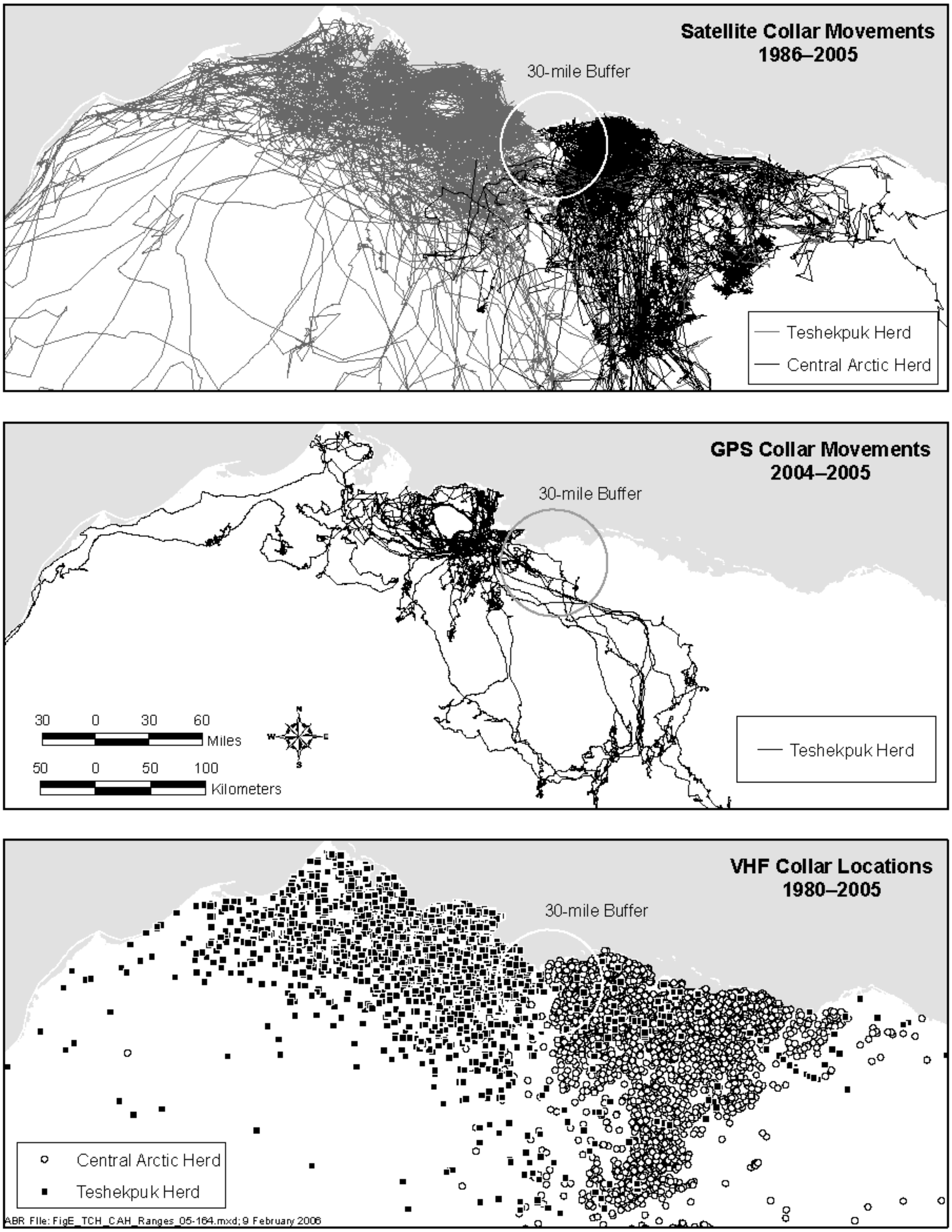

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Figure 7. Ranges of the Teshekpuk and Central Arctic herds in relation to the ASDP study area, based on satellite, GPS, and VHF radio telemetry of collared caribou in northern Alaska, 1980–2005.

Table 4. Number (percentage in parentheses) of VHF-collared caribou within 30 miles of CD-4 during summer and fall surveys in 2005; sample sizes of collared animals in June were 76 and 34 caribou in the CAH and TCH, respectively.

Date	CAH collars	TCH collars
June 24–25	19 (25)	0 (0)
July 12	0 (0)	0 (0)
July 21	8 (11)	6 (18)
July 26	1 (1)	5 (15)
August 2	9 (12)	10 (29)
August 10	1 (1)	0 (0)
October 13	0 (0)	2 (6)

Four TCH collars were found in the northern portion of the NPRA survey area on 2 August, the same day on which the largest number of caribou was found on the aerial transect surveys (Table 3, Figure 6).

Satellite Collars

The percentage of satellite-collared TCH animals (with at least 5 active duty cycles per month) by month in the ASDP study area varied between 7 and 20 percent of the total collared samples during 1990–2005 (*n* = 72–110; Table 5). The highest percentages occurred in August and October and the lowest percentages in June and February (Table 5, Figure 9). The monthly percentages varied substantially (0 to 80 percent) within years, largely due to small samples of collared animals in most years.

Satellite telemetry indicated more use of the ASDP study area by CAH caribou than by TCH animals, although virtually all of that use occurred east of the Colville River and not in the area of the ASDP facilities (Figure 9). The percentage of satellite-collared CAH caribou (with at least 5 active duty cycles per month) by month in the study area ranged from 13 to 51 percent of the total collared sample during 1986–1990 and 2001–2005 combined (*n* = 39–54; Table 5). The highest occurrence of collared CAH caribou was in June and July (50–51 percent) and the lowest was during October–February (13–19 percent) (Table 5, Figure 9). As with the TCH sample, the monthly percentages varied substantially (0 to 88 percent) within years, at least in part due to small samples of collared animals. The number of collared animals using the ASDP study area during the winter months appeared to be higher during 1986–1990 than during 2001– 2005 (Table 5). This difference in winter use may have been affected by the timing and location of collaring, but we did not have access to that information for this analysis.

Only one satellite-collared TCH animal crossed the alignment of the proposed ASDP road (data includes January–July). Caribou 0518 crossed the proposed road alignment from west to east at the end of July 2005. No satellite-collared CAH crossed the proposed road in any year (1986–1990 and 2001–2005), although several collared individuals moved through the vicinity of the Alpine project facilities in July 1989, 9 years before construction.

The data show that 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) (Figure 9). This timing indicates that the animals harvested on the delta by subsistence hunters from Nuiqsut at that time are from the CAH rather than the TCH, whereas caribou harvested in NPRA in October are more likely to be TCH animals migrating to winter range. 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 participation of hunters in fall whaling.

GPS Collars

The percentages of the GPS-collared sample from the TCH that were present at least once each month in the ASDP study area were similar to the results from satellite-collared caribou. Up to 10 percent (one collar) of the 10 GPS-collared caribou in the TCH sample was in the study area sometime between January and April (Table 6, Figure 10). The monthly percentages increased to 10–20 percent between May and September and peaked at 70 percent in October before declining to 30 percent during November and December. The percentages of the GPS-collared sample from the

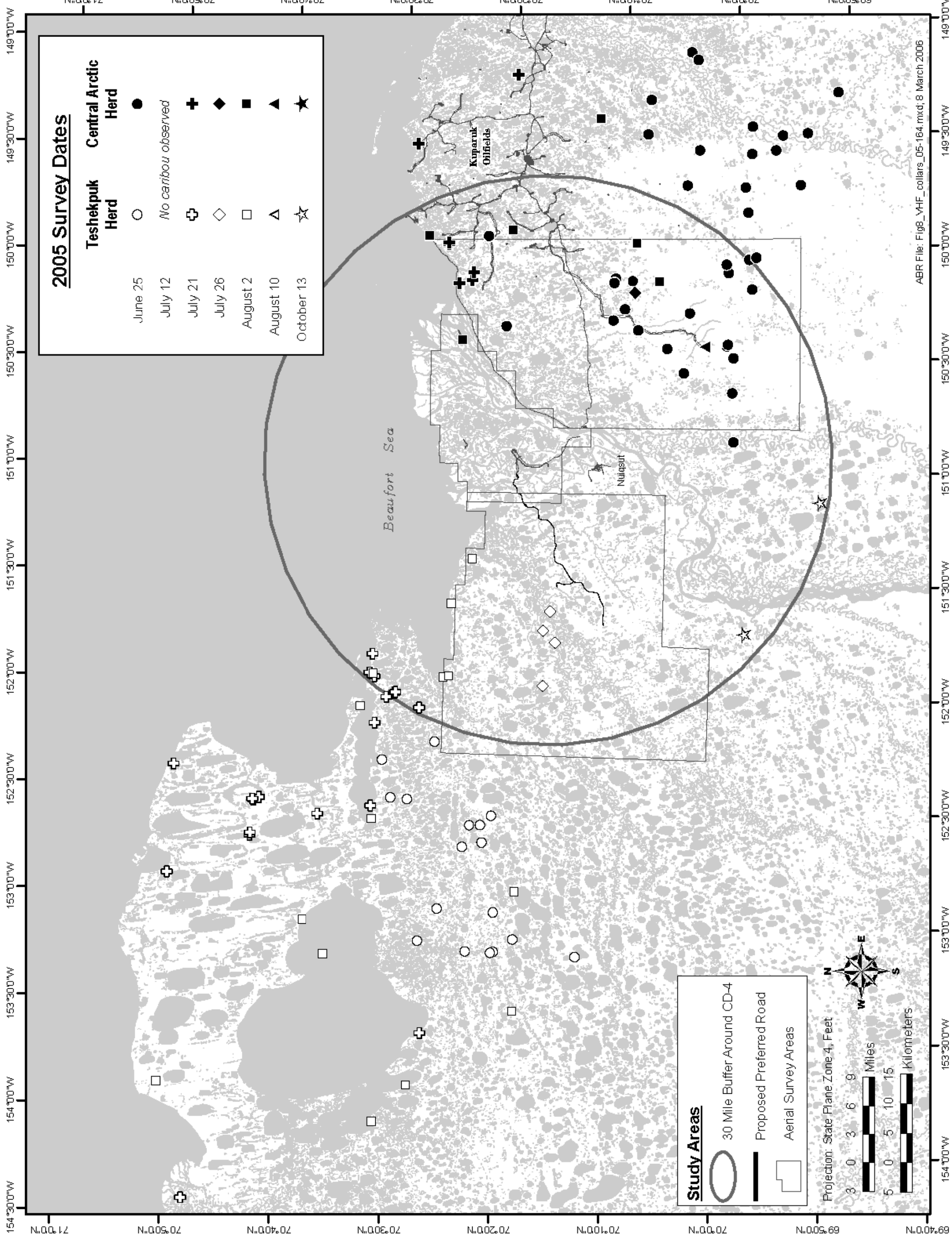

Figure 8. Distribution of VHF-collared caribou from the Teshekpuk and Central Arctic herds during 7 surveys in and near the ASDP study area, 25 June–13 October 2005.

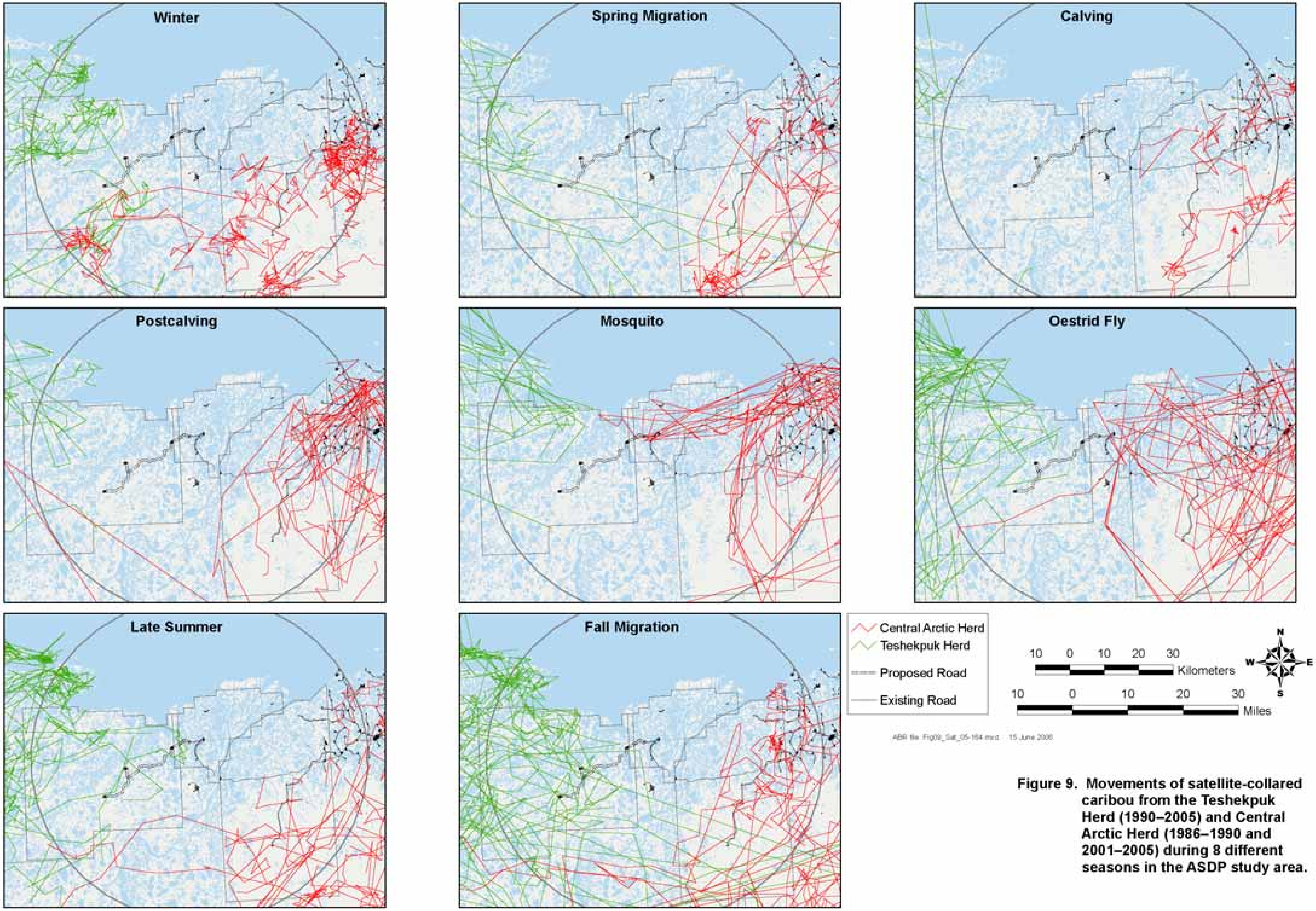

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Figure 9. Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2005) and Central Arctic Herd (1986–1990 and 2001–2005) during 8 different seasons in the ASDP study area.

Table 5. Percentage of satellite-collared caribou samples (*n*) from the Teshekpuk and Central Arctic herds that were within 30 miles 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.
TCH	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)	1 (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)	13 (16)	7 (15)	8 (12)	0 (10)
	2003	8 (12)	10 (10)	33 (9)	11 (9)	10 (10)	0 (10)	0 (24)	33 (21)	29 (21)	19 (21)	12 (17)	6 (16)
	2004	6 (16)	8 (12)	7 (14)	7 (14)	13 (15)	0 (15)	0 (13)	8 (13)	17 (12)	73 (11)	45 (11)	40 (10)
	2005	38 (8)	25 (8)	29 (7)	25 (8)	38 (8)	0 (8)	30 (10)	–	–	–	–	–
	Total	13 (88)	8 (72)	13 (72)	10 (73)	14 (76)	7 (74)	15 (110)	20 (96)	16 (106)	20 (103)	17 (92)	13 (87)
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	–	–	–	–	–	–	–	25 (8)	43 (7)	0 (9)	0 (9)	0 (9)
	2002	0 (9)	0 (8)	0 (8)	0 (8)	63 (8)	88 (8)	75 (8)	25 (8)	20 (10)	0 (10)	0 (10)	0 (10)
	2003	0 (10)	0 (8)	17 (6)	0 (5)	25 (4)	67 (3)	0 (3)	0 (2)	0 (2)	40 (5)	0 (5)	0 (5)
	2004	0 (4)	0 (5)	0 (5)	0 (5)	40 (5)	60 (5)	0 (5)	0 (4)	0 (2)	0 (2)	0 (2)	0 (1)
	2005	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	–	–	–	–	–
	Total	19 (48)	18 (45)	24 (42)	23 (40)	39 (41)	51 (39)	50 (40)	30 (44)	28 (39)	14 (52)	13 (54)	15 (52)

Table 6. Percentage of GPS-collared caribou samples (*n*) from the Teshekpuk and Central Arctic herds that were within 30 miles of CD-4 at least once in each month.

Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
TCH	2004	–	–	–	–	–	–	10 (10)	20 (10)	20 (10)	70 (10)	30 (10)	30 (10)	90 (10)
	2005	10 (10)	0 (10)	0 (10)	0 (10)	20 (10)	20 (10)	–	–	–	–	–	–	30 (10)
	Total	10 (10)	0 (10)	0 (10)	0 (10)	20 (10)	20 (10)	10 (10)	20 (10)	20 (10)	70 (10)	30 (10)	30 (10)	
CAH	2003	–	–	–	4 (24)	54 (24)	75 (24)	8 (24)	13 (24)	21 (24)	8 (24)	0 (24)	0 (24)	79 (24)
	2004	0 (24)	0 (24)	0 (24)	4 (24)	33 (24)	58 (24)	13 (24)	4 (24)	42 (24)	0 (24)	0 (24)	0 (24)	75 (24)
	2005	0 (33)	0 (33)	0 (33)	0 (33)	24 (33)	45 (33)	33 (33)	27 (33)	21 (33)	9 (33)	–	–	58 (33)
	Total	0 (57)	0 (57)	5 (57)	2 (81)	36 (81)	58 (81)	20 (81)	16 (81)	27 (81)	6 (81)	–	–	69 (81)

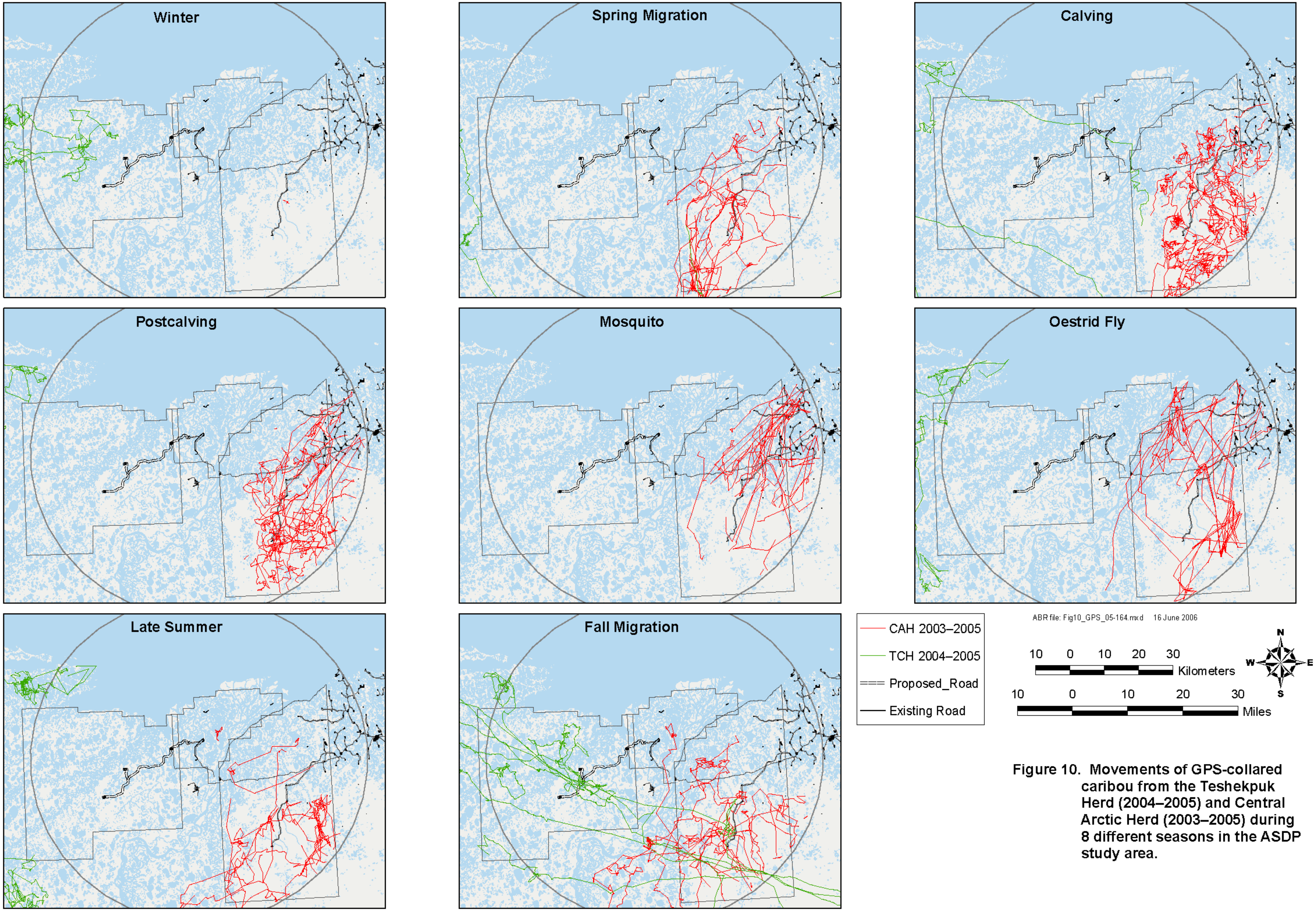

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Figure 10. Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2005) and Central Arctic Herd (2003–2005) during 8 different seasons in the ASDP study area.

CAH that were present in the study area at least once during each month in 2003–2005 varied between 0 and 6 percent during the winter months of October–April (Table 6, Figure 10). The monthly percentage increased to 36 percent in May and peaked at 58 percent in June, then decreased to 16–27 percent for July through September.

The detailed movement tracks of individual GPS-collared TCH animals were examined in the vicinity of the proposed ASDP road alignment from July 2004 to July 2005, the only period of GPS-collar operation to date for this herd. Many TCH animals moved southeast from Teshekpuk Lake during the fall migration in October 2004. Some of those animals stopped and returned west, whereas others continued southeast to winter in the Brooks Range foothills. Several collared caribou crossed the proposed ASDP road alignment during the fall migration.

Caribou 0401—This cow traveled southwest from Teshekpuk Lake in October 2004 and approached within ~10 km of the western terminus of the alignment in early November before moving slowly west.

Caribou 0403—This individual traveled southwest from Teshekpuk Lake in October 2004 and crossed the road alignment on 26 October. It moved ~8 km east before turning back to the west and again crossing the road alignment on 7 November.

Caribou 0404—This individual traveled southwest from Teshekpuk Lake in October 2004, crossed the road alignment on 24–25 October, and then stopped ~5 km east of the alignment. It remained in the vicinity until mid-November, crossing the road alignment at least three more times before moving away to the west.

Caribou 0405—This caribou traveled southwest from Teshekpuk Lake in October 2004 and crossed the road alignment on 3 October. It then continued moving to the southeast and crossed the Trans-Alaska Pipeline (TAPS) on 11 October. In spring 2005, the animal migrated northwest toward Teshekpuk Lake, passing ~15 km south of the alignment on 3 June.

Caribou 0406—This individual was found consistently ~35 km southwest of the road alignment in August and September 2004. It moved eastward ~25 km south of the alignment in late September, crossed TAPS, and spent the winter east of there. It returned to Teshekpuk Lake in spring 2005, crossing the newly constructed CD-4 pipeline/road corridor and then the proposed ASDP road alignment in NPRA on 6 June.

Caribou 0407—This caribou entered the ASDP study area briefly in August 2004, ~40 km northwest of CD-4, but was not found in the study area during the rest of the year.

Caribou 0408—This animal moved southeast from the Kogru River in October 2004 and crossed the proposed road alignment on 3 October. It continued east and remained for several days just west of the Meltwater road before moving south around the Meltwater pad (DS-2P) and then moving rapidly away to the southeast, eventually paralleling the west side of the TAPS/Dalton Highway corridor without crossing. It returned to the Kogru River area in late May 2005, passing ~25 km west of the terminus of the road alignment.

Caribou 0409—This individual moved southwest from Teshekpuk Lake in October 2004, passing ~7 km southwest of the western terminus of the road alignment on 23 October. It wintered west of TAPS before returning to Teshekpuk Lake in spring 2005, passing ~37 km southwest of the road alignment on 9 June.

Caribou 0410—This caribou moved southwest from Teshekpuk Lake in October 2004 and crossed the road alignment on 6 October. It wintered along the western side of the TAPS/Dalton Highway corridor, moving parallel but not crossing. It passed far west of the ASDP study area when it returned to Teshekpuk Lake in spring 2005.

All but one of the GPS-collared CAH caribou remained east of the Colville River or occasionally the eastern Colville River delta. Caribou GPS403 was ~4 km northeast of CD-1 during most of September 2004 before moving south in late September. No other locations of GPS-collared CAH caribou were within 4 km of CD-4.

The overall patterns of monthly occurrence by collared caribou show that the ASDP study area is used at low levels by the TCH throughout most of the year, primarily in the western half of the study area. The highest level of use by collared caribou occurred in the fall, the only season in which collared TCH animals moved east of the Colville

River. This pattern mirrors the results of aerial transect surveys (Table 3, Figure 6, Appendices B–J).

In contrast, the study area is used most extensively by the CAH during June and virtually all of the movements by CAH caribou were east of the Colville River. Few collared CAH caribou were present in the area during winter, especially in recent years, reflecting the findings of previous work that found few CAH caribou in winter on the coastal plain (Murphy and Lawhead 2000, Arthur and Del Vecchio 2004). 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 movements on the summer range by the CAH in relation to temperature and 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, affording good hunting opportunities for local residents.

Taken together, the telemetry data (using all three types of transmitters) indicate little overlap in the summer ranges of the TCH and CAH. Most CAH stay east of the Colville River and most TCH stay west of it (Figure 7). In recent years, however, several unusual movements by both herds have been noted. The most notable instance occurred in July 2001, when thousands of CAH caribou moved west onto and across the Colville River delta and far into NPRA, with many remaining there into September (Lawhead and Prichard 2002, Arthur and Del Vecchio 2004). The herd ranges overlap in fall and winter. Although most of the TCH usually 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 2003–2004, a large portion of the TCH moved east across the Colville River in the fall and wintered in and near ANWR (Carroll et al. 2004).

REMOTE SENSING

MODIS imagery covers large areas at relatively coarse resolution (500-m pixels), so 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 context in terms of variability in snow cover and chronology of vegetation green-up.

SNOW COVER

The progression and pattern of snow melt in 2005 were analyzed and depicted as a time series (Figure 11). In the map figure, 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 is used for pixels with >50 percent of their area as pond, lake, and river (or ice) cover. Because the snow fraction is most relevant to caribou habitat conditions, we simply masked out water-dominated pixels for our analysis.

Snow melt in April and May 2005 was confined to the southern portion of the region. Although patches of melting snow appeared to be present farther north in the 12 May image, they did not recur in the 25 May image and closer examination of the raw images indicated these patches were spurious, caused by clouds over snow. An area of melting snow was observed on the west side of Franklin Bluffs as early as 26 April, which expanded across the time series to a very large open area by 5 June. By 25 May, snowmelt also occurred southeast and southwest of the Itkillik uplands (east of the Itkillik River in the area of the Meltwater project), along some tributaries of the Colville River, and along Fish and Judy creeks. The Fish and Judy creek floodplains in the NPRA survey area are located parallel to the prevailing wind direction and become snow-free earlier than do surrounding areas, due to the dust-shadow effect caused by soil blown from dunes and banks along the stream courses.

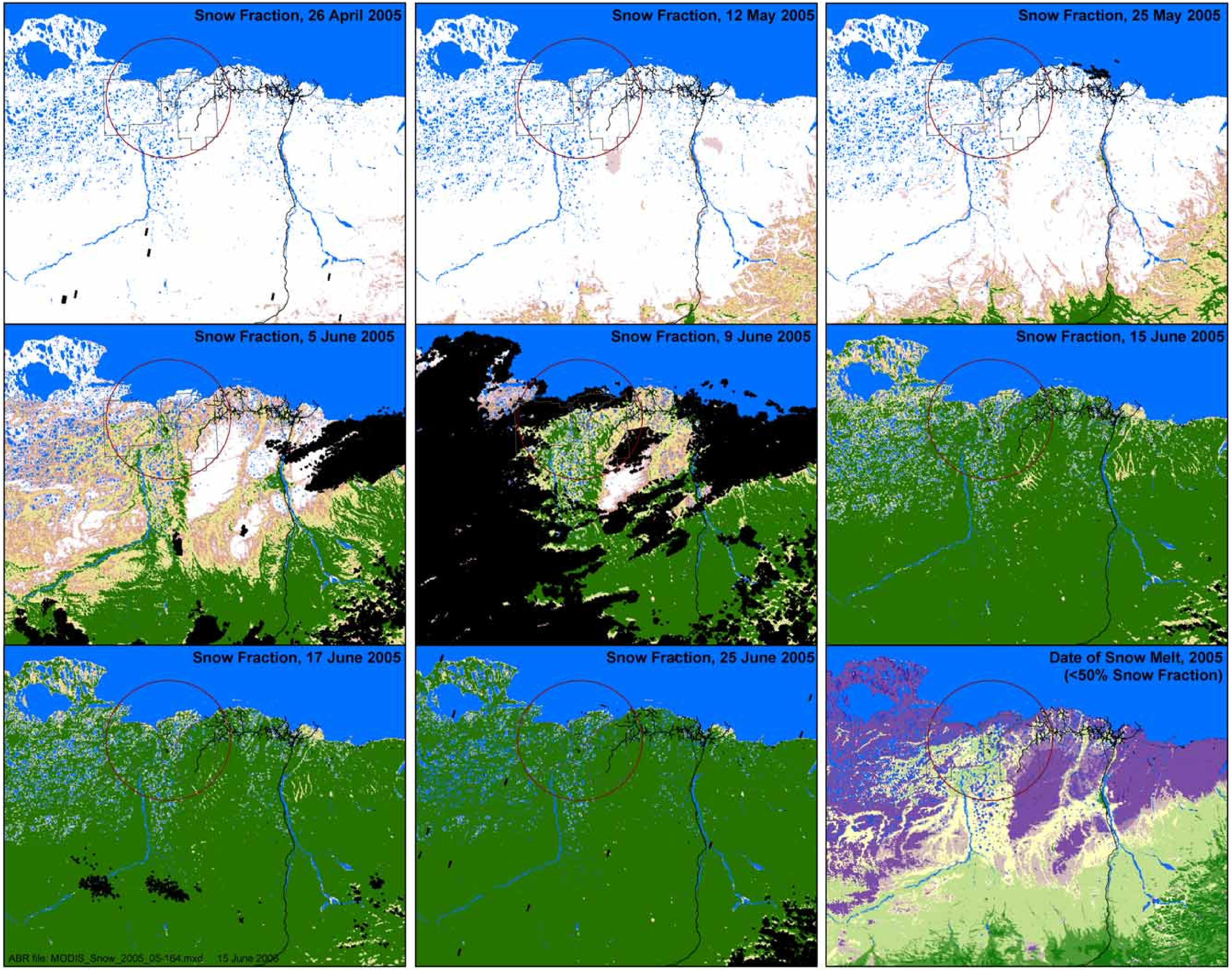

Figure 11. Snow cover during late April to late June 2005 and the progression of snow melt (<50% cover) on the central North Slope of Alaska, as estimated from MODIS satellite imagery.

Persistent cloud cover obscured the snow-melt pattern for 12 days after 25 May.

By 5 June, during caribou calving, snow melt had advanced considerably. The Itkillik uplands and other elevated features, as well as the sea coast, remained snow-covered but most of the rest of the coastal plain had only partial snow cover and low-lying areas without many lakes had melted completely. Our three aerial-survey areas covered a gradient from near-complete snow cover in the north to less snow cover farther inland. The date of snow melt in the aerial survey areas fell into two broad categories: the northern third, closest to the coast, which retained continuous snow cover until sometime between 5 and 15 June 2005, and the southern portions, which already had patchy snow by 5 June 2005. The presence of snow-free areas west of the Colville River delta and along Fish and Judy creeks showed that our NPRA survey area had less snow cover than did the other survey areas, a tendency noted on calving surveys in previous years. By 9 June, four days later in the calving period, the snow-free area had expanded considerably within the aerial survey areas (where cloud-free conditions allowed viewing). Complete snow cover had been replaced by patchy snow cover in the portion of the TCH calving grounds southeast of Teshekpuk Lake. By 15 June, the coastal plain was largely free of snow. Incised stream valleys, such as those in the Itkillik uplands, retained thick accumulations of wind-blown snow. Patchy snow cover persisted in the area around Teshekpuk Lake, as well as on the Colville and Sagavanirktok river deltas. Over the next 10 days, most of those snow remnants melted.

The performance of the MODIS subpixel-scale snow-cover algorithm in the 15 June 2005 scene was evaluated for both the simple linear model of aggregated subpixel-scale snow cover and with the additional ninth-order polynomial correction term calculated from a Landsat-5 TM image acquired on the same date. The performance of both models was similar (Table 7), which is not surprising because the ninth-order polynomial correction is a relatively minor refinement of the linear model (Déry et al. 2005). The correlations of determination were fairly high (R^2 = 0.592 and 0.600 for the linear and error-corrected models, respectively) and the mean absolute error (MAE) and root-mean-square errors (RMSE) were low. The generally low snow cover on 15 June 2005 is largely responsible for the low

Table 7. Subpixel snow-cover algorithm performance and error analysis for Kuparuk River watershed and surrounding area. The 15 June 2005 image was analyzed in this study, the May 2002 scenes were analyzed by Déry et al. (2005), and the undated scene was analyzed by Salomonson and Appel (2004).

Date (Sensor) and Algorithm [a]	Pixels	R^2	MAE (%)	RMSE (%)	f_{Landsat} (%)	f_{MODIS} (%)
15 June 2005 (Landsat 5 TM)						
0.06 + 1.21 * NDSI	100,830	0.592	4.7	10.5	6.32	5.01
0.06 + 1.21 * NDSI + E [b]	100,830	0.600	4.7	10.7	6.32	5.35
22 May 2002 (Landsat 7 ETM+)						
0.06 + 1.21 * NDSI	35,022	0.890	8.7	13.9	40.0	37.6
30 May 2002 (Landsat 7 ETM+)						
0.06 + 1.21 * NDSI	13,413	0.19	2.1	6.5	2.2	0.4
Unknown, ~41% snowmelt (L7 ETM+)						
0.06 + 1.21 * NDSI	120,141	0.95	8	12	n/a	41

[a] R^2 = Coefficient of determination; MAE = Mean absolute error; RMSE = Root mean-square error; f_{Landsat} = Landsat snow fraction; f_{MODIS} = MODIS snow fraction.

[b] E = Error-correction term.

values for these error estimates, however, because many cells had zero snow cover (and so zero errors) in both the Landsat and MODIS calculations. The algorithm performance was similar to the 30 May 2002 scene analyzed by Déry et al. (2005), which had even less snow cover (2.2 percent from Landsat), a low coefficient of determination (R^2 = 0.19), and even lower error statistics. In contrast, when snow cover was greater (~40 percent in two other comparisons), the coefficients of determination were much higher (R^2 = 0.89 or 0.95) but the MAE and RMSE also were greater. A more detailed error analysis was conducted by calculating the error for each cell (subtracting the MODIS snow fraction from the Landsat snow fraction), binning the MODIS snow fraction data into 1-percent increments, and calculating the mean error for each bin (Figure 12). The difference between the linear model and the linear model with the error term again were minor. Large errors were observed at higher MODIS snow fractions, however. The error was ~20 percent for MODIS snow fractions above 50 percent cover, indicating that the MODIS snow fraction overestimated the Landsat snow fraction by a substantial amount.

The other studies to which we compared our results used Landsat-7 Enhanced Thematic Mapper+ (ETM+) to calibrate and evaluate the subpixel-scale snow-cover algorithm. We had to use the Landsat-5 TM sensor because the ETM+ sensor developed a technical problem in May 2003, which caused the loss of about 20 percent of the pixels in all subsequent acquisitions. The Landsat-7 satellite is on the same orbit as the Terra satellite (carrying MODIS), so the MODIS-sensor

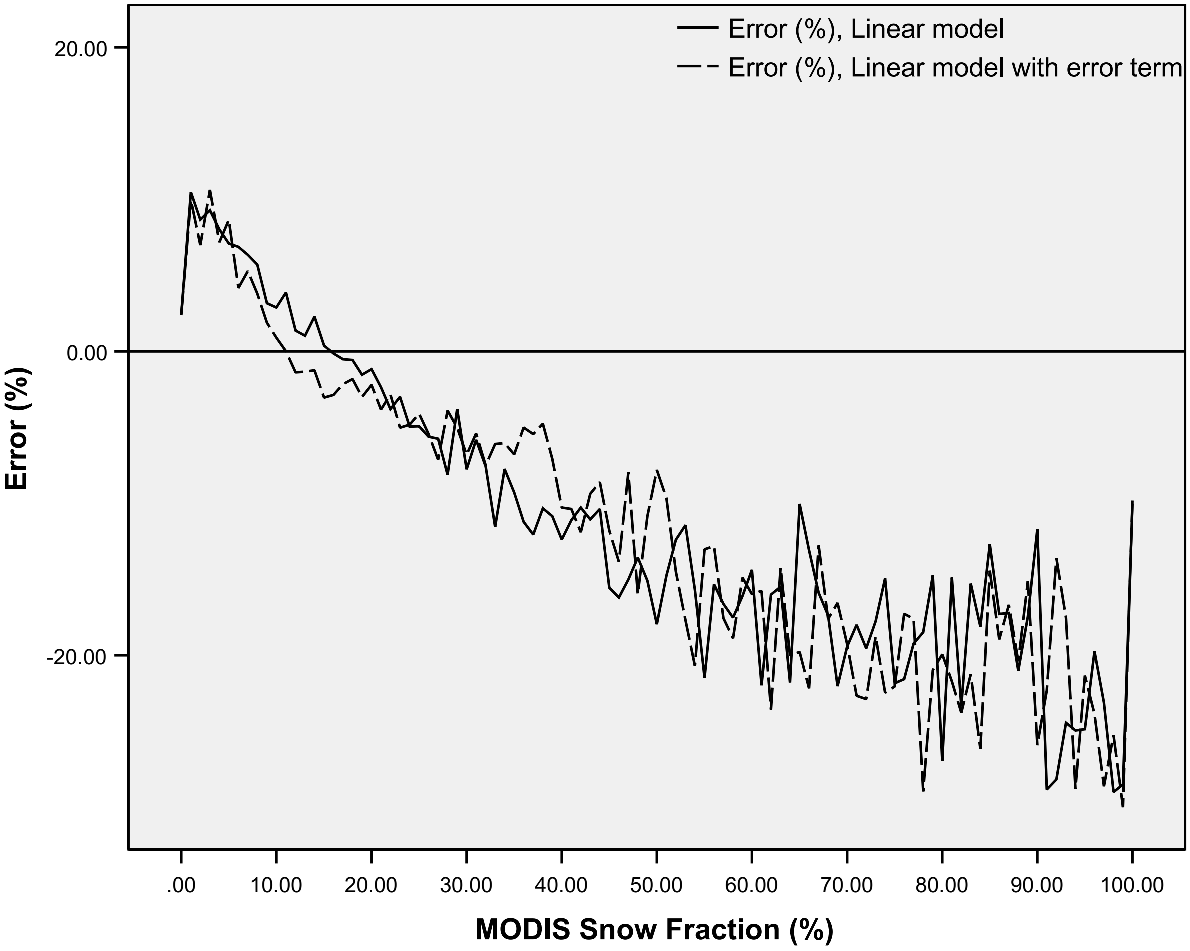

Figure 12. Error analysis of snow-cover estimates from Landsat-5 and MODIS images acquired 15 June 2005.

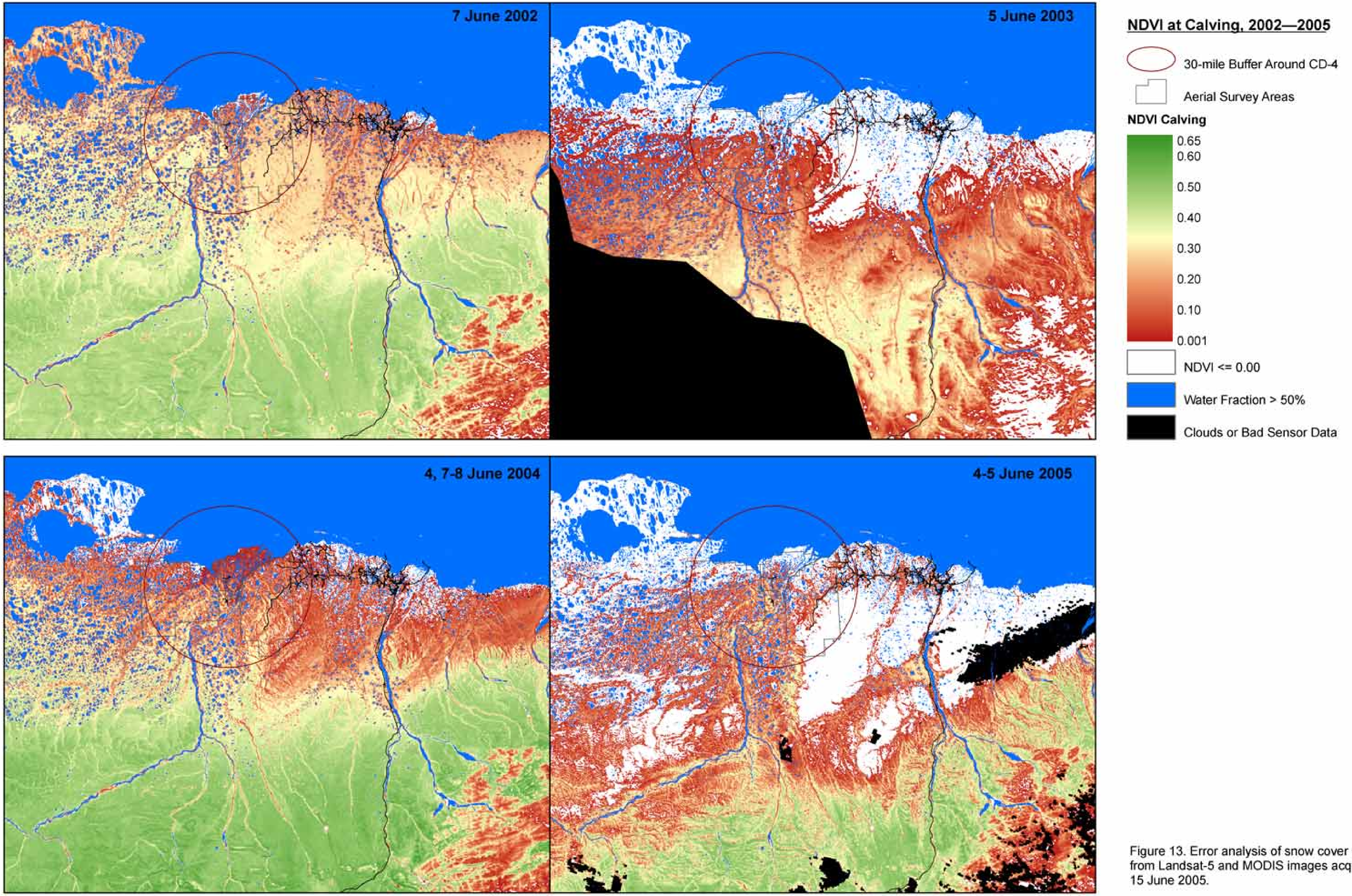

Figure 13. Error analysis of snow cover estimates from Landsat-5 and MODIS images acquired 15 June 2005.

ABR file: NDVI_Calving_05-164.mxd 15 June 2006

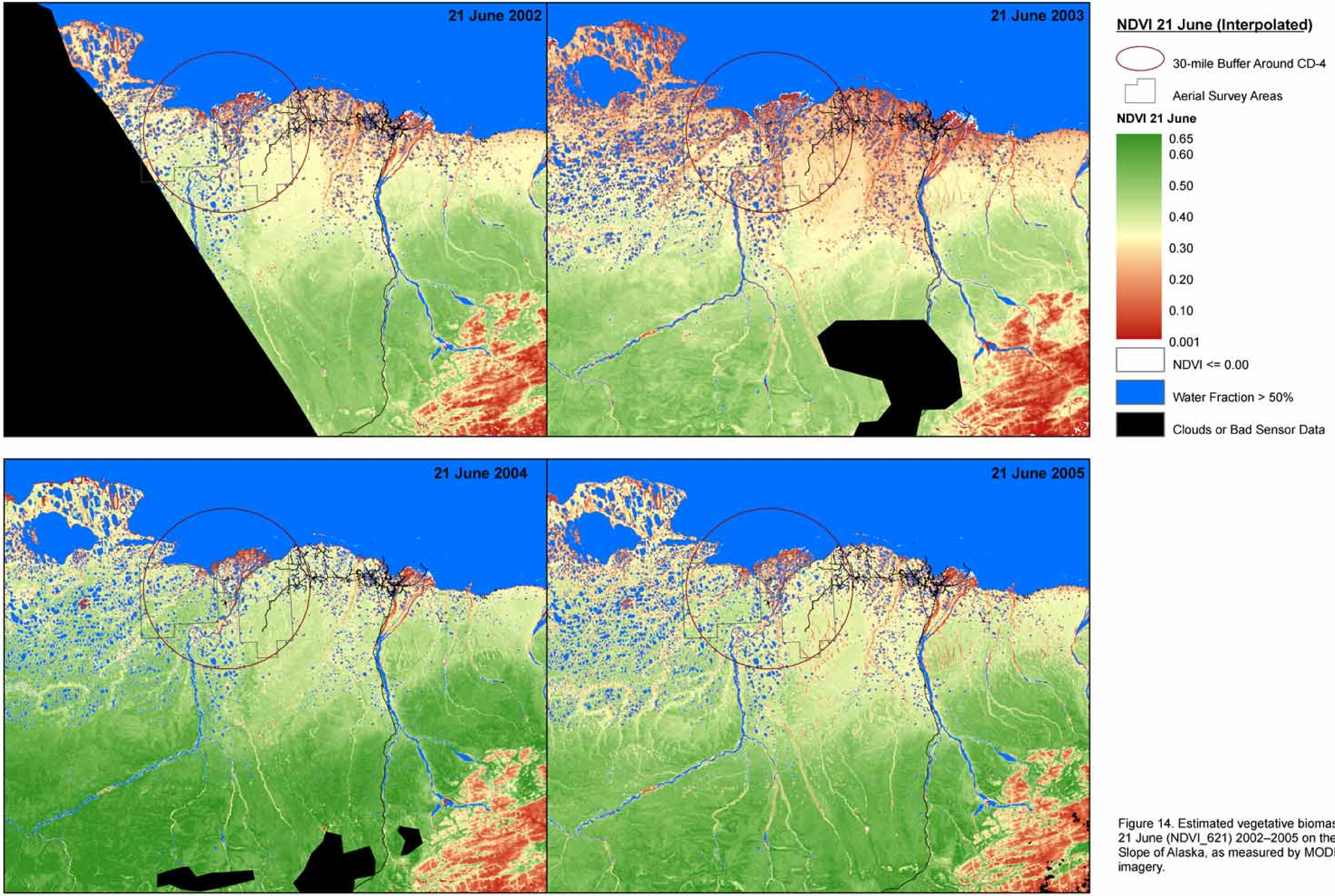

Figure 14. Estimated vegetative biomass interpolated to 21 June (NDVI_621) 2002–2005 on the central North Slope of Alaska, as measured by MODIS satellite imagery.

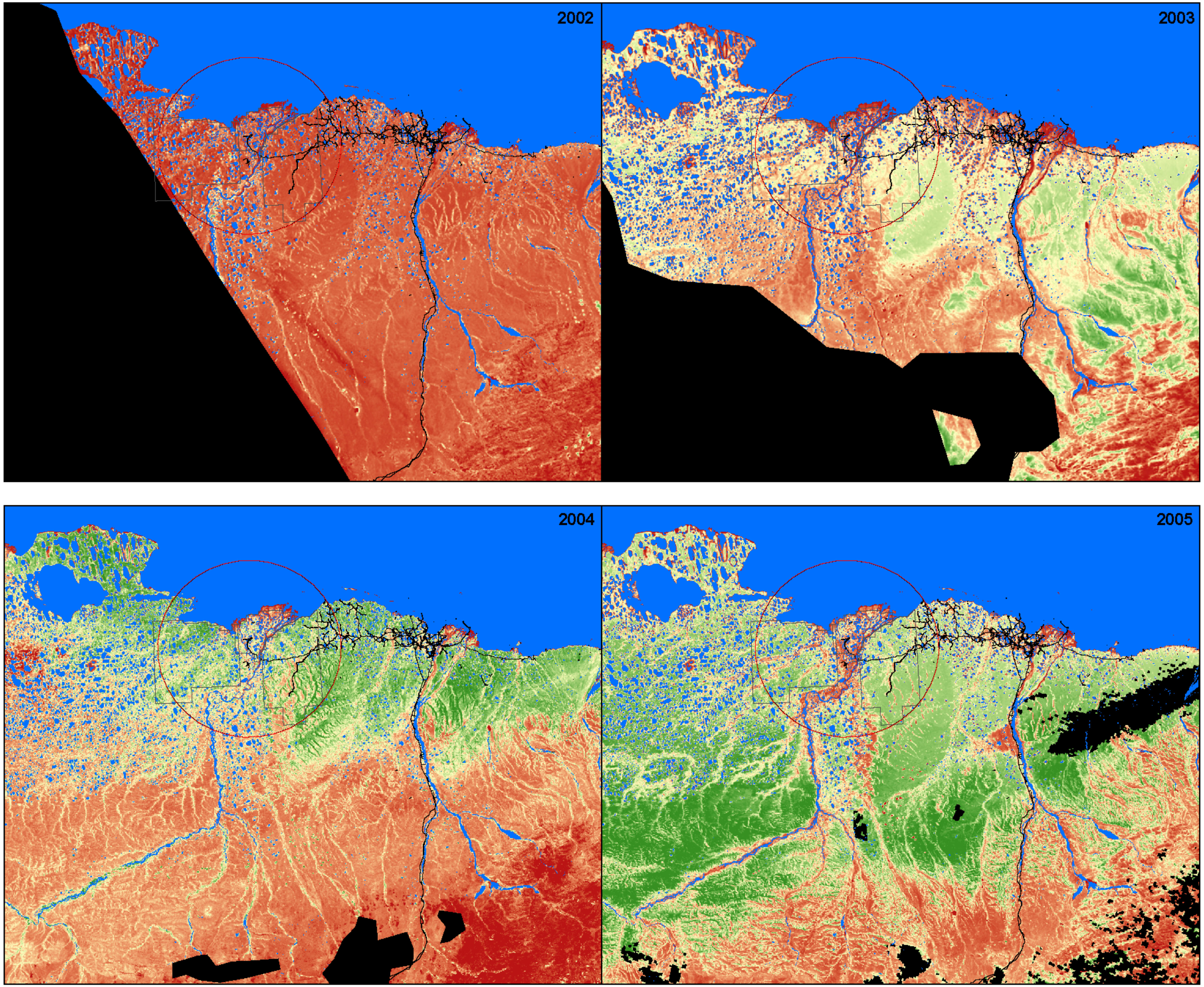

Figure 15. Estimated rate of increase in vegetative biomass from early June to 21 June (NDVI_rate) 2002–2005 on the central North Slope of Alaska, as measured by MODIS satellite imagery.

ABR file: NDVI_Rate_05-164.mxd 15 June 2006 zenith angle was close to zero (near nadir) for the previous studies. The Landsat-5 satellite is on a different orbit than the Terra satellite. The sensor zenith angle of the corresponding MODIS image is much higher (25–39 degrees), resulting in less favorable imaging conditions. Another important difference was that two of the three scenes used in earlier studies were acquired earlier in the snowmelt process. Salomonson and Appel (2004) did not specify the date of their Kuparuk scene, but reported snow cover of about 33 percent. Déry et al. (2005) used Landsat scenes from 22 May and 30 May 2002, with average snow cover of 40.0 and 2.2 percent, respectively. Our comparison was a useful test of the performance of the subpixel-scale snow-cover algorithms later in the season and under less favorable viewing geometry.

Our analysis suggests that the overall performance of the subpixel-scale snow-cover algorithm degrades near the end of snowmelt. This error also might be explained by the higher sensor zenith angle of the MODIS imagery we used for comparison, although it will be necessary to use such observations in operational monitoring. Further research using Landsat data and oblique aerial photography will improve the accuracy and understanding of errors in subpixel-scale snow-cover mapping.

VEGETATIVE BIOMASS

To examine the chronological dynamics of vegetation green-up, we compiled a 4-year time series for the variables NDVI_calving, NDVI_621, and NDVI_rate (Figures 13, 14 and 15, respectively). Some caution must be exercised in comparing NDVI values between the 2002–2003 images and the 2004–2005 images because the processing approach used with the older data differed somewhat. The focus in this first year of study was to analyze the 2005 NDVI data and develop an approach to improve the extraction of vegetation information from a study area with a high concentration of snow and ice.

NDVI_calving (imagery for 4–5 June) was quite low across most of the coastal plain (including the ASDP study area) in 2005 (Figure 13). These low values indicated high snow cover; a comparison with the subpixel-scale snow-cover map for 5 June (Figure 11) demonstrated that these low values are associated with both continuous and patchy snow. In contrast, the snow-free areas, mainly in the foothills, had much greater NDVI values on that date. NDVI_calving was low in 2003 also, somewhat higher in 2004, and substantially higher in 2002. The aerial-survey areas had very low values of NDVI_calving in three of the four years (all except 2002).

The first flush of vegetative growth that occurs among melting patches of snow cover is valuable to foraging caribou (Klein 1990, Kuropat 1994, Johnstone et al. 2002), but the spectral signal of snow complicates NDVI-based inferences regarding patchy snow conditions. Variation in dates with clear sky conditions in early June also can confound the effect of snow cover on NDVI values. For example, the dates of imagery in 2002 and 2004 were a few days later than in 2003 and 2005. Snow cover can change rapidly in early June, such as between 5 and 9 June in 2005 (Figure 11). 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 snow melt. Therefore, it may be more appropriate to infer habitat conditions from the subpixel-scale snow fraction until all detectable snow in a pixel has melted, and then to incorporate NDVI metrics after pixels are snow-free. Beck et al. (2006) proposed that the NDVI value of senesced vegetation is more appropriate to use as a baseline for vegetation phenology calculations than are early-season NDVI values affected by snow. The NDVI of senesced 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.

By 21 June, the date considered to represent peak lactation (Griffith et al. 2002), the study area is generally free of snow (other than incised valleys) but ice remains a prominent feature, particularly in the northern portion of the region. In calculating 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 percent water. The late July image used to calculate NDVI_peak was generally ice-free (except for Teshekpuk Lake) and a fringe of lower NDVI values around lake edges was no longer evident. This change suggests that the presence of lake ice decreases NDVI values in pixels adjacent to lakes, suggesting that removal of the negative bias caused by subpixel-scale lake ice may require masking more pixels around waterbodies. Another promising approach would be to apply spectral tests to determine the presence of snow or ice on the raw swath imagery. Then, snow-affected pixels could be excluded before the imagery is registered to a common coordinate system.

The estimated rate of change in biomass from calving in early June to 21 June, represented by the variable NDVI_rate, is highest where NDVI_calving was low (often zero or lower; Figures 13 and 15). NDVI_rate in 2002 was extremely low throughout the study area because of the early snow melt that year.

VEGETATION SAMPLING

The total biomass measured in sampling plots was significantly greater in moist tussock tundra than in moist sedge–shrub tundra ($P < 0.001$; Table 8). No differences were found among distance-to-road categories ($P = 0.539$) and the interaction term between habitat class and distance-to-road categories was not significant ($P = 0.665$). Moist tussock tundra contained higher mean levels of lichens, forbs, *Eriophorum vaginatum*, and evergreen shrubs, whereas moist sedge–shrub tundra mainly comprised graminoids other than *E. vaginatum* (Table 8). The biomass of willows (*Salix* spp.), which provide important summer forage for caribou, was similar between habitat classes.

The difference between habitat classes was due to the presence of evergreen shrubs, which are not preferred forage for caribou. When evergreen shrubs were excluded from the measurements, total biomass did not differ significantly between the two habitat classes ($P = 0.169$). Biomass did not differ significantly among distance-to-road categories ($P = 0.243$) and the interaction term was not significant ($P = 0.486$). Although the biomass of non-evergreen shrub species did not differ between moist tussock tundra and moist sedge–shrub tundra, tussock tundra should be favored in spring when *E. vaginatum* flowers are emerging and in winter when caribou feed heavily on lichens (Kuropat 1984,Russell et al. 1993). The higher density of forbs also may attract caribou to tussock tundra.

Hobbie and Chapin (1998) reported a mean peak value of 126.1 g/m² for total above-ground vascular plant biomass (excluding lichens and mosses) in upland tussock tundra at the Toolik field station in the northern foothills of the Brooks Range. That value was similar to our non-lichen estimate of 123.7 g/m² for moist tussock tundra. Because June and July 2005 were cooler than average (Appendix B), the biomass levels we measured probably were lower than would be expected in a more typical year. Hope et al. (1993) reported a photosynthetic biomass value of ~270 g/m² in late July on tussock-tundra plots in the northern foothills of the Brooks Range, but their estimate included moss and lichens.

Russell et al. (1993) reported biomass values for different plant groups sampled on 12 July 1980 in the PCH calving range. Tussock meadow had mean values of 18.9 g/m² for lichens, 56.1 g/m² for graminoids, 76.8 g/m² for deciduous shrubs, 22.7 g/m² for evergreen shrubs, and 8.8 g/m² for forbs. Wet sedge meadow had means of 17.0 g/m² for lichens, 91.5 g/m² for graminoids, 66.4 g/m² for deciduous shrubs, and 1.4 g/m² for forbs; evergreen shrubs were absent from that habitat class. These values were generally higher than we found in the NPRA survey area, although the among-sample variation in biomass estimates was substantial.

We calculated estimated biomass in the larger 500×500-m areas in which our plots were located, using the mean biomass values for moist tussock tundra and moist sedge–shrub tundra from the ELS classification (Jorgenson et al. 2003) and the relative proportions of tussock tundra and non-tussock tundra types from the NPRA earth-cover classification (BLM and Ducks Unlimited 2002), to compare biomass from field sampling with remote sensing data. The biomass values for moist sedge–shrub tundra were assigned to all habitat types other than tussock tundra, constituting predominantly wet tundra, sedge/grass meadow, and dwarf shrub (BLM and Ducks Unlimited 2002). Jia et al (2003) found that wet tundra (using a different habitat classification system) had the lowest NDVI value of all types.

Table 8. Vegetative biomass (g/m²; mean plus SE in parentheses) in the two dominant wildlife habitat classes in the NPRA survey area, July 2005.

			Sample Category								
Habitat Class [a]	Distance to Road (km)	*n*	Lichens	Forbs	*Eriophorum vaginatum*	Other Graminoids	*Salix pulchra*	Other *Salix*	Evergreen Shrubs	*Betula nana*	Total Biomass
Moist Sedge–Shrub Tundra	0–1	9	0.8 (0.65)	0.1 (0.04)	0.4 (0.31)	65.0 (6.30)	5.9 (2.54)	1.5 (1.11)	5.7 (2.34)	1.1 (0.89)	80.5 (8.54)
	2–3	9	0.5 (0.20)	0.6 (0.23)	1.2 (1.21)	60.9 (12.03)	3.6 (1.23)	1.1 (0.45)	3.0 (1.40)	0.5 (0.41)	71.4 (12.29)
	4–5	10	0.5 (0.47)	0.3 (0.16)	0.2 (0.24)	81.9 (12.88)	6.4 (2.07)	1.6 (0.91)	0.8 (0.47)	2.6 (1.41)	94.3 (12.66)
	Total	28	0.6 (0.27)	0.3 (0.10)	0.6 (0.40)	69.7 (6.36)	5.3 (1.15)	1.4 (0.49)	3.1 (0.94)	1.4 (0.59)	82.5 (6.61)
Moist Tussock Tundra	0–1	10	21.7 (3.54)	5.7 (2.04)	23.4 (7.25)	6.2 (2.39)	3.7 (2.25)	4.2 (1.69)	75.3 (9.17)	3.8 (2.45)	143.8 (8.75)
	2–3	9	16.2 (2.12)	1.9 (1.17)	30.3 (4.21)	5.0 (1.32)	7.2 (1.91)	0.7 (0.37)	69.5 (6.91)	5.5 (1.73)	136.3 (8.56)
	4–5	11	15.5 (2.47)	1.9 (1.35)	28.4 (3.20)	7.6 (2.17)	8.4 (3.32)	0.5 (0.30)	70.7 (2.63)	10.4 (3.88)	143.5 (5.16)
	Total	30	17.8 (1.65)	3.2 (0.94)	27.3 (2.91)	6.3 (1.17)	6.5 (1.54)	1.8 (0.64)	71.9 (3.71)	6.7 (1.75)	141.4 (4.21)

[a] Wildlife habitat classes from Ecological Land Survey classification (Jorgenson et al. 2003).

The relationship between the NDVI_peak values and the estimated biomass values in these comparisons was marginally significant (*R* = 0.665, *P* = 0.051, *n* = 9). The NDVI_peak value was significantly correlated with mean biomass for moist sedge–shrub tundra (*R* = 0.730, *P* = 0.026, *n* = 9), but was not correlated with mean biomass for tussock tundra (*R* = 0.340, *P* = 0.371, *n* = 9). Biomass estimates varied considerably more among plots in moist sedge–shrub tundra than in moist tussock tundra (Table 8). Oechel et al. (2000) found that NDVI values of nonacidic tundra (similar to tussock tundra in our study area) in the upper Kuparuk River basin increased at an average daily rate of 0.011 during late May–early June and then slowed to a steady daily rate of ~0.005 until the annual peak in late July. However, wet sedge tundra showed a linear increase over the entire time period, suggesting that the temporal pattern in NDVI may be influenced more by the growth in wet sedge tundra than tussock tundra later in the summer.

Using the mean number of fecal-pellet groups per plot as an indicator, habitat use by caribou was greater in tussock tundra than in moist sedge–shrub tundra, although the difference was not significant (*P* = 0.100; Table 9). More groups of winter pellets than summer pellets were found in the plots, but after adjusting for the longer duration of the winter season, the data suggest higher rates of pellet deposition during summer. The number of pellet groups declined farther from the proposed road in moist sedge–shrub tundra and increased in tussock tundra. Fecal deposition rates of ungulates vary among seasons (Timmerman and Buss 1998), however, so it is difficult to equate pellet density with caribou density across seasons. At best, the presence and number of fecal pellets in a plot is an indicator of relative levels of use rather than an absolute measure.

TRAIL MAPPING

After reviewing the field waypoints and oblique aerial photographs for trail observations from aerial surveys, areas of interest for evaluating the feasibility of mapping caribou trails were identified in the Colville East and NPRA survey areas and on the Fish Creek delta (Figure 16). Visual examination was used to compare trail locations on the oblique, standard orthophoto base-map, and high-resolution scans (Appendices N–S). The emphasis in our evaluation was to

Table 9. Number of caribou fecal-pellet groups (mean, plus SE in parentheses) in 25-m transects (50 m²) at vegetation-sampling plots, by habitat class and distance to the proposed ASDP road, in the NPRA survey area, July 2005.

Species	Date	Total Number	Number of Adults	Number of Young	Specific Location
Muskox	April 23	9	9	0	Near the Kalikpik River
	June 11	15	9	6	Near the Kalikpik River
	June 13	15	9	6	Near the Kalikpik River
	July 30	8	5	3	Near the Kalikpik River
	August 3	16	13	3	Near the Kalikpik River
	August 17	16	10	6	Near the Kalikpik River
	August 31	2	2	0	Near the Kalikpik River
	August 31	18	14	4	Near the Kalikpik River
	October 21	16	12	4	Fish Creek Delta
Moose	April 23	1	1	0	Near Fish Creek

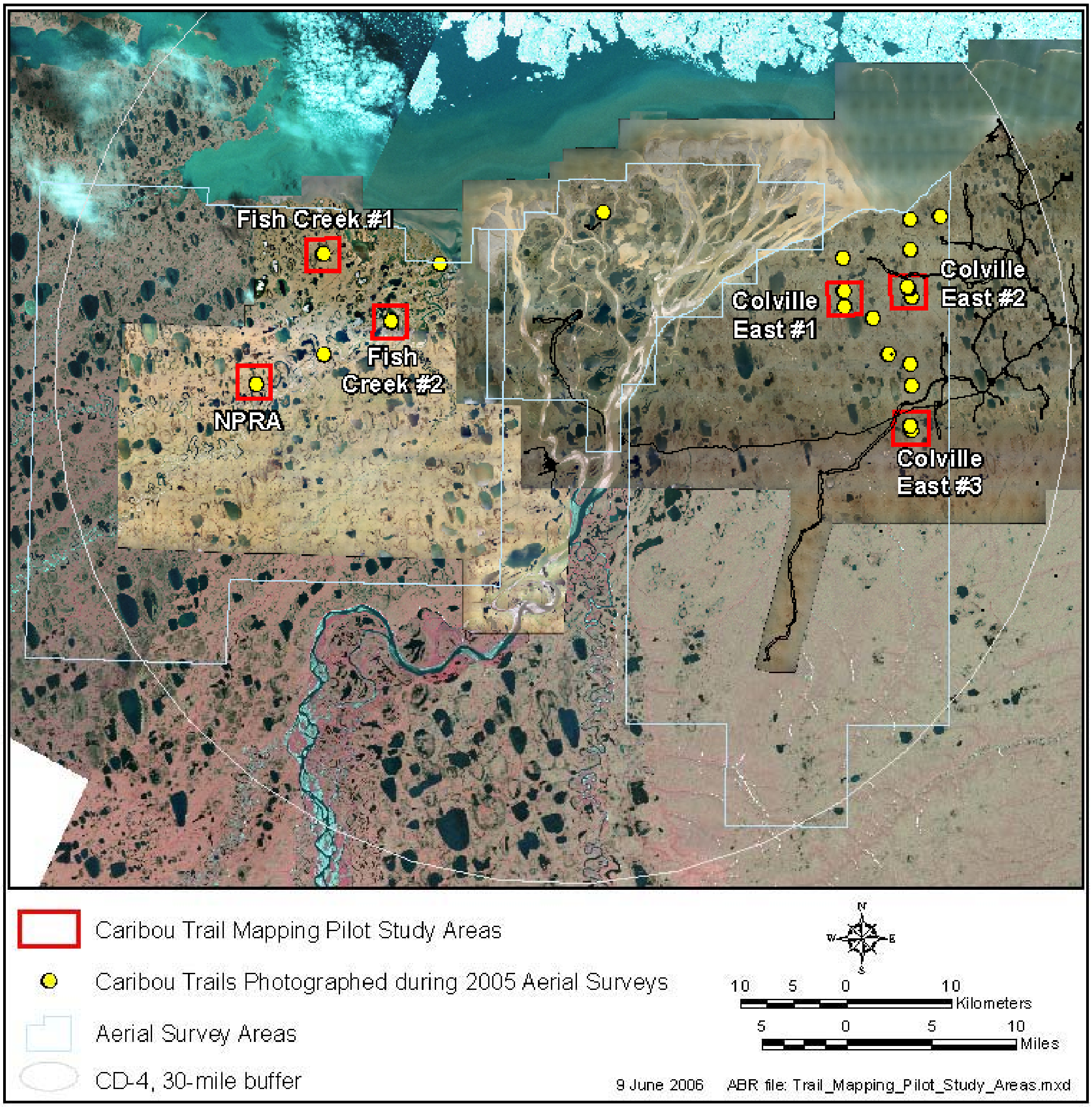

Figure 16. Locations used to evaluate feasibility of caribou trail mapping in the ASDP study area, 2005.

identify perennial trails in vegetated areas (persisting over multiple years, including the years in which vertical aerial photography was taken) rather than ephemeral trails (made in 2005) in silt or sand on river bars, mudflats, or lake bottoms.

Colville East #1—A well-defined corridor with multiple trails was clearly visible on the oblique photo taken on the aerial survey on 4 October 2005. No sign of these trails was detected on the 1-ft digital orthophoto mosaic and the trails were faintly visible as texture features in the raw 8-micron scan (~ 0.5 ft resolution) of the same vertical photography (Appendix N).

Colville East #2—Several branching trails were photographed over this site during the aerial survey on 4 October 2005. Some of the trails are visible but blurry on the 1-ft digital orthophoto mosaic. The trails are much more distinct and several more trails are visible on the 8-micron scan of the same vertical photography (Appendix O).

Colville East #3—The oblique photography from 4 October 2005 depicts trails converging between two waterbodies. Two ruts are visible for a short distance on the 1-ft digital orthophoto, but not an identifiable trail. The converging trails are faintly visible, mostly as texture features, on the 8-micron scan of the same vertical photography (Appendix P).

Fish Creek #1—Several trails paralleling a lakeshore are distinct in the oblique photo from 31 August 2005. No evidence of these trails could be discerned on the 2-ft digital orthophoto over the same area, which also appeared quite blocky. The 8-micron scan of the area provided a substantial increase in resolution, however, and multiple trails were distinctly visible (Appendix Q).

Fish Creek #2—Trails were visible on both sides of a channel of the Colville River on the oblique photograph taken on 31 August 2005. No evidence of these trails could be discerned on the 2-foot digital orthophoto of the same area. Trails south of the river channel were clearly visible in the 8-micron scan of the area, but trails to the north were not detectable (Appendix R).

NPRA—A wide swath of trails was visible across a wet, low landscape on the oblique photograph taken on 31 August 2005. No evidence of these trails could be discerned on either the 2-ft digital orthophoto or the 8-micron scan over the same area (although some trails were visible along the north side of the lake in the 8-micron scan, these were not covered by the oblique photography). The four-year time difference between air photo and oblique photo acquisition may explain the absence of these trails, because the level of detail of the 8-micron scan appeared sufficient to identify trails if present (Appendix S). The air photo was acquired on 13 July 2001, about a week before a large-scale movement of CAH caribou into the NPRA survey area.

Overall, the existing orthophoto base-maps were not suitable for creating a baseline map of the locations of perennial caribou trails in the study area (Table 10). The resolution of the imagery was too coarse, particularly in the western area (NPRA and Fish Creek delta). The raw, unprocessed

Table 10. Details of aerial photography and detectability ratings for caribou trail-mapping evaluation in the Colville East and NPRA survey areas, 2005.

Area of Interest	Oblique Aerial Photo Date	Vertical Aerial Photo Date	Vertical Aerial Photo Scale	Vertical Aerial Photo Scan Resolution (microns)	Vertical Aerial Photo Ground Resolution, (ft)	Vertical Aerial Photo Trail Detectability Rating [a]
Colville East #1	4 Oct 2005	26 July 2004	1":1500'	16	1.0[b]	None
Colville East #2	4 Oct 2005	26 July 2004	1":1500'	16	1.0[b]	Moderate
Colville East #3	4 Oct 2005	26 July 2004	1":1500'	16	1.0[b]	None
Fish Creek #1	31 Aug 2005	30 June 1999	1":1200’	24	2.0[c]	None
Fish Creek #2	31 Aug 2005	30 June 1999	1":1200’	24	2.0[c]	None
NPRA	31 Aug 2005	30 June 1999	1":1200’	24	2.0[c]	None
Colville East #1	4 Oct 2005	26 July 2004	1":1500'	8	0.47	Faint
Colville East #2	4 Oct 2005	26 July 2004	1":1500'	8	0.47	Distinct
Colville East #3	4 Oct 2005	26 July 2004	1":1500'	8	0.47	Faint
Fish Creek #1	31 Aug 2005	30 June 1999	1":1200’	8	0.38	Distinct
Fish Creek #2	31 Aug 2005	30 June 1999	1":1200’	8	0.38	Distinct
NPRA	31 Aug 2005	30 June 1999	1":1200’	8	0.38	None

[a] Detectability ratings: None, Faint, Moderate, Distinct; n/a = not available.

[b] Nominal resolution 0.94 ft.

[c] Nominal resolution 1.14 ft.

vertical aerial photographs had a higher level of detail, however, that allowed more trail features to be distinguished, particularly in the NPRA and Fish Creek delta areas of interest, where more detailed photography (scale 1":1200') was available. The eastern area was covered by coarser photography (scale 1":1500'; even though the derived digital orthophoto mosaic for the eastern area was more detailed). However, the raw data were not georeferenced or mosaicked and substantial processing would be required to reproduce the digital mosaics at a higher resolution. In addition, some trail features were either faint or indistinct even at maximum resolution.

Resolution and image quality are crucial for mapping perennial caribou trails with remote sensing, and it appears that available photography can be reprocessed to facilitate trail mapping. Other options are available as well. High-resolution color-infrared imagery may have superior spectral characteristics for distinguishing wet trails from surrounding vegetation, but we have not evaluated that method. More conventional trail-mapping approaches—such as compiling maps from ground-based surveys, helicopter surveys, or low-altitude oblique aerial photographs—may also be applied to map trails in the study area. These methods have been used in the past (Child 1973, LeResche and Lindeman 1975). These options are labor-intensive and expensive, however, so a limited sampling strategy to identify critical mapping areas along the proposed ASDP road alignment is probably the most feasible approach for mapping caribou trails in the study area.

CARIBOU DISTRIBUTION ANALYSES

GEOGRAPHIC LOCATION

The distribution of caribou groups was not uniform across the six geographic zones of the NPRA survey area (Figure 3) for most combinations of season and year (Table 11). The difference between the 2002–2004 and 2005 survey areas resulted in different areas of availability for this analysis. Variations in snow cover, NDVI, and habitat abundance among zones (Appendix M) were reflected in seasonal differences in caribou distribution. Patterns of significance within individual years largely were reflected in the analysis of the combined samples for all 4 years (2002–2005; Table 11).

The River zone contained more groups than expected during postcalving, the oestrid fly season, and late summer, but had fewer than expected during spring migration. The Southwest zone also tended to contain more groups than expected, with significantly more occurring in winter, calving, and fall migration, but fewer during the mosquito season.

The North and West zones tended to have minor departures from expected numbers. The North zone had fewer groups in winter and oestrid fly season and more than expected during spring migration. The West zone contained more groups during postcalving and fewer than expected during the oestrid fly season; this zone had the fewest departures from a uniform distribution.

Among all years, the Southeast zone, which includes nearly the entire proposed ASDP road alignment, contained fewer groups than expected in all seasons except winter and spring migration. The Coastal zone also tended to contain fewer groups than expected, with the differences being significant during winter, calving, postcalving, late summer, and fall migration. Significantly more groups than expected occurred in that zone during the mosquito season, however, consistent with the use of coastal relief habitat. Although the number of groups in the coastal zone did not differ from expected during oestrid fly season, this group-based analysis does not reflect the large numbers of caribou found in a few groups in the Coastal zone on 2 August 2005, a date on which mosquitoes also were active.

These results are consistent with generally understood patterns of caribou movements on the central Arctic Coastal Plain of northern Alaska. During calving, the highest densities of TCH females calve near Teshekpuk Lake and densities decrease farther from the lake (Prichard and Murphy 2004, Carroll et al. 2005). When mosquito harassment begins, typically in late June, caribou move toward the coast where lower temperatures and higher wind speeds prevail. When oestrid flies emerge, typically by mid-July, the large groups formed in response to mosquito harassment break

Table 11. Number of caribou groups in different geographic zones of the NPRA survey area, by year and season, with results of chi-square goodness-of-fit tests, assuming a uniform distribution.

				Geographic Zone							
Year	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
Total	Winter	2	411	12^{--}	47^{--}	90	111	129^{++}	22	55.92	<0.001
	Spring Migration	4	144	0	30^{+}	18^{--}	44	40	12	25.67	<0.001
	Calving	5	315	4^{--}	50	78	65^{--}	96^{++}	22	46.44	<0.001
	Postcalving	4	467	8^{--}	79	162^{++}	92^{--}	82	44^{+}	73.91	<0.001
	Mosquito	5	40	10^{+}	12	9	4^{--}	1^{--}	4	61.56	<0.001
	Oestrid Fly	5	165	9	9^{--}	87^{++}	31^{--}	27	2^{--}	91.20	<0.001
	Late Summer	8	342	3^{--}	67	134^{++}	64^{--}	61	13	75.52	<0.001
	Fall Migration	8	691	6^{--}	73	191	141^{--}	238^{++}	42	121.45	<0.001
	Total	41	2575	52^{--}	367	769^{++}	552^{--}	674^{++}	161	231.85	<0.001
Available area, 2002–2004 (km²)				8.9	64.8	133.7	191.0	115.9	32.3		
Available area, 2005 (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 ($P < 0.01$).

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

The Southwest zone consistently contained higher densities of caribou than did the Southeast zone. The reasons for this difference are unknown but possible explanations may include distance from Teshekpuk Lake and location on the fringe of the TCH range, differences in habitat quality, or avoidance of human activity (hunting pressure from 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 were significantly related to the distribution of habitat types (using the NPRA earth-cover classification; BLM and Ducks Unlimited 2002). Across all seasons and years (2002–2005), riverine habitats and the moss/lichen and dwarf shrub types were used more than expected and the wet tundra types (*Carex aquatilis* and flooded tundra) were used less than expected (Table 12). Among seasons over all years, caribou used tussock tundra more than expected in winter and less than expected in summer (mosquito, oestrid fly season, and late summer). Riverine habitats were used less than expected during spring migration but more than expected from postcalving through fall migration. *Carex aquatilis* and flooded tundra habitat types were used less than expected during calving and postcalving and dwarf shrub was used more than expected during late summer and fall migration. Use of sedge/grass meadow was greater than expected during calving and postcalving but less during oestrid fly season. The moss/lichen class was used less than expected during winter and calving and more than expected during the oestrid fly season and late summer. The selection of tussock tundra in winter may be related to the relatively high levels of lichens available in that type (Table 8), but the reason for avoidance of the moss/lichen type in winter is unknown.

During calving, caribou may seek dry, snow-free areas, but habitat type generally was a poor predictor of group location during calving. Different studies have used different habitat classifications. Kelleyhouse (2001) reported that TCH caribou selected wet graminoid vegetation during calving and Wolfe (2000) reported that CAH caribou selected wet graminoid or moist graminoid areas; 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 area and 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 ASDP study 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 emerge, caribou distribution was dominated by selection for rivers and coastal areas for insect-relief habitat, rather than for biomass availability. The Fish and Judy creek drainages are important influences on caribou distribution. The proportions of different habitat types around the proposed ASDP road alignment show strong trends that are largely influenced by the presence of the Fish and Judy creeks to the north of the proposed road (Table 13). The proportion of tussock tundra generally decreases from north to south. The proportions of dunes, sparsely vegetated, and barren ground types are higher north of the road alignment, with only small amounts of these habitat types near or south of the proposed road. Future evaluations of caribou distribution in relation to the proposed infrastructure will need to take these habitat differences into account.

SNOW COVER

We compared the locations of caribou groups within our aerial-survey strip-transects during the 2005 calving period (n = 98) with the availability of different snow-cover classes (Table 14). Although the proportion of groups in the 76–100% cover class was less than expected, the overall

Table 12. Seasonal use of different habitat types by caribou, expressed as use (% of the area within 100 m of each group) divided by availability (%; excluding water), during aerial surveys of the NPRA survey area in 2002–2005.

Season	Variable	Mean	SE	*P*-value
Winter	Intercept	–2.146	1.277	0.093
	Presence of Creek	–0.174	0.225	0.439
	Includes Proposed Road	–1.000	0.308	0.001
	NDVI_peak	6.030	3.286	0.066
	Distance to Coast (km)	0.040	0.011	<0.001
	Tussock Tundra (%)	1.425	0.65	0.028
	Wet Habitat (%)	–1.181	0.634	0.063
	Transect Number (West to East)	–0.048	0.027	0.072
Spring Migration	Intercept	–1.854	0.585	0.002
	Presence of Creek	–0.515	0.151	0.001
	Includes Proposed Road	–0.262	0.221	0.236
	NDVI_peak	1.703	2.258	0.451
	Distance to Coast (km)	0.005	0.008	0.566
	Tussock Tundra (%)	0.344	0.441	0.436
	Wet Habitat (%)	–0.012	0.438	0.979
	Transect Number (West to East)	–0.036	0.015	0.018
Calving	Intercept	–0.756	1.322	0.567
	Presence of Creek	0.276	0.151	0.067
	Includes Proposed Road	0.168	0.199	0.399
	NDVI_peak	4.727	2.067	0.022
	Distance to Coast (km)	0.009	0.007	0.210
	Tussock Tundra (%)	0.859	0.399	0.031
	Wet Habitat (%)	–0.857	0.391	0.029
	Transect Number (West to East)	–0.086	0.016	<0.001
Postcalving	Intercept	1.790	0.503	<0.001
	Presence of Creek	0.873	0.157	<0.001
	Includes Proposed Road	–0.061	0.23	0.790
	NDVI_peak	0.072	2.483	0.977
	Distance to Coast (km)	–0.026	0.008	0.001
	Tussock Tundra (%)	0.529	0.467	0.258
	Wet Habitat (%)	–0.453	0.458	0.323
	Transect Number (West to East)	–0.125	0.019	<0.001
Mosquito	Intercept	–1.408	0.228	<0.001
	Presence of Creek	–0.040	0.051	0.437
	Includes Proposed Road	–0.099	0.075	0.188
	NDVI_peak	–0.801	0.812	0.324
	Distance to Coast (km)	–0.009	0.003	0.001
	Tussock Tundra (%)	0.032	0.156	0.839
	Wet Habitat (%)	–0.167	0.15	0.264
	Transect Number (West to East)	–0.020	0.006	0.001
Oestrid Fly	Intercept	2.922	2.913	0.316
	Presence of Creek	0.586	0.252	0.02
	Includes Proposed Road	–0.302	0.356	0.396
	NDVI_peak	–11.093	3.611	0.002
	Distance to Coast (km)	0.000	0.012	1.000
	Tussock Tundra (%)	–1.987	0.705	0.005
	Wet Habitat (%)	0.718	0.699	0.304
	Transect Number (West to East)	0.024	0.029	0.412
Late Summer	Intercept	1.568	1.043	0.133
	Presence of Creek	0.407	0.11	<0.001
	Includes Proposed Road	0.123	0.152	0.42
	NDVI_peak	–3.972	1.601	0.013
	Distance to Coast (km)	–0.009	0.006	0.122
	Tussock Tundra (%)	–0.247	0.323	0.444
	Wet Habitat (%)	0.049	0.317	0.876
	Transect Number (West to East)	–0.064	0.012	<0.001
Fall Migration	Intercept	0.653	0.722	0.366
	Presence of Creek	0.334	0.162	0.04
	Includes Proposed Road	0.146	0.229	0.526
	NDVI_peak	–2.881	2.471	0.244
	Distance to Coast (km)	0.023	0.008	0.004
	Tussock Tundra (%)	–0.747	0.477	0.117
	Wet Habitat (%)	0.714	0.465	0.125
	Transect Number (West to East)	–0.061	0.020	0.002

Table 13. Area (percentage) of habitat types within distance-to-road categories north and south of the proposed ASDP road in the NPRA survey area.

			Habitat Type [a]										
Zone	Distance to Road (km)	Water	*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).

Table 14. Use of different snow-cover classes by caribou groups during calving season (30 May–15 June) in 2005, expressed as number (percentage) of groups (aerial survey samples) or individuals (telemetry samples) by class. Use was compared with availability using chi-square goodness-of-fit tests. Availability was defined as the entire survey area for aerial survey samples and the area within the 95% kernel contours (utilization distribution) for telemetry samples.

Data Source	Herd	Variable	*n*	Snow Cover 0–25%	Snow Cover 26–50%	Snow Cover 51–75%	Snow Cover 76–100%	Chi-square
Aerial surveys	TCH	Used	98	20 (20)	33 (34)	17 (17)	28 (29)	*P* = 0.160
		Available	%	19.8	25.0	17.4	37.8	
	CAH	Used	169	17 (10)	30 (18)	25 (15)	97 (57)	*P* = 0.194
		Available	%	8.6	14.0	12.1	65.3	
Radio telemetry	TCH	Used	311	11 (3.5)	19 (6.1)	24 (7.7)	257 (82.6)	*P* = 0.099
		50% Kernel	%	0.1	1.2	4.3	94.4	
		95% Kernel	%	3.2	8.5	11.0	77.3	
	CAH	Used	44	4 (9.1)[--]	3 (6.8)	8 (18.2)	29 (65.9)	*P* = 0.023
		50% Kernel	%	12.5	9.6	8.0	70.0	
		95% Kernel	%	22.6	13.1	9.3	55.1	

[--] Use less than expected ($P < 0.01$).

distribution was not significantly different from expected (*P* = 0.160). The proportions of caribou in areas with patchy snow cover likely were underrepresented, however, due to greater difficulty of detection. Caribou are difficult to see during aerial surveys when viewed against the complex visual background formed by patchy snow cover. Therefore, the number of caribou groups in the two intermediate snow-cover classes likely was higher than indicated.

Snow cover at the locations of collared caribou (VHF, satellite, and GPS samples) during calving in 2005 did not differ significantly from availability (as defined by the 95% kernel-density contour for each herd) for the TCH (*P* = 0.099), but it did for the CAH (*P* = 0.023). The proportion of CAH caribou in the 0–25% cover class was significantly lower than expected (*P* < 0.01). The 50% kernel-density contour (estimating the concentrated calving area) had a higher proportion of the 76–100% snow cover class and lower proportions of the other classes than did the 95% kernel-density contour for both herds (Table 14).

The results of previous studies often were contradictory. Kelleyhouse (2001) found that TCH females selected areas of low snow cover and Carroll et al. (2005) reported that TCH caribou calved farther north in years of early snow melt. Wolfe found that the CAH did not consistently select any snow-cover classes (Wolfe 2000). Griffith et al. (2002) and Eastland et al. (1989) found that calving caribou of the PCH used areas with 25–75% snow cover more than was expected based on availability. The presence of patchy snow in calving areas is associated with the emergence of highly nutritious new growth of forage species (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).

VEGETATIVE BIOMASS

For each season, values of the four NDVI variables (NDVI_calving, NDVI_621, NDVI_rate and NDVI_peak) at caribou group locations were compared with their availability in the 2005 NPRA survey area (Table 15). NDVI_calving at caribou locations did not differ from availability except during the oestrid-fly season, when caribou were in locations with lower NDVI_calving. The values of NDVI_calving are affected heavily by the presence of snow in the study area. We found no evidence for selection or avoidance of areas with high NDVI_calving except during oestrid fly season. During oestrid-fly season, many caribou groups

Table 15. Estimated vegetative biomass (mean NDVI values) at locations used by caribou groups in the NPRA survey area in 2005, compared with availability using a bootstrap analysis.

Season	*n*	NDVI_calving	NDVI_621	NDVI_rate	NDVI_peak
Winter	98	0.0538	0.3470	0.0179	0.5372^{+}
Calving	98	0.0665	0.3866^{++}	0.0197^{++}	0.5550^{++}
Postcalving	112	0.0558	0.3593^{++}	0.0186^{++}	0.5457^{++}
Mosquito	32	0.0395	0.2618^{--}	0.0135^{--}	0.4925^{--}
Oestrid Fly	25	0.0281^{--}	0.2340^{--}	0.0124^{--}	0.4484^{--}
Late Summer	29	0.0471	0.3021^{-}	0.0155	0.5155
Fall Migration	46	0.0581	0.3629^{+}	0.0187	0.5341
Total Use	440	0.0546	0.3450^{++}	0.0178^{++}	0.5333^{++}
Available		0.0580	0.3342	0.0168	0.5250

$^{+}$ 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).

were found near the coast where snow cover was high in spring and NDVI_calving was lower (Figure H).

NDVI_621, NDVI_rate, and NDVI_peak values all were correlated, so results were similar for all three variables (Table 15). Caribou used areas with greater values of NDVI_621 during calving, postcalving, and fall migration but used areas with lower values during the mosquito, oestrid fly, and late summer seasons. Areas with greater values of NDVI_rate were used during calving and postcalving but areas with lower NDVI_rate were used in the mosquito and oestrid-fly seasons. NDVI_peak values at caribou locations were greater during winter, calving, and postcalving, whereas areas with lower values of NDVI_peak were used during the mosquito and oestrid fly seasons. Overall, caribou used areas with NDVI values that exceeded availability during calving and postcalving, seasons when caribou presumably selected areas with high forage availability and probably quality. When mosquitoes and oestrid flies were present, caribou used areas with lower plant biomass as they moved to the coastline, river bars, and barren areas to avoid insect harassment.

We analyzed biomass indicators 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) found 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 (NDVI_rate) than was available in the entire calving grounds. In addition, the area of concentrated calving contained higher NDVI_calving and NDVI_621 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 TCH 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 differences in spring phenology may account for these differences among herds. The calving grounds of the CAH and TCH 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 (*Eriophorum vaginatum*) flowers are no longer available.

In the eastern portion of the ASDP study area (Meltwater project area), use of areas of high NDVI_rate by caribou varied according to the timing of snow melt (Lawhead et al. 2004). In years when snow melt occurred early, NDVI_calving was high and NDVI_rate was low throughout the region. In years when snow cover lingered through calving, NDVI_rate and NDVI_calving were inversely correlated. NDVI increases rapidly during snow melt 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 snow melt (and possibly flooding), the rate of increase in NDVI values decreases.

DISTANCE TO PROPOSED ROAD

In most seasons and years, the number of caribou groups in each distance-to-road zone did not differ significantly from those expected based on a uniform distribution (Table 16). For all years combined, significantly more groups occurred 4–6 km north of the road and fewer groups occurred 2–4 km south of the road than expected during the oestrid-fly and late summer seasons, however. These results were consistent with greater use of areas near Fish and Judy creeks during those seasons, as was found in the geographic-zone and habitat-use analyses above.

Caribou density did not differ significantly by distance zone (Greenhouse Geisser *P*-value = 0.138; Figure 17) or with a zone-by-season

Table 16. Number of caribou groups in distance-to-road categories by year and season, with results of a chi-square goodness-of-fit test assuming a uniform distribution.

				Distance to Proposed ASDP Road						
Year	Season	No. of Surveys	Total Groups	4–6 km North	2–4 km North	0–2 km	2–4 km South	4–6 km South	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
Total	Winter	2	90	14	10	21	22	23	10.70	0.030
	Spring Migration	4	39	7	6	6^{-}	7	13	8.62	0.071
	Calving	5	87	16	9	30	13	19	2.74	0.602
	Postcalving	4	219	48	31	72	27	41	4.42	0.352
	Mosquito	4	9	3	0	3	0	3	5.37	0.252

Table 16. Continued.

				Distance to Proposed ASDP Road						
Year	Season	No. of Surveys	Total Groups	4–6 km North	2–4 km North	0–2 km	2–4 km South	4–6 km south	Chi-square	*P*-value
	Oestrid Fly	5	57	24^{++}	14	7^{--}	3^{--}	9	31.11	<0.001
	Late Summer	8	127	37^{+}	28	35	9^{--}	18	18.94	0.001
	Fall Migration	8	238	45	33	87	32	41	2.87	0.580
	Total	41	866	194^{+}	131	261	113	167	14.36	0.006
Area surveyed, 2002–2004 (km²)				34.5	29.5	61.9	31.4	35.1		
Area surveyed, 2005 (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 ($P < 0.01$).

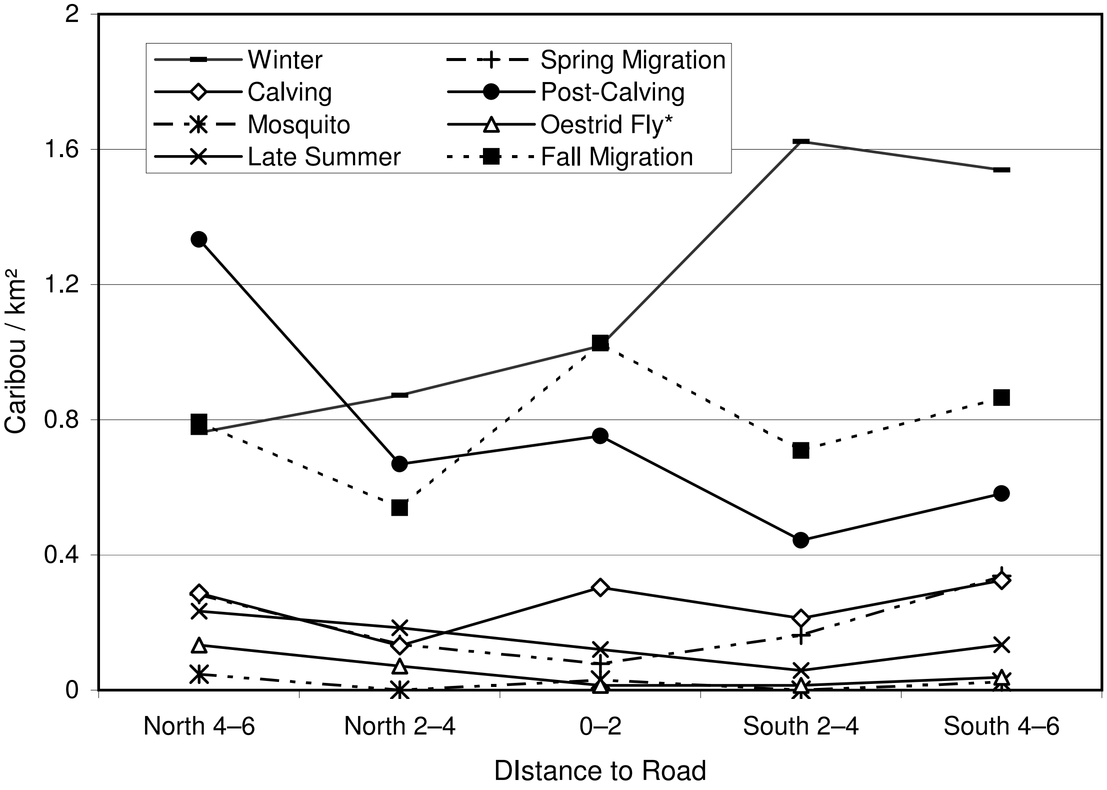

Figure 17. Density of caribou in 2-km-wide distance zones north and south of the proposed ASDP road, based on aerial surveys during 8 different seasons in 2001–2005.

interaction ($P = 0.175$), but significant differences in density were found among seasons ($P < 0.001$). Caribou density was significantly lower during the mosquito and oestrid fly seasons than during fall migration, postcalving, and winter (all $P < 0.045$; the 2005 oestrid-fly season was dropped from the analysis to avoid undue influence on test results). Because caribou aggregate into large groups when mosquitoes are present and move quickly when harassed by insects, densities during the mosquito and oestrid-fly seasons tend to fluctuate widely as groups move through an area. Densities in the road area generally were low during the mosquito and oestrid-fly seasons, but large groups did occur in the NPRA survey area occasionally, as implied by the VHF telemetry survey on 26 July and documented by the aerial survey on 2 August 2005. Caribou densities in other seasons were fairly consistent and did not show any pattern in relation to the road corridor.

CARIBOU DENSITY ANALYSIS

Caribou densities in aerial strip-transect grid-cells in the NPRA survey area were analyzed to evaluate the effects of geographic zone, snow cover, vegetative biomass, habitat type, and distance to the proposed ASDP road during the calving season in 2005 and among all seasons for the years 2002–2005. A number of variables used in the grid-cell analyses were correlated. Peak vegetative biomass (NDVI_peak) was highly correlated with NDVI_621 ($R = 0.834$). NDVI_peak increased with increasing proportions of tussock tundra ($R^2 = 0.653$; $P < 0.001$) but decreased with increasing proportions of water ($R^2 = 0.305$; $P < 0.001$), riverine habitat (dunes, sparsely vegetated, and barren classes combined; $R^2 = 0.257$; $P < 0.001$), and wet habitat (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; $R^2 = 0.412$; $P < 0.001$). The proportion of tussock tundra alone explained 65.3% of the variation in NDVI_peak values, and the combination of tussock tundra with the proportion of water explained 72.9% of the variation. Proximity to the coast also had an effect; coastal grid-cells had lower NDVI_peak values ($P < 0.001$) than did inland grid-cells.

The estimated proportion of snow melt on 5 June 2005 was highly correlated with NDVI_calving (measured from the same image but with different spectral bands; $R = 0.942$). NDVI_621 was not correlated with either NDVI_calving ($R = 0.251$) or snow melt at calving ($R = –0.216$). Because snow melt had not progressed much by 5 June, NDVI_rate was largely determined by NDVI_621, and the two variables were positively correlated ($R = 0.712$).

The best model for caribou density in the NPRA survey area during the 2005 calving season included four independent variables: presence of Fish or Judy creeks (all models), presence of proposed road (all models), transect number (west to east), and NDVI_peak values (Appendix T). This model had a 57.1% chance of being the best model, providing strong evidence that it was the best model of the candidate model set ($w_i = 0.571$; Appendix T). The model-weighted parameter estimates indicated that the presence of the proposed road corridor ($P = 0.592$), presence of Fish or Judy creeks ($P = 0.102$), and snow cover ($P = 0.879$) were not significantly related to caribou density. NDVI_peak ($P < 0.001$), NDVI_rate ($P < 0.001$), proportion of tussock tundra ($P = 0.004$), proportion of wet habitat ($P = 0.017$), and the transect number ($P = 0.005$) all were significantly related to caribou density during calving (Table 17). Caribou density during calving increased with NDVI_peak values, NDVI_rate values, and the proportion of tussock tundra, decreased with the proportion of wet habitat, and was lower in the eastern transects than in the western transects.

These results indicate that caribou densities during calving were highest in the western transects but, even after removing the linear trend from west to east, significant selection for high values of NDVI_peak was evident. NDVI_peak values increase with the proportion of tussock tundra and decline as the proportion of wet habitat increases, so NDVI_peak appears to be a good measure of caribou selection for tussock tundra and against wet habitats, confirming the selection for tussock tundra during calving 2005 in the analysis of habitat use reported above (Table 11).

The analysis of calving densities for all years combined (2002–2005; Appendix U) provided similar results, as the best model contained the presence of the creeks and the proposed road (both variables were included in all models), the transect number from west to east, and NDVI_peak values.

Table 17. Model-weighted parameter estimates for calving caribou density (*ln* [*calving density + 1/6*]) in the NPRA survey area, June 2005.

Variable	Coefficient	SE	*P*-value
Intercept	–4.513	1.109	<0.001
Presence of creeks	–0.063	0.126	0.616
Presence of proposed road	–0.285	0.178	0.108
NDVI_peak	6.281	1.469	<0.001
NDVI_rate	52.135	13.850	<0.001
Snow cover (%)	–0.001	0.004	0.879
Tussock tundra (%)	0.962	0.338	0.004
Wet habitat (%)	–0.858	0.360	0.017
Transect number (west to east)	–0.030	0.011	0.005

The model-weighted parameter estimates indicated that caribou density during calving increased with increasing NDVI_peak values ($P = 0.022$) and proportion of tussock tundra ($P = 0.031$). Caribou density decreased with increasing proportions of wet habitat ($P = 0.029$) and decreased from west to east ($P < 0.001$). The presence of the creeks, the presence of the proposed road, and distance to coast were not significant factors ($P > 0.05$; Table 18, Appendix V).

These results for the calving season are consistent with those from the Meltwater study area in the eastern portion of the ASDP study area (Lawhead et al. 2004), which indicated that NDVI during calving is strongly influenced by snow cover. As snow cover melts, it reveals standing dead biomass that has an NDVI value substantially greater than zero (Stow et al. 2004). After snow melt, the spatial pattern of NDVI is strongly influenced by habitat type and does not vary much from year to year. The absolute value of NDVI for a given pixel, after snow melt, appears to reflect the chronology of green-up and plant growth.

Caribou densities in our NPRA survey area during calving suggest a weak preference for areas with higher NDVI. Given the high correlation between NDVI and habitat type, it is difficult to determine if caribou are selecting areas with high vegetative biomass or specific habitat types, or are avoiding wet areas and barrens. Our vegetation sampling indicates that moist tussock tundra has higher biomass than does moist–sedge shrub tundra, but that difference disappears if evergreen shrubs are excluded. Tussock tundra does contain higher biomass of plant species and types that are preferred by caribou, such as *Eriophorum vaginatum*, forbs, and lichens.

For the combined sample across all years, the variables that were significantly related to caribou density in the NPRA survey area varied by season (Table 18, Appendix V). During winter, caribou density was lower near the proposed road and higher farther from the coast and in areas with more tussock tundra. During spring migration, caribou density decreased from west to east and was lower near Fish and Judy creeks. During postcalving, density was higher near the creeks and decreased going inland from the coast and going 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 higher near the creeks and was lower in areas with higher NDVI_peak levels and higher proportions of tussock tundra. In late summer, density was higher near the creeks and in the west and was lower in areas with higher NDVI_peak values. During fall migration, caribou density was higher near the creeks, inland from the coast, and in the western portion of the survey area.

Overall, strong seasonal patterns in caribou density were evident. Throughout most of the year a west-to-east gradient of decreasing density was evident, probably because our NPRA survey area is on the eastern edge of the TCH range. The riverine area of Fish and Judy creeks had lower

Table 18. Significance levels of model-weighted parameter estimates of independent variables used in analyses of caribou density within 123 grid cells in the NPRA survey area, 2002–2005.

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 (km)	++			--	--			++
Tussock tundra (%)	+		+			--		
Wet habitats (%)			-					
Transect number (west to east)		-	--	--	--		--	--

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

densities during the spring and higher densities during postcalving and oestrid-fly season through fall migration. This riverine area has abundant willows and forbs that may attract caribou following calving and also has barrens and dunes that 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 were higher in areas with high proportions of tussock tundra during winter and calving. 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 *Eriophorum vaginatum* and also provides drier conditions during snow melt and regional flooding, which also is reflected by lower caribou density in wet habitats during calving. Throughout most of the year there was little evidence that the area around the proposed road was used by caribou to a greater or lesser degree than adjacent areas, although caribou density was lower during winter in grid cells containing the road.

SUMMARY AND CONCLUSIONS

Analysis of the VHF, satellite, and GPS telemetry data sets clearly demonstrates that the Colville River delta and ASDP study area is at the interface of the annual ranges of the TCH and CAH. Although caribou from both herds occur on the delta occasionally, large movements across the delta are unusual for both herds. 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 this herd. TCH caribou use the NPRA survey area year-round, however, so our detailed analyses focused primarily on the NPRA survey area in the western half of the ASDP study area, in which the proposed road alignment is located. The number of TCH caribou in the study 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. Although some calving does occur in the western half of the ASDP study area, it is not an area of concentrated calving for the TCH (Kelleyhouse 2001, Prichard and Murphy 2004, Carroll et al. 2005, this study).

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. During calving, caribou use areas of higher biomass (indicated by NDVI), higher proportions of tussock tundra, and lower proportions of wet habitats. Calving tends to occur in areas of patchy snow cover during most years, although there does not appear to be strong selection for specific snow-cover classes.

The riverine habitats along Fish and Judy creeks are selected by caribou in some seasons. The sand bars and dunes along the creeks create a dust-shadow effect of earlier snow melt in spring than on the surrounding area. Riverine habitats provide both foraging opportunities during postcalving and barrens for relief from oestrid-fly harassment from mid-July through late summer.

Because the NPRA survey area is on the eastern edge of the TCH 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 road alignment is located, tends to have lower caribou densities than do other sections of the survey area. Within 6 km of the proposed road, there was little evidence for selection or avoidance of the area around the proposed road corridor.

Radio-collared TCH caribou moved across the proposed ASDP road alignment in NPRA, primarily during fall migration, but the road alignment is in an area of low-density use. This first year of study provided useful baseline data on caribou density and movements in the study area. The data reported here will be valuable for evaluating and mitigating the potential impacts of ASDP development on caribou distribution, as well as focusing efforts in future years of the research program.

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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 one 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.

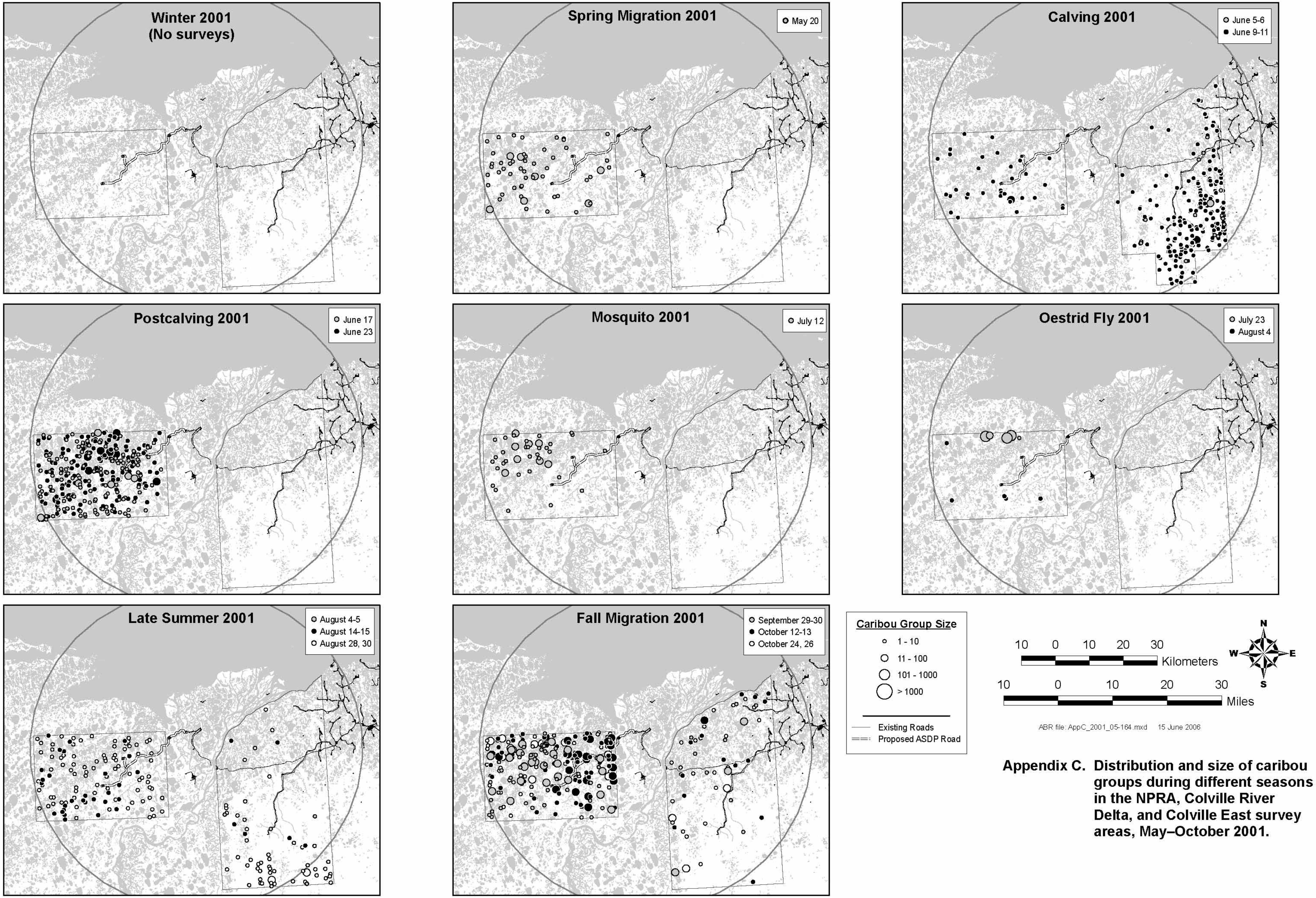
Appendix A. (Continued).

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; April 1–May 31) and sum of thawing degree-days (TDD; ° C above freezing; May 1–August 15) at the Kuparuk airstrip, 1983–2005.

	Snow Depth (cm)			Sum of TDD (º C)						
Year	April 1	May 15	May 31	May 1–15	May 16–31	June 1–15	June 16–30	July 1–15	July 16–31	August 1–15
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
Mean	22	11	3	0.7	10.6	37.9	98.6	124.9	140.0	128.0

[a] Value for June 1



Appendix C. Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2001.

Appendix D. Number and density of caribou in the NPRA and Colville East survey areas during aerial strip-transect surveys, May–October 2001.

Survey Area Date	Large Caribou [a]	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 [b]	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

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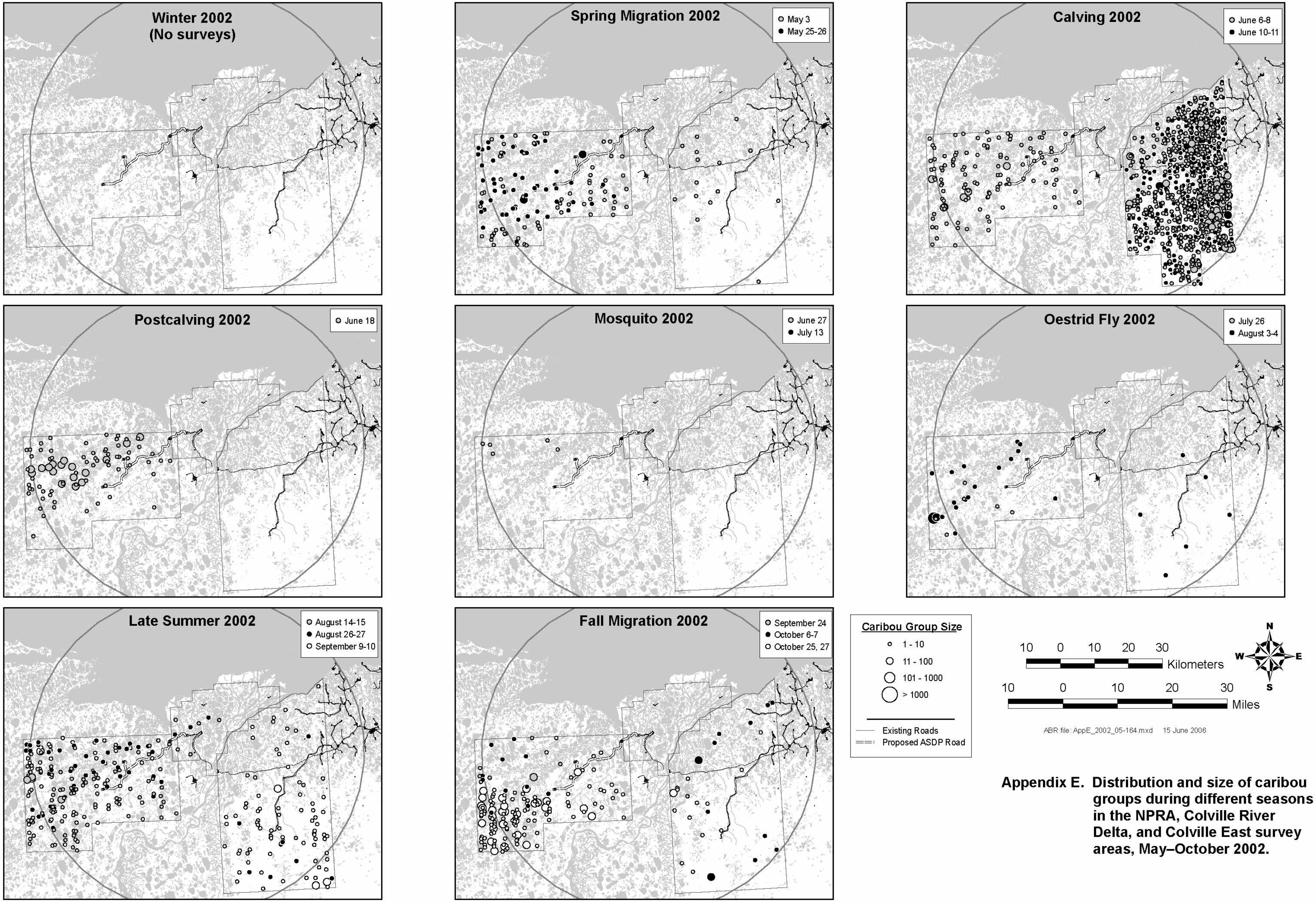
[a] Adults + yearlings.
[b] nr = Not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[d] Standard Error of Total Caribou calculated as described by Gasaway et al. (1986), using transects as sample units
[e] Density = Estimated Total / survey area.
[f] Survey coverage was 50% (453–494 km² in NPRA and 850 km² in Colville East were surveyed).
[g] Total area equals 988 km².
[h] Total area equals 948 km².
[i] Total area equals 906 km².
[j] Part of transects not flown due to fog.

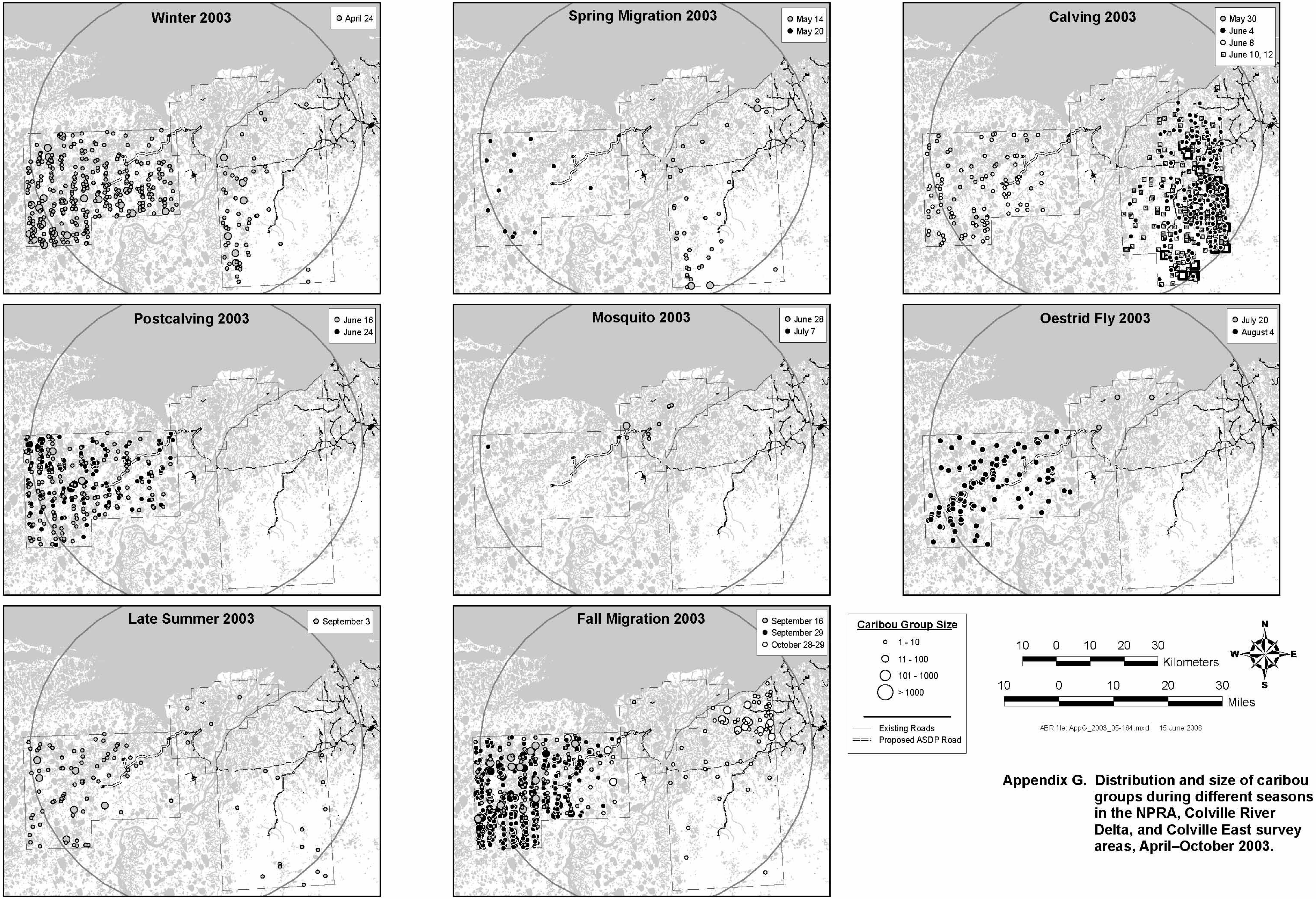


Appendix E. Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2002.

Appendix F. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas during aerial strip-transect surveys, May–October 2002.

Survey Area Date	Large Caribou [a, b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km^2) [e]	Mean Group Size
NPRA (1310 km^2) [f]							
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 km^2) [f]							
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 km^2) [f]							
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 [g]	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] nr = Not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[d] Standard Error of Total Caribou calculated as described by Gasaway et al. (1986), using transects as sample units
[e] Density = Estimated Total / survey area.
[f] Survey coverage was 50% (654 km^2 in NPRA, 247 km^2 on the Colville R. Delta, and 850 km^2 in Colville East were surveyed).
[g] Part of area not flown due to fog.



Appendix G. Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2003.

Appendix H. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas during aerial strip-transect surveys, April–October 2003.

Survey Area 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.

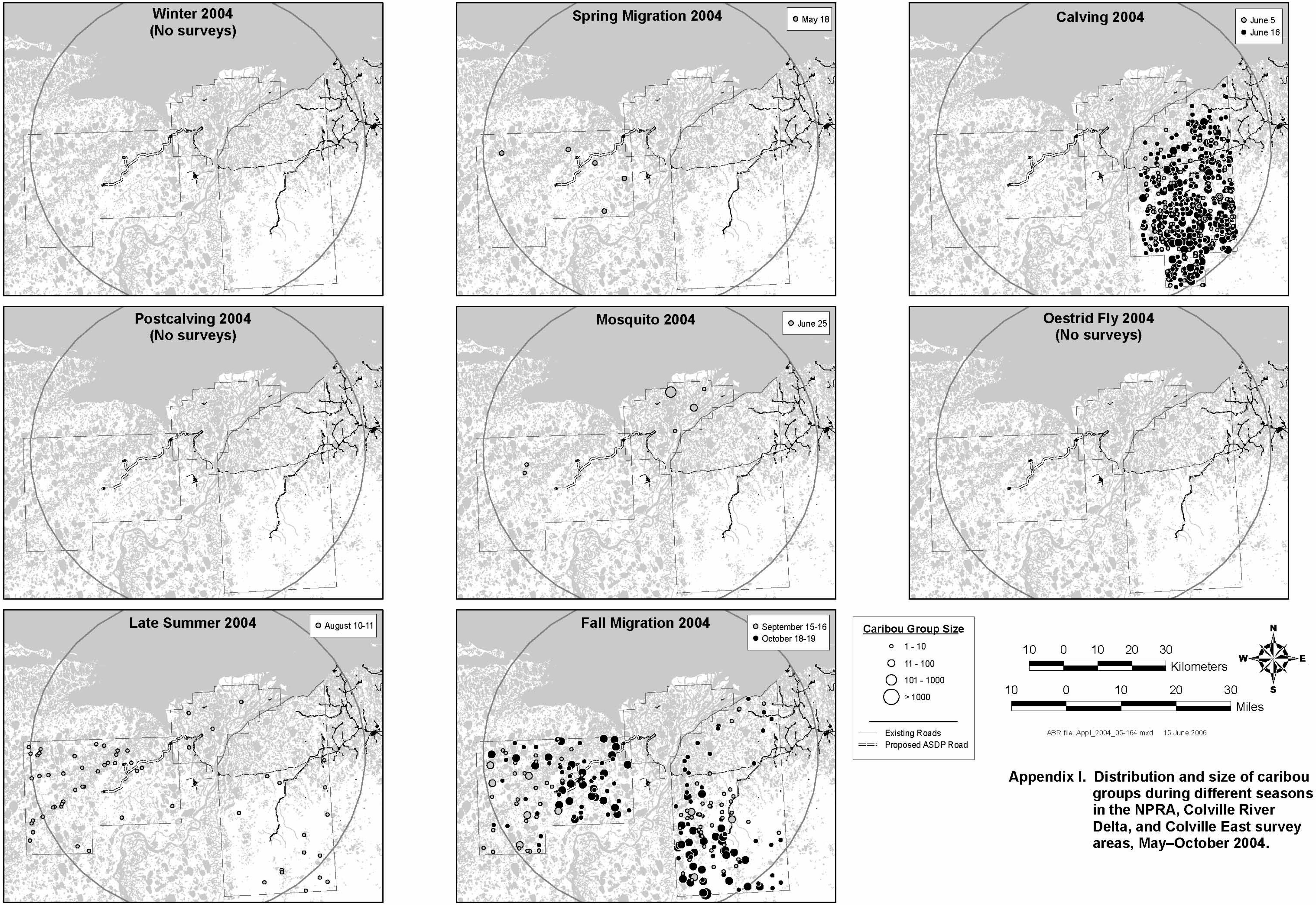
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.

[d] Standard Error of Total Caribou calculated as described by Gasaway et al. (1986), using transects as sample units.

[e] Density = Estimated Total / survey area.

[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] Sightability correction factor of 1.88 applied due to patchy snow cover (Lawhead et al. 1994).



Appendix I. Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2004.

Appendix J. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas during aerial strip-transect surveys, May–October 2004.

Survey Area 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] Standard Error of Total Caribou calculated as described by Gasaway et al. (1986), using transects as sample units.

[e] Density = Estimated Total / survey area.

[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 K. Estimated numbers and densities of caribou in the Colville East and Colville River Delta survey areas observed during spring calving surveys, June 1993 and 1995–2005 (Lawhead and Prichard 2006).

Survey Area	Date	Total Area (km^2)	Estimated Total Caribou [a]	Total Density (per km^2)	Estimated Total Calves [a]	Calf Density (per km^2)	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
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	636	0	0	0	0	High; SCF not used
	12 & 20 June 1997	636	0	0	0	0	Patchy; SCF used

[a] Incorporates Sightability Correction Factor (SCF) of 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.

[f] Unable to survey 2 westernmost transects on 16 June 2004.

Appendix L. General location and number of adults and young of muskoxen and moose observed in the NPRA survey area, April–October 2005.

Species	Date	Total Number	Number of Adults	Number of Young	Specific Location
Muskox	April 23	9	9	0	Near the Kalikpik River
	June 11	15	9	6	Near the Kalikpik River
	June 13	15	9	6	Near the Kalikpik River
	July 30	8	5	3	Near the Kalikpik River
	August 3	16	13	3	Near the Kalikpik River
	August 17	16	10	6	Near the Kalikpik River
	August 31	2	2	0	Near the Kalikpik River
	August 31	18	14	4	Near the Kalikpik River
	October 21	16	12	4	Fish Creek Delta
Moose	April 23	1	1	0	Near Fish Creek

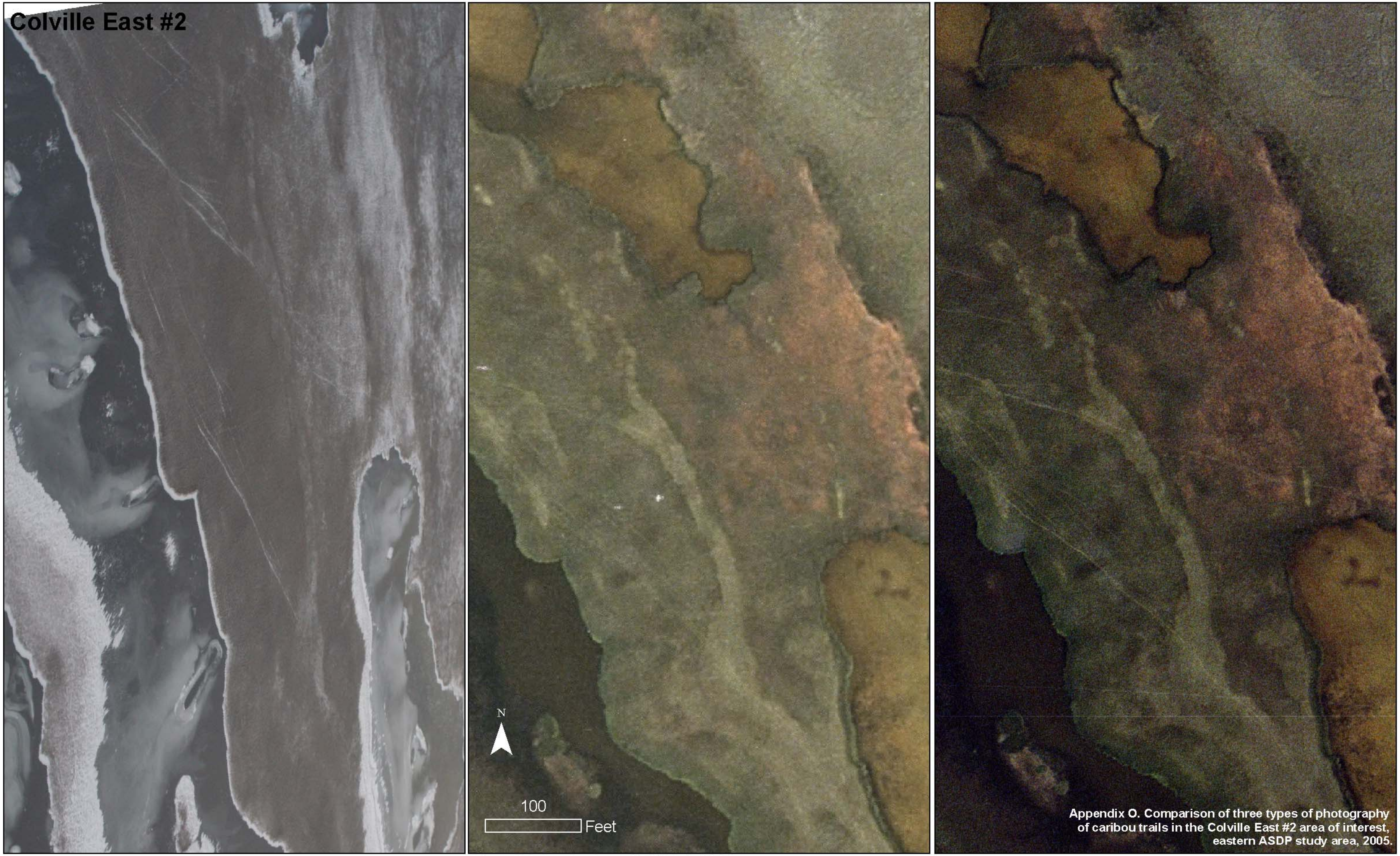
Appendix M. Descriptive statistics for snow cover, vegetative biomass (NDVI), and DU habitat type (BLM and Ducks Unlimited 2002), within different geographic sections of the 2002–2004 and 2005 survey areas in NPRA.

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
	NDVI	Calving	0.0773	0.0177	0.0801	0.0994	0.0529	0.0578
		621	0.3244	0.3186	0.3092	0.3678	0.3806	0.3749
		Rate	0.0152	0.0181	0.0141	0.0166	0.0200	0.0194
		Peak	0.5052	0.5222	0.5174	0.5454	0.5494	0.5585
	Snow Cover	Mean %	50.1	73.9	38.2	37.5	57.5	54.7
	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	Area	km²	93.2	206.6	160.7	232.2	130.9	36.4
	NDVI	Calving	0.0117	0.0128	0.0791	0.0994	0.0529	0.0578
		621	0.2509	0.3126	0.3059	0.3678	0.3806	0.3749
		Rate	0.0142	0.0180	0.0140	0.0166	0.0200	0.0194
		Peak	0.4552	0.5155	0.5165	0.5454	0.5494	0.5585
	Snow Cover	Mean %	81.9	76.4	38.8	37.5	57.5	54.7
	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

Colville East #1

Appendix N. Comparison of three types of photography of caribou trails in the Colville East #1 area of interest, eastern ASDP study area, 2005.

ABR file: Trail_Photos_Colville_East_1_05-164 20 Feb 2006



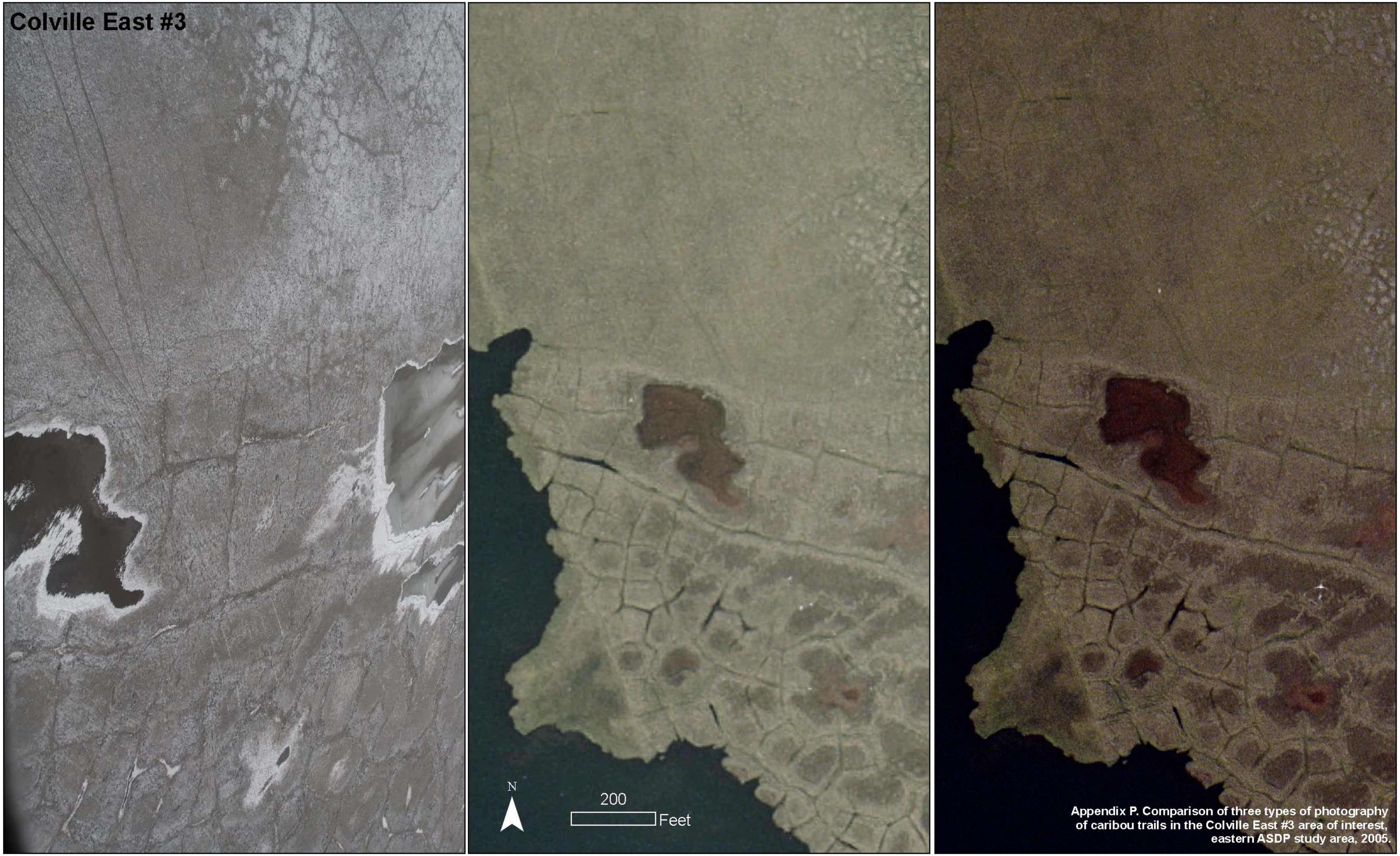
Appendix O. Comparison of three types of photography of caribou trails in the Colville East #2 area of interest, eastern ASDP study area, 2005.

8 Megapixel Oblique digital photo, 4 October 2005
P10040885.JPG

1-foot digital orthophoto, 25-26 July 2004
1208se.tif
Rendered at 100 dpi

Frame 8-15, 1" : 1500', 26 July 2004
8 micron scan (~0.5 ft res.)
Rendered at 200 dpi

ABR file: Trail_Photos_Colville_East_2_05-164 7 March 2006



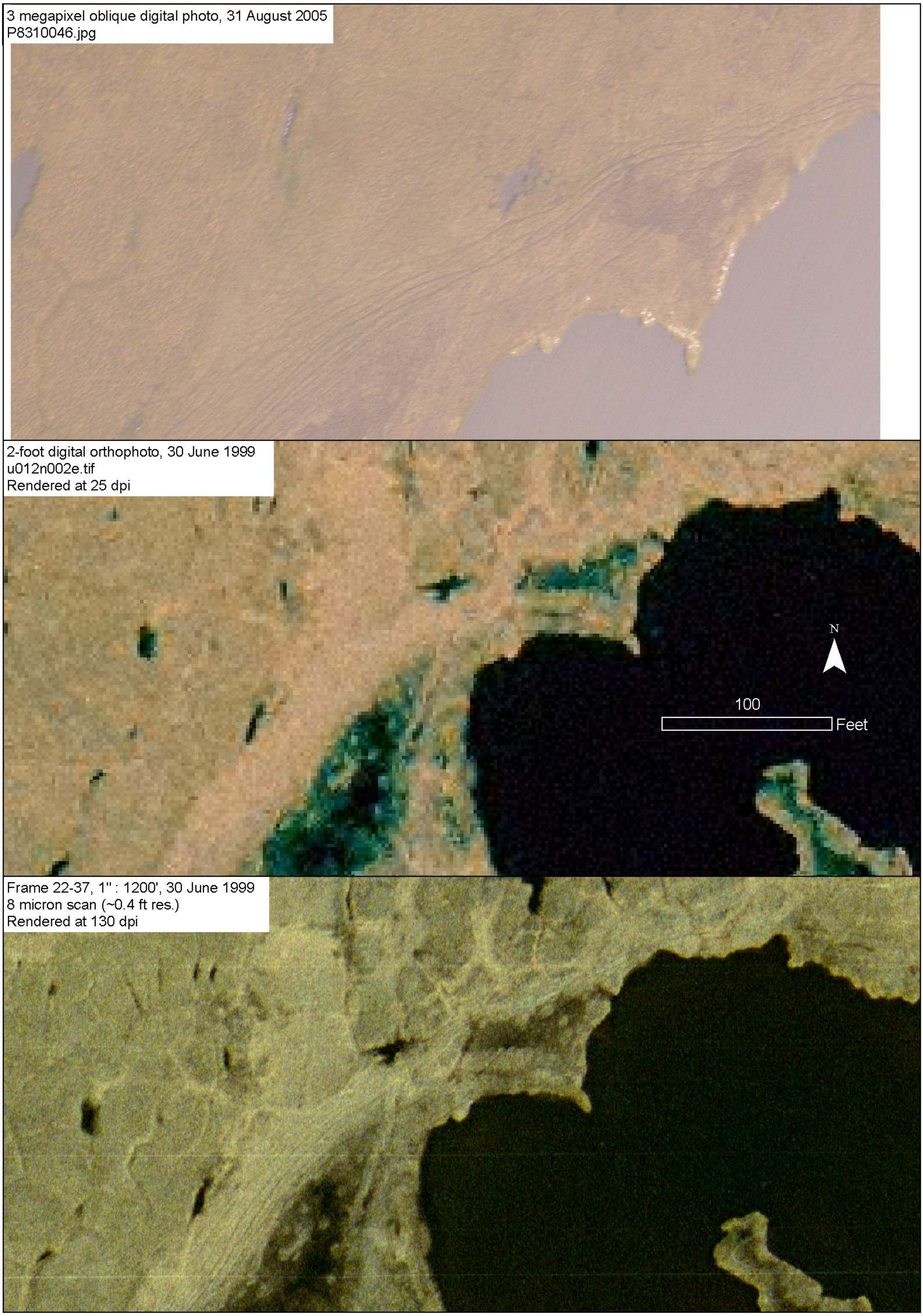
Appendix P. Comparison of three types of photography of caribou trails in the Colville East #3 area of interest, eastern ASDP study area, 2005.

8 Megapixel Oblique digital photo, 4 October 2005
P10040774.JPG

1-foot digital orthophoto, 25-26 July 2004
1008ne.tif
Rendered at 100 dpi

Frame 13-18, 1" : 1500', 26 July 2004
8 micron scan (~0.5 ft res.)
Rendered at 200 dpi

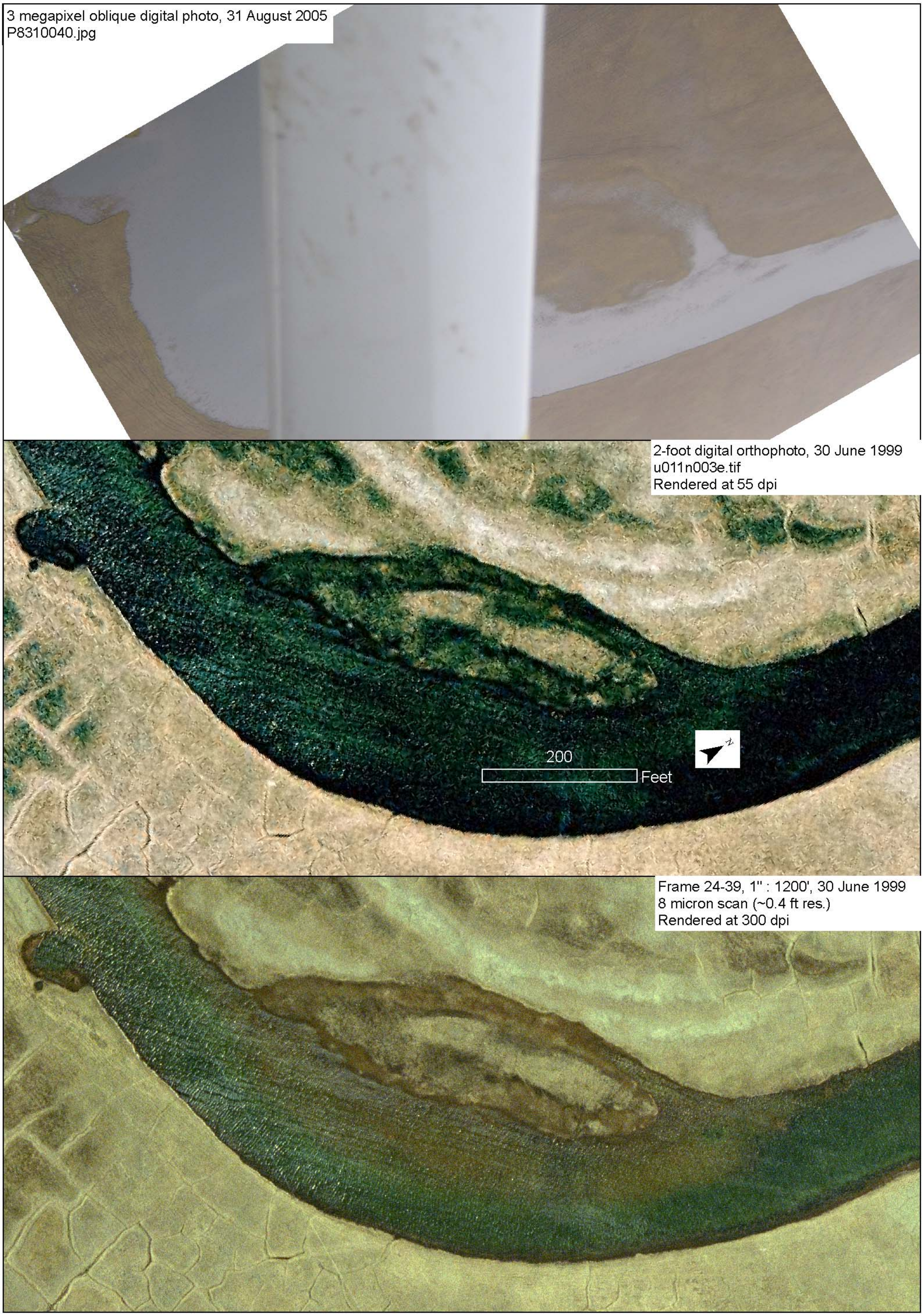
ABR file: Trail_Photos_Colville_East_3_05-164 7 March 2006



Fish Creek #1

Appendix Q. Comparison of three types of photography of caribou trails in the Fish Creek #1 area of interest, western ASDP study area, 2005.

ABR file: Trail_Photos_Fish_Creek_1_05-164 7 March 2006



Fish Creek #2

Appendix R. Comparison of three types of photography of caribou trails in the Fish Creek #2 area of interest, western ASDP study area, 2005.

ABR file: Trail_Photos_Fish_Creek_2_05-164 7 March 2006

NPRA

Appendix S. Comparison of three types of photography of caribou trails in the NPRA area of interest, western ASDP study area, 2005.

ABR file: Trail_Photos_NPRA_05-164 7 March 2006

Appendix T. Model selection results for ANCOVA tests of caribou density during calving 2005 in the NPRA survey area in 163 grid cells. The best model (bold type) contained the variables indicating presence or absence of Fish or Judy creeks (Creek), presence or absence of proposed road (Road), transect number west to east (W to E), and NDVI peak value (NDVI_peak).

Model [a]	RSS [b]	*n* [c]	K [d]	AICc [e]	ΔAICc [f]	w_i [g]
Creek, Road, NDVI_peak	39.64	163	5	–220.07	7.26	0.015
Creek, Road, NDVI_rate	40.46	163	5	–216.76	10.57	0.003
Creek, Road, Snow	45.27	163	5	–198.42	28.91	<0.001
Creek, Road, Tussock	44.19	163	5	–202.37	24.96	<0.001
Creek, Road, Wet Habitat	44.55	163	5	–201.04	26.29	<0.001
Creek, Road, W to E	42.57	163	5	–208.45	18.88	<0.001
Creek, Road, Snow, NDVI_peak	38.81	163	6	–221.39	5.94	0.029
Creek, Road, Snow, NDVI_rate	39.09	163	6	–220.22	7.11	0.016
Creek, Road, Snow, Tussock	44.19	163	6	–200.22	27.11	<0.001
Creek, Road, Snow, Wet Habitat	44.55	163	6	–198.90	28.43	<0.001
Creek, Road, W to E, Snow	41.10	163	6	–212.05	15.28	<0.001
Creek, Road, W to E, NDVI_peak	**37.42**	**163**	**6**	**–227.33**	**0.00**	**0.571**
Creek, Road, W to E, NDVI_rate	39.61	163	6	–218.05	9.29	0.006
Creek, Road, W to E, Tussock	39.91	163	6	–216.83	10.50	0.003
Creek, Road, W to E, Wet Habitat	40.44	163	6	–214.65	12.68	0.001
Creek, Road, W to E, Snow,	37.32	163	7	–225.55	1.78	0.235
Creek, Road, W to E, Snow,	37.64	163	7	–224.19	3.14	0.119
Creek, Road, W to E, Snow, Tussock	39.75	163	7	–215.30	12.03	0.001
Creek, Road, W to E, Snow, Wet	40.19	163	7	–213.50	13.83	0.001

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[a] Snow = % snow cover; Tussock = proportion of tussock tundra; Wet Habitat = proportion (4 types combined 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 AICc 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 U. Model selection results for ANCOVA tests of caribou density in different seasons during 2002–2005 (123 grid cells) in the NPRA survey area. Bold type denotes the best model for each season.

		Model [a]														
Season	Value	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]	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123
	K[c]	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7
Winter	RSS[d]	100.6	85.9	107.4	108.3	98.9	83.7	83.7	84.3	84.9	90.6	88.3	90.1	82.4	**80.7**	81.7
	AICc[e]	–14.3	–33.6	–6.2	–5.2	–16.3	–34.6	–34.6	–33.7	–32.8	–24.9	–28.0	–25.6	–34.3	**–36.9**	–35.4
	w_i[f]	0.00	0.07	0.00	0.00	0.00	0.11	0.11	0.07	0.05	0.00	0.00	0.00	0.09	**0.35**	0.16
Spring	RSS	45.4	44.7	45.8	45.8	**43.4**	44.6	44.7	44.6	43.4	43.2	43.1	43.4	43.2	43.1	43.4
	AICc	–112.2	–113.9	–110.9	–111.0	**–117.5**	–112.0	–111.7	–112.2	–115.5	–115.9	–116.2	–115.3	–113.7	–113.9	–113.2
	w_i	0.02	0.05	0.01	0.01	**0.28**	0.02	0.02	0.02	0.10	0.13	0.15	0.10	0.04	0.05	0.03
Calving	RSS	47.2	42.2	51.0	51.0	36.9	41.5	42.2	42.2	35.7	**34.9**	35.1	35.1	34.6	34.7	34.6
	AICc	–107.3	–121.0	–97.7	–97.9	–137.6	–121.0	–118.9	–118.8	–139.5	**–142.2**	–141.5	–141.7	–141.2	–140.8	–141.0
	w_i	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.06	**0.22**	0.16	0.17	0.14	0.11	0.12
Postcalving	RSS	65.2	65.1	64.1	64.2	50.7	65.0	63.9	63.9	**46.4**	50.2	50.7	50.7	46.4	45.9	46.0
	AICc	–67.6	–67.8	-69.6	–69.6	–98.4	–65.7	–67.9	–67.8	**–107.3**	–97.6	–96.2	–96.2	–105.1	–106.4	–106.1
	w_i	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	**0.39**	0.00	0.00	0.00	0.13	0.25	0.22
Mosquito	RSS	5.4	5.4	5.5	5.6	5.5	5.3	5.3	5.4	**4.9**	5.3	5.5	5.5	4.9	4.9	4.9
	AICc	–373.3	–374.1	–371.4	–369.8	–371.7	–373.3	–373.1	–372.0	**–382.9**	–374.5	–370.6	–369.6	–381.6	–380.7	–382.0
	w_i	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	**0.39**	0.01	0.00	0.00	0.20	0.13	0.25
Oestrid Fly	RSS	**115.8**	124.1	117.9	124.3	124.7	115.8	117.3	123.3	124.0	115.7	115.5	123.2	115.6	115.5	123.0
	AICc	**3.1**	11.6	5.3	11.8	12.2	5.3	6.9	13.0	13.8	5.2	5.0	12.9	7.3	7.2	14.9
	w_i	**0.35**	0.01	0.12	0.00	0.00	0.12	0.05	0.00	0.00	0.12	0.13	0.00	0.04	0.05	0.00
Late	RSS	26.4	26.8	25.7	26.3	21.6	25.6	25.3	25.9	20.7	**20.2**	21.3	21.5	19.9	20.6	20.7
Summer	AICc	–178.9	–176.7	–182.0	–179.4	–203.3	–180.2	–181.7	–178.8	–206.7	**–209.7**	–203.0	–201.8	–209.4	–204.9	–204.5
	w_i	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.10	**0.42**	0.02	0.01	0.37	0.04	0.03
Fall	RSS	64.1	69.5	62.7	62.8	48.9	50.8	48.2	48.4	46.0	48.9	48.8	48.8	45.5	**45.1**	45.1
Migration	AICc	–69.7	–59.7	–72.4	–72.1	–103.1	–96.1	–102.5	–102.0	–108.1	–100.9	–101.1	–101.1	–107.5	**–108.5**	–108.4
	w_i	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.23	0.01	0.01	0.01	0.16	**0.28**	0.27

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[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] Sample size.

[c] Number of estimable parameters in the approximating model.

[d] Residual Sum of Squares.

[e] Akaike's Information Criterion corrected for small sample size.

[f] Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix V. Model-weighted parameter estimates, standard error, and *P*-value of variables included in the grid-cell analyses of caribou densities in the NPRA survey area, 2002–2005.

Season	Variable	Mean	SE	*P*-value
Winter	Intercept	–2.146	1.277	0.093
	Presence of Creek	–0.174	0.225	0.439
	Includes Proposed Road	–1.000	0.308	0.001
	NDVI_peak	6.030	3.286	0.066
	Distance to Coast (km)	0.040	0.011	<0.001
	Tussock Tundra (%)	1.425	0.65	0.028
	Wet Habitat (%)	–1.181	0.634	0.063
	Transect Number (West to East)	–0.048	0.027	0.072
Spring Migration	Intercept	–1.854	0.585	0.002
	Presence of Creek	–0.515	0.151	0.001
	Includes Proposed Road	–0.262	0.221	0.236
	NDVI_peak	1.703	2.258	0.451
	Distance to Coast (km)	0.005	0.008	0.566
	Tussock Tundra (%)	0.344	0.441	0.436
	Wet Habitat (%)	–0.012	0.438	0.979
	Transect Number (West to East)	–0.036	0.015	0.018
Calving	Intercept	–0.756	1.322	0.567
	Presence of Creek	0.276	0.151	0.067
	Includes Proposed Road	0.168	0.199	0.399
	NDVI_peak	4.727	2.067	0.022
	Distance to Coast (km)	0.009	0.007	0.210
	Tussock Tundra (%)	0.859	0.399	0.031
	Wet Habitat (%)	–0.857	0.391	0.029
	Transect Number (West to East)	–0.086	0.016	<0.001
Postcalving	Intercept	1.790	0.503	<0.001
	Presence of Creek	0.873	0.157	<0.001
	Includes Proposed Road	–0.061	0.23	0.790
	NDVI_peak	0.072	2.483	0.977
	Distance to Coast (km)	–0.026	0.008	0.001
	Tussock Tundra (%)	0.529	0.467	0.258
	Wet Habitat (%)	–0.453	0.458	0.323
	Transect Number (West to East)	–0.125	0.019	<0.001
Mosquito	Intercept	–1.408	0.228	<0.001
	Presence of Creek	–0.040	0.051	0.437
	Includes Proposed Road	–0.099	0.075	0.188
	NDVI_peak	–0.801	0.812	0.324
	Distance to Coast (km)	–0.009	0.003	0.001
	Tussock Tundra (%)	0.032	0.156	0.839
	Wet Habitat (%)	–0.167	0.15	0.264
	Transect Number (West to East)	–0.020	0.006	0.001
Oestrid Fly	Intercept	2.922	2.913	0.316
	Presence of Creek	0.586	0.252	0.02
	Includes Proposed Road	–0.302	0.356	0.396
	NDVI_peak	–11.093	3.611	0.002
	Distance to Coast (km)	0.000	0.012	1.000
	Tussock Tundra (%)	–1.987	0.705	0.005
	Wet Habitat (%)	0.718	0.699	0.304
	Transect Number (West to East)	0.024	0.029	0.412
Late Summer	Intercept	1.568	1.043	0.133
	Presence of Creek	0.407	0.11	<0.001
	Includes Proposed Road	0.123	0.152	0.42
	NDVI_peak	–3.972	1.601	0.013
	Distance to Coast (km)	–0.009	0.006	0.122
	Tussock Tundra (%)	–0.247	0.323	0.444
	Wet Habitat (%)	0.049	0.317	0.876
	Transect Number (West to East)	–0.064	0.012	<0.001
Fall Migration	Intercept	0.653	0.722	0.366
	Presence of Creek	0.334	0.162	0.04
	Includes Proposed Road	0.146	0.229	0.526
	NDVI_peak	–2.881	2.471	0.244
	Distance to Coast (km)	0.023	0.008	0.004
	Tussock Tundra (%)	–0.747	0.477	0.117
	Wet Habitat (%)	0.714	0.465	0.125
	Transect Number (West to East)	–0.061	0.020	0.002