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Habitat Use and Movement Patterns of Grizzly Bears in Denali National Park Relative to the Denali Park Road

Natural Resource Technical Report NPS/XXXX/NRTR—2011/XXX

ON THE COVER
A grizzly bear crosses the Denali Park Road.
NPS photo by Bridget Borg.

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Natural Resource Technical Report NPS/XXXX/NRTR—2011/XXX

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Abstract

The relationships between grizzly bear movements and vehicular traffic were investigated in Denali Park and Preserve in 2006. Hourly locations were obtained from May through September from global positioning system (GPS) collars fitted to 20 bears. To our knowledge, this was the first telemetry study to investigate relationships between brown bears and vehicular traffic along a single unpaved road with relatively low traffic volumes in a national park setting.

Based on telemetry locations, bears were classified as either inactive or moving during the early season or late season. Inactive bout length averaged 2 hrs for both sexes and differed by sex and season. There was no clear timing of inactive bouts during the early season, but during late season bears were more likely to be active during daylight hours. Seventy-one percent of inactive bouts (both sexes and seasons) occurred in the mountain land type. Thirteen percent of all locations were within 1 km of the Denali Park Road. During both seasons, bears were, on average, closest to the road during mid-afternoon hours. Conversely, bears were furthest from the road between midnight and 0900. The fact that our study bears were most active during periods of high traffic suggest that bears were not measurably altering their temporal patterns of activity to avoid human disturbance from the road. Periods of inactivity were more confined to hours of darkness. We documented 444 crossing of the Denali Park Road by 11 grizzly bears. The number of crossings varied among individuals from 2 to 136. Bears crossed the Denali Park Road during all hours of the day, but crossings were more frequent during the period when most vehicles were on the road.

Several behavioral effects of the road were inferred from telemetry data. First, bears moved faster when crossing the road than immediately before or after the crossing. Second, while in the inactive state, distance to the road increased with bout length and we concluded that bears were uncomfortable resting for prolonged periods near the road. These findings corroborate previous observational studies suggesting that some individual bears react negatively to vehicular traffic at relatively fine spatial and temporal scales, while others do not.

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Introduction

National Park Service (NPS) managers are faced with the challenge of protecting park resources while assuring that they are available for the enjoyment of people (Everhart 1972). This challenge is particularly great in Denali National Park and Preserve (Denali), which has become one of the most heavily visited subarctic national parks in the world (Singer and Beattie 1986). Mount McKinley National Park was created in 1916 for the primary purpose of conserving wildlife and the opportunities to view wildlife. The Alaska National Interest Lands Conservation Act (ANILCA, PL96-487, 2 Dec 1980) expanded the park in 1980 to form Denali National Park and Preserve. ANILCA states that Denali is intended to be a large sanctuary where fish and wildlife roam freely, developing their social structures and evolving over long periods of time as nearly as possible without human interference. In Denali, park managers must protect wildlife, tundra ecosystems, and mountain scenery while maintaining opportunities for visitors to view and enjoy these resources (Singer and Beattie 1986).

Most of Denali's 350,000 annual visitors access the park via the Denali Park Road, where they expect to view wildlife, especially grizzly bears (Ursus arctos) (Manning and Hallo 2010). The Denali Park Road is a 147 km unpaved road accessing the northern portion of the park. It was completed in 1936 with no restrictions on its use. Until 1972, visitation to the park was low because travelers arrived at Denali either by train or by an arduous overland route on the Denali Highway (Singer and Beattie 1986). The completion of State Highway 3 between Fairbanks and Anchorage in 1971 provided the first direct paved-road access to the Denali Park Road, and park visitation increased 100% in direct response (Yost and Wright 2001). Anticipating the increase in visitation, park management implemented a mandatory public transportation system in 1972 to minimize disturbances to wildlife and scenery, to minimize road hazards, and to maximize wildlife and scenery viewing with the least resource impact (U.S. Department of Interior 1982).

In 1986, a General Management Plan (GMP) for Denali National Park and Preserve was developed which limited motor vehicle use to 10,512 vehicle round trips on the unpaved portion of the Denali Park Road during the summer season, which runs annually from late May through mid-September (U.S. Department of Interior 1986). Due to steadily increasing tourism, shuttle and tour buses have been operating at or near established limits during peak visitation periods for several years. Park managers face pressure to permit more traffic along the park road. In order to meet the congressional mandate for managing wildlife resources in Denali, managers must continue to be attentive to increases in traffic and changes in human activities along the Denali Park Road (Burson et al. 2000) and must understand how animals respond to increasing levels of human activities. Managers will need scientific data to defend traffic limits or to change them appropriately. However, the existing data on movements and behavior of wildlife along the park road do not provide park managers with adequate information to make informed decisions about managing traffic levels on the road.

Historic studies have not provided park management with the information necessary to address issues concerning the effects of the Denali Park Road on grizzly bears, and the ambiguous results of these studies suggest that park management take a different approach to determining the effects of the park road on wildlife. Studies in other areas clearly demonstrate displacement of wildlife along roads. Displacement of individual animals can result in population-level effects and may decrease the opportunities for visitors to view grizzly bears in Denali. Therefore, it is important and timely to determine whether grizzly bears are displaced along the Denali Park Road before park managers make decisions regarding traffic levels and increased human activity along the road. Further, there is only limited information on grizzly bear populations along the park road. Results of contemporary monitoring of grizzly bears suggest that cub mortality in Denali appears to be as high as any other grizzly bear population that has been studied in North America (Owen and Mace 2007).

This project will quantify the distribution, movement patterns, habitat use, and daily activity patterns of grizzly within the park road corridor. Spatio-temporal relationships among these ecological parameters and traffic flow along the road corridor will be investigated. This investigation of grizzly bear movements in relation to the park road is one component of a larger park road capacity study examining the potential impacts of vehicle traffic on wildlife behavior and visitor experience in Denali. Results of the study will be used to determine best management practices for the Denali Park Road in order to maintain a high quality experience for the greatest number of visitors while preserving park resources and values and maintaining the integrity of park road infrastructure.

Study Area

Denali National Park and Preserve is located in interior Alaska between Anchorage and Fairbanks. Most visitors to Denali access the park's 2.4 million ha via the 147 km park road that connects the Alaska Highway 3 to the private in-holding town of Kantishna. The park road is a narrow winding road, unpaved for all but the first 24 km. It follows a 1 to 10 km wide valley between the Alaska Range and foothills to the north commonly referred to as the Outer Range. Along its path, the road crosses five braided rivers and numerous streams.

The climate in Denali is subarctic, with short cool summers averaging 0º to 24º C (Western Regional Climate Center 2007). Annual precipitation is 38 cm with over half occurring during the summer months. Snow cover is generally present from October through early May. Daylight varies during the year from more than 20 hours of daylight in June to 4 hours in December.

Habitat along the park road includes forests dominated by spruce (Picea spp.), shrub tundra dominated by birch (Betula spp.) and willow (Salix spp.), and high-elevation tundra characterized by Dryas (spp.) or herbaceous Carex and Eriophorum spp. Elevation of the road varies from 484 m to 1230 m.

Traffic levels are unrestricted on the first 24 km of the park road, after which traffic levels are subject to the GMP-authorized limit of 10,512 vehicle trips seasonally (from late May to mid September). Restricted traffic levels are highest between kilometers 24 and 48, and then decrease with increasing road distance.

From 1996 to 2006, there was an average of 9,903 vehicle trips on the park road seasonally. Shuttle and tour bus traffic accounted for an average of 5,600 of those trips. A maximum of 80 shuttle and tour bus trips is allowed on the park road on any one day, a limit which is frequently reached during peak visitation in July and August. NPS administrative traffic averages 1,554 vehicles per year and is limited to 1,754 vehicles per year. Vehicles from Kantishna area businesses and private inholders also contribute to traffic levels on the park road.

Methods

Capture and Telemetry

Grizzly bears were captured in May 2006 using standard aerial darting techniques. We targeted bears for capture that were dispersed along the entire length of, and as close as possible to, the park road. Grizzly bears were immobilized by aerial darting, using Telazol (tiletamine HCL and zolazepam HCL) as the anesthetizing drug. Blood, tissue, and hair samples were obtained for health and genetic analyses. Each individual bear was discreetly tagged with a uniquely numbered subcutaneous microchip that provides permanent identification (AVID Microchip I.D. Systems, Folsom, LA). We fitted bears with Global Positioning System (GPS) collars (Telonics, Inc., Mesa, AZ), with onboard data storage and automatic collar drop-off capabilities. We programmed GPS collars to obtain 1 fix per hour and to release from the bear on 20 September 2006. Collars remained in the field for 1 day before being retrieved. We estimated positional error of each collar from location data collected after the collars had dropped. We used the "spider distance analysis" within the Animal Movement Extension (Hooge and Eichenlaub 2000) for ArcView Geographic Information System (GIS) Version 3.2 (1998) to quantify this error by calculating the distance each location was from the geographic center of the location constellation. We did not differentially correct GPS data.

Categorization of Activity States

In keeping with terminology of Turchin (1998), we defined a "path" as the complete record of a followed individual from beginning to end of sampling (generally 15 May through 20 September 2006). A "move" was defined as the displacement between stopping (inactive) points. Each consecutive one hour displacement was termed a "step".

Each telemetry location was categorized as one of two behavioral states based on the length of consecutive hourly steps. We considered the bear to be inactive during the period when steps were <10 m apart. This cutoff was based on the upper 95% confidence interval of our GPS positional error analyses. Therefore, when steps were <10 m, it was not possible to differentiate an inactive bout from telemetry error with certainty. We considered the bear as moving when consecutive locations were >10 m apart. Consecutive steps of each bear were recorded in telemetry databases as either stationary or moving. The spreadsheet could be visualized as a repetitive pattern of a stationary bout followed by a move, followed again by a stationary bout. The first geographic coordinate in a consecutive string of stationary locations was used as the coordinate (point) for that stationary bout. The hourly steps >10 m were collapsed into a single move (Alternate Movement Path Extension, Jenness 2004) that varied in duration. Each stationary point and movement path was given a unique numerical identifier, a beginning and ending time, and a date. We used point analyses in GIS for stationary bouts and poly-line analyses for movement bouts.

For each move, we calculated a measure of sinuosity (S) as follows:

$$S = Lt / Lsf$$

where Lt was the length of the move, and Lsf was the distance between the start and finish locations. We used Hawth's Tools (Beyer 2004) in ArcGIS Version 9.2 (2006) for these movement analyses.

Variables

Time Periods

We delineated 2 seasons, an early season (≤15 July) and a late season (≥16 July). We designated seasonality based on the availability of berries as a food source for bears in Denali. Berries are generally ripening in the park by mid July (Murie 1985). Hours of potential darkness and daylight were generalized for these 2 seasons. During the early season, hours 0100-0300 were potentially dark. In the late season, hours 2300-0500 were considered dark.

Three diel periods were established to coincide with daily traffic volume levels: low traffic (hourly time steps beginning 0000-0500 hr and 2200-2300 hr), moderate traffic (0600-0700 hr and 1800-2100 hr), and high traffic (0800-1700 hr). Hourly traffic volumes represent the average number of vehicles for a road segment and not for the entire length of the road.

Road Characteristics and Traffic Volume

We used park road information created by the NPS from U.S. Geological Survey (USGS) 1:63,360 transportation files in GIS applications. Segments that correspond to mile markers along the road were created in ArcGIS using dynamic segmentation.

We partitioned the Denali Park Road into 6 segments based on the placement of traffic counters. The NPS installed inductive wire loops for use with traffic counters under the park road in 2000 as part of another study. In 2006, we deployed 5 Sprite (Diamond Traffic Products, Oakridge, CA) traffic counters along the park road at the wire loop locations beginning at mile 15 (Figure 1). Traffic counters provided hourly summaries of traffic passing over the loops for all segments of the road except the entrance segment.

Digital Elevation Model (DEM)

We used a subset of the National Elevation Dataset (NED) for Alaska with 60 m resolution to calculate elevation, slope and aspect for habitat models using ArcView GIS. We categorized aspect into 4 classes: northerly (0^{o}- 45 ^{o} and 315 ^{o}- 360 ^{o}), easterly (46 ^{o}- 135^{o}), southerly (136 ^{o}- 225 ^{o}), and westerly (226 ^{o}- 269^{o}). These aspect classes represented 46%, 22%, 20%, and 13% of the study area respectively. Percent slope was categorized into 10 equal intervals.

Land Type

We constructed a generalized 3-class land type map (mountain habitats, tundra habitats, and river channels) in GIS using a variety of existing map sources for Denali. We built the mountain land cover type using the surface area extension for ArcView GIS (Jenness 2002) which provided a measure of topographic roughness and convolutedness from the DEM. We used the surface area values of 3600-54199 to depict the mountain land type. This range in values roughly corresponded to a slope of >25%. The mountain land type was composed of both non-vegetated and vegetated areas (U.S. Department of Agriculture, Natural Resources Conservation Service 2004). Areas of persistent snow, ice, and glaciers were classified in the mountain land type regardless of their surface area measure. We considered non-river channel areas of Denali that had surface area values <3600 to be tundra habitats (generally <25% slope). The tundra land type was composed of non-vegetated and vegetated areas. Bare ground, shrub lands, herbaceous areas, and forested zones were included in the tundra land type. We derived the river channel land type from soils maps for Denali using the soil classes 7FP2 (alpine flood plains) and G (non-vegetated alluvium) to depict these channels (U.S. Department of Agriculture, Natural Resources Conservation Service 2004). The mountain land type constituted 55% of the composite home range of bears. Tundra and river channel land types comprised 40% and 5% of the composite range respectively. The Denali Park Road traversed these 3 land types. Fifty percent of the road occurred in the tundra land type, while 46% and 4% of the road length were in the mountain and river channel types. To compare bear use of these land types to availability, we calculated "selection ratios" (White and Garrott 1990) as percent used / percent available.

Statistical Analyses

Univariate

Univariate tests were conducted using analysis of variance (ANOVA) techniques, where the alpha level was set at 0.05. For several categorical habitat variables, we determined whether use differed from availability using chi-square and bonferonni confidence intervals (Byers et al. 1984). Habitat was classified as being used less than available, as available, or greater than available. Availability was determined at the study area level of selection.

Results

Capture, Telemetry, and GPS Error

Twenty grizzly bears were captured in May 2006, 14 of which were female bears (Table 1, see Appendix A for Tables and Figures). Seventeen of these bears (4 male, 13 female) were considered focal bears for study, although of these, 1 collar fell off a male bear prematurely and was retrieved in early August. For the 3 bears that did not produce useful data, 1 collar placed on a female was not retrieved from the field, and. 2 male bears were not used in analyses as they were dependent young of a collared adult female and their movements were auto correlated with those of their mother. We obtained 48,325 2-dimensional and 3-dimensional locations from the 17 focal bears (Figure 13). On average 2,848 locations were obtained per bear. Mean positional GPS error was 9.0 m (95% CI = 8.0 - 10.0 m). Fix success for the GPS collars averaged 94.0% (n = 19, SD = 3.49).

Characteristics of Inactive States

All study bears alternated between periods of inactivity and directed movements. Timing and duration of inactive periods varied by sex, season, and hour of the day. Most inactive bouts were within a single one-hour time step for both sexes and season (Figure 2). Shorter inactive bouts were more common in the early season than later. Inactive bouts of >5 hr were relatively rare for both sexes. The longest inactive bout was 14 hr for a male and 13 hr for a female.

Mean inactive bout length differed significantly between sexes ($F = 45.38_{1,3167}$, df = 1, $p = 0.00$), and seasons ($F = 46.95_{,3167}$, df = 1, $p = 0.00$) and for the interaction among sexes and season ($F = 13.63_{,3167}$, df = 1, $p = 0.00$, Table 2).

We observed no clear timing of inactive bouts during the 24 hr cycle for bears during the early season (Figure 3). Conversely, in the late season, both sexes were more inactive during periods of darkness, particularly from 0 to 500 hrs (Figure 3). Therefore, during the late season, both sexes were more likely to be active during daylight hours.

When seasons and sexes were combined, bear use of land types varied significantly from random ($X^2 = 630.66$, $p < 0.05$). Seventy-one percent of inactive bouts occurred in the mountain land type; use of this type was significantly above availability (Table 3). Females used the tundra land type significantly less than its availability would predict, during both seasons. The most pronounced shift in land type use between seasons occurred with males. During the late season, males shifted away from the mountain land type and increased use of both tundra and river channel types (Table 3).

While the mean elevation of inactive bouts for both males and females across both seasons was 1114 m, use of elevation differed significantly between sexes ($F = 45.38_{1,3167}$, df = 1, $p = 0.00$), and seasons ($F = 46.95_{,3167}$, df = 1, $p = 0.00$) and for the interaction among sexes and season ($F = 13.63_{,3167}$, df = 1, $p = 0.00$, Table 4). The slope of inactive bouts averaged 18% and varied widely (SD = 16%). We found a significant difference in slope between sexes ($F = 36.27_{,3167}$, df = 1, $p = 0.00$), seasons ($F = 76.01_{,3167}$, df = 1, $p = 0.00$) and for the interaction among sex and season ($F = 17.02_{1,3167}$, df = 1, $p = 0.00$). Bears selected specific aspects while inactive. For both sexes and seasons, westerly aspects were selected for while northerly aspects were selected against (X^2 = 1038.38, p = 0.00). Easterly and southern facing slopes tended to be used as available (Table 5). This same pattern of selection occurred for each sex and season individually.

Characteristics of Movements

Steps

Mean movement distances for females were shorter during the early season ($\bar{x}$ = 299 m/hr) than during the late season ($\bar{x}$ = 466 m/hr). Conversely, male bears moved longer distances during the early season ($\bar{x}$ = 589 m/hr) than during the late season ($\bar{x}$ = 504 m/hr, Table 6). Hourly speed differed significantly between sexes ($F = 645.27_{1,40211}$, df = 1, p = 0.00), and seasons ($F = 40.79_{,40211}$, df = 1, p = 0.00) and for the interaction among sexes and season ($F = 379.09_{,40221}$, df = 1, p = 0.00).

For females, early season movement speeds were slowest in the early morning and increased during the remainder of the day (Figure 4). During late season, female bears exhibited a pronounced increase in movement speeds during diurnal hours relative to early morning hours of darkness. During late season, males also tended to move at greater speeds during daylight hours.

Moves

For female bears, distance moved between inactive periods averaged 2,852 m and 6,958 m during the early and late seasons respectively (Table 7). Although less dramatic, movement lengths for male bears also increased from early to late season. Movement length differed significantly between sexes ($F = 12.90_{1,3592}$, df = 1, p = 0.00), and seasons ($F = 80.05_{,3592}$, df = 1, p = 0.00), and for the interaction among sexes and season ($F = 331.72_{,3592}$, df = 1, p = 0.00). Both sexes generally increased the duration of movements from approximately 10 hr in mid-May to 20 hr moves by the end of August (Julian week 30), after which the hours moving between inactive periods declined (Figure 5).

Grizzly bears in Denali spent most of their time moving through the mountain land type relative to tundra and river channel types. When seasons and sexes were combined, bears spent 61% of their time, on average, moving through mountains (Table 8), which was 6% above availability. Twenty-eight percent and 10% of moves by bears were through the tundra and river channel land types, respectively. When season and sex were pooled, habitat selection was significantly different from random (X^2 = 3649.31, p = 0.00). Females spent relatively little time moving through the tundra habitat relative to males. Female bears avoided moving though tundra habitats during both seasons, preferring to move through both mountain and river channel land types (Table 8). Early season male movements were more evenly distributed among land types.

Active bears preferred using northerly aspects, while more southerly aspects were avoided (X^2 = 390.64, p = 0.00, Table 9). More southern aspects were avoided by both males and females during each season.

Bears tended to make more sinuous moves during the early season than they did later in the summer. During the late season, mean sinuosity values for both sexes were twice as great in the mountain land type as in the tundra and river channels (Figure 6).

Paths
On average, female and male grizzly bears were radio monitored for 133 and 122 days from early-May through mid-September. During this period, total path length averaged 1,165 km for males and 975 km for females (Table 10). The shortest movement path during the period was 736 km while the longest was 1381 km.

Spatial and Temporal Relationship to the Denali Park Road

Road Proximity and Crossings
Individual grizzly bears lived at varying distances from the Denali Park Road. Eleven grizzly bears were classified as having home ranges that straddled the park road. The home ranges of 3 individuals abutted (telemetry locations <500m) but did not cross the road, and 2 bears were classified as living far (locations >3km) from the road.

Approximately 13% of all locations were within 1 km of the road (Figure 7). Eighty percent of all locations were <13 km from the road. When analyses were confined to <3 km of the road, it was apparent that the pooled sample of bears was closer to the road during the early season than during the late season (Figure 8). During both seasons, bears were, on average, closest to the road during mid-afternoon hours and furthest from the road between midnight and 0900.

We documented 444 crossings of the Denali Park Road by 11 grizzly bears whose ranges straddled the road. The number of crossings varied among these individuals from 2 to 136 (Table 11). One bear, female F607, accounted for 31% of the crossings. Ninety-two percent of the crossings were by female bears (Table 12). Fifty-four percent of the road crossings occurred during the early season, while 46% occurred during the late season. We documented only 1 road crossing by males during the late season (Table 12). When individuals were pooled, bears crossed the road least in September (n = 47) and most frequently in June (n = 128, Table 11).

Bears crossed the Denali Park Road during all hours of the day (Table 13). Road crossings were most frequent between 0900-2300 hr. During both seasons, early morning road crossings (0000-0600 hr) were relatively rare (Figures 9 and 10). When categorized by traffic diel periods, 19% of crossings occurred during periods of low hourly traffic, 32% when traffic volume was moderate, and 50% during high traffic periods (Table 14).

Movements Relative to Road
We compared movement rates (m/hr) of bears while they traveled within the 3 km road corridor to movements outside of the corridor. Movement rates varied significantly for most seasons and land types (Table 15). For most land types and season combinations, female grizzly bears moved at significantly slower rates while within the road corridor. For females, the only instance when rates did not differ was for the tundra land type during the early season. For males, the converse was true: males moved at faster speeds while traveling within the road corridor for most seasons and land types (Table 15). In general within the road corridor, males moved the fastest through the river channel land type and slowest through the mountains.

The speeds at which bears moved during the hour prior to crossing the road, the hour during the crossing, and the hour subsequent to crossing were evaluated. We determined that bears moved at significantly faster speeds ($\bar{x}$ = 985 m/hr) when crossing the road than immediately prior to crossing ($\bar{x}$ = 700 m/hr), and subsequent to crossing ($\bar{x}$ = 611 m/hr, $F = 29.49_{1,1132}$, df = 1, p = 0.00, Table 16, Fig. 9).

We documented the initial and final land types used by grizzly bears when crossing the Denali Park Road. In most cases (51.8%), paths that crossed the road were both initiated and ended within the mountain land type, although other land types may have been traversed along the paths (Table 17). Also common were crossings that initiated in the tundra and ended in the mountain land type, or vice versa. Overall, 84% of all crossings involved bears either starting or ending in the mountain land type. Crossings that started or ended in river channel or tundra habitats constituted 17% and 35% of movement paths.

Bears crossed the Denali Park Road through each of the 3 land types (Table 17). During the early season, bears differentially selected land types when crossing the road ($X^2 = 11.46$, $p = 0.00$). An equal number of crossings occurred in tundra and mountain land type (46% each). During the early season, 8.5% of all crossing were along river channels, and use of this type was significantly greater than availability. No selection for a specific land type for road crossings was seen during the late season ($X^2 = 0.71$, $p = 0.70$, Table 18).

Inactive Bouts Relative to the Road

Thirty-two and 27% of the inactive bouts were within 2 km of the road during the early and late seasons, respectively. Mean distance from the road differed seasonally for females ($F = 10.16_{1,635}$, df = 1, $p = 0.00$), but not for males ($F = 0.62_{1,57}$, df = 1, $p = 0.65$, Table 19). While in the inactive state, distance from the road was greater for longer bout lengths (Figure 12). For example, the closest to the road that a bear was inactive for 1 hr was 7 m beginning at 0800 hrs. The closest 4 hr inactive bout was 57 m and occurred between the hours of 9 pm and 1 am.

The majority of inactive bouts within the road corridor for both sexes and seasons were within the mountain land type, while the tundra type was avoided ($X^2 = 192.33$, $p = 0.00$, Table 20). During both seasons, females selected for mountain and river channel habitats, and against tundra habitats. During the early season, female inactive location use was 28% below availability for tundra habitats. Male inactive locations were generally distributed in mountain and tundra habitats in proportion to their availability.

Discussion

This study was a part of an integrated study of road capacity for the Denali Park Road as outlined by Phillips et al. (2007, 2010). The purpose of the broader study was to investigate baseline conditions in Denali by evaluating key wildlife movements relative to the road, evaluating visitor experience through social science research, and developing models of traffic patterns. The ultimate goal is to determine whether traffic on the Denali Park Road is under capacity, at capacity, or over capacity, and to investigate methods of mitigating traffic impacts. The current study was designed to ascertain whether the park road impacted the habitat use, behavior, and movements of grizzly bears.

Roads have been shown to have significant impacts on wildlife populations in other areas (Forman and Alexander 1998, Trombulak and Frissell 2000). Roads can cause direct loss of habitat, alter the quality of habitat, and impede animal movements (Forman and Alexander 1998). Animals may respond negatively to human activity along roads and other developed areas by reducing their use of certain areas or habitats (Morrison et al. 1995, Bjornlie and Garrott 2001, Papouchis et al. 2001), by altering their movement patterns within an area (Kuck et al. 1985, Cherry and Kratville 1999) or by leaving the area (Tyler 1991, Cote 1996). Roads may also present barriers to movement to many species of wildlife or may act as partial barriers, blocking some but not all movements across them (Forman and Alexander 1998).

Grizzly bears need to travel widely to meet life requisites including foraging and raising young (Weaver et al. 1996, Servheen et al. 1998). Reduced landscape connectivity and impeded movements due to roads may result in higher mortality, lower reproduction, and ultimately smaller populations and lower population viability in grizzly bears (Chruszcz et al. 2003). Although grizzly bears are not territorial, normal finer-scale home range dynamics of adjacent bears can be disrupted when individual bears avoid specific areas (Mace and Waller 1997). Proximal avoidance of roads by grizzly bears has been demonstrated in Denali (Tracy 1977) and elsewhere (Harding and Nagy 1980, Archibald et al. 1987, Mace et al. 1996, Mattson et al. 1987, McLellan and Shackleton 1988, Kasworm and Manley 1990). Grizzly bears may tend to stay further away from roads with higher vehicular traffic (Mace et al. 1996, Wielgus et al. 2002, Chruszcz et al. 2003). Avoidance of high quality habitat near roads or development may decrease the overall health of bears and, under certain circumstances, cause an increase in mortality (Gibeau et al. 2002). Also, subdominant grizzly bear sex or age classes may place themselves within these fracture zones in order to avoid more dominant bears (Mattson et al. 1987, Waller and Servheen 2005).

Our studies of grizzly bears and road traffic in Denali constitute a stark contrast to most bear-road impact studies to date. To our knowledge, this is the first telemetry study to investigate relationships between grizzly bears and vehicular traffic along a single, unpaved road with relatively low traffic volumes in a national park setting. Conversely, previous studies were conducted in non-park environments where bears were either hunted legally or illegally, or where other forms human-caused mortality were prevalent. In most of these cases, it may be assumed that bears were somewhat wary of human presence. In contrast, it is generally assumed that brown bears in Denali are habituated to, or have become tolerant of human presence over time. The high number of bear sightings from visitor buses show that bears have not been overtly displaced from the road corridor. Human-caused mortality levels are low in Denali, and the population appears stable with evidence of density-dependent population regulation (Owen and Mace 2007). To complicate comparisons further, most other studies were situated along paved highways with higher traffic speeds and volumes than Denali, and with established infrastructures of human development adjacent to the road corridor itself.

Animal behaviorists differentiate between habituation and tolerance in their characterization of animal's reactions to humans and other stimuli. Habituation is defined as "the waning of a response to a repeated, neutral stimuli" (Whittaker and Knight 1998). As defined by Nisbet (2000), tolerance is the intensity of disturbance that an individual accepts without responding in a defined way. For bears, Smith et al. (2005) suggested that habituation refers to a loss of avoidance and flight responses. Wilker and Barnes (1998) found that low or neutral response of bears to humans was the result of consistent and predictable patterns of human activity. Bear habituation to human activity results as bears adapt to the presence of humans in a non-threatening atmosphere (Smith et al. 2005). Smith et al. (2005) cautioned that it may be incorrect to assume that a seemingly tolerant bear is human-habituated; although they may behave similarly towards humans, the pathway leading to this observed tolerance differs. It is wrong, therefore, to assume that the tolerant behavior of bears towards humans is always a result of repeated innocuous interaction. Numerous published findings of such habituation exist at bear-viewing areas in Alaska, although some individuals habituated slowly while others did not habituate at all (Olson and Gilbert 1994). In this light, it is plausible for a seemingly habituated or tolerant population of bears to show some aversion to human presence, as is seen along the Denali roadway.

Previous observational studies of wildlife abundance and behavior along the Denali road support this concept of differential tolerance of individuals to vehicular traffic. Tracy (1977) and Singer and Beattie (1986) concluded that some individual bears within 400 m of the park road showed behavioral responses to road-related disturbances including loud unexpected noises and people exiting from buses at wildlife sightings. Extreme behavioral responses (e.g. running, excitation, alarm) occurred in approximately 10% of the observed cases. Conversely, Burson et al. (2000) were unable to measure an adverse effect of traffic disturbance on caribou, Dall's sheep, grizzly bear, or moose behavior.

Wildlife may respond to human activity by changing the timing of their activities to minimize deleterious interactions. This may include altering periods of feeding activity when near humans (Schultz and Bailey 1978), or by reducing time spent feeding (Murphy and Curatolo 1987). Such behavioral changes in response to disturbance may result in energetic losses that could negatively affect bear physiology (MacArthur et al. 1979, Stemp 1983, Miller and Smith 1985, Belden et al. 1990). In some instances, bears may become less active during periods when human disturbance is high (Roth 1983, Clevenger et al. 1990). For example, at lower latitudes than Denali, in regions with distinct periods of daylight and darkness, bears may use either the security of vegetative cover or the security of darkness to avoid human contact (McLellan 1990).

We sampled the movements and activity patterns of 17 grizzly bears. Most (13) were female bears. Eleven of these bears had home ranges that straddled the road, 4 abutted the road, and 2 bear ranges were considered far from the road. Movements of these study bears spanned the length of the Denali Park Road (Figure 13). We believe that this was an adequate sample from which to ascertain whether the road was affecting bear behavior and movement patterns.

Radio-instrumented grizzly bears in this study were most active during the period of day when road traffic was most pronounced. This generally occurred between the hours of 600 and 1800 hrs for both early and late seasons. Diurnal activity was especially pronounced during the late season. Previous observational studies within the park reinforce these findings (Stemlock and Dean 1986, Murie 1985). This pattern of relatively high activity during the daylight hours is the norm for brown bears across their range (Hechtel 1985, Wenum 1998, MacHutchon 2001, Munro et al. 2006). The fact that our study bears were most active during periods of high traffic suggest that bears were not measurably altering their temporal patterns of activity to avoid human disturbance from the road. Periods of inactivity were more confined to hours of darkness. This contrasts the findings of Moe (2005) and Yri (2006) for brown bears in Scandinavia, where bears were most likely to exhibit resting behavior during periods when human activity was highest.

Grizzly bears in Denali exhibited periods of relative inactivity that varied from 1 to and 14 hrs in duration. For both seasons, inactive bouts (movements of <10 m per hour) were most likely to occur during hours of darkness. From the telemetry data, we were unable to ascertain the extent to which bears were actually sleeping during these inactive bouts. However, it is probable that bears did exhibit both short and long periods of sleep.

We found a relationship between the duration of inactivity and distance to the Denali road. Inactive bouts were of shortest duration nearest the road, and increased in duration as distance to the road increased. The longest bouts of inactivity at over 300 m from the road occurred during high traffic volume periods. These data suggest that bears were less comfortable being either relatively stationary or sleeping while near the road corridor.

Some differential use of 3 land types (tundra, mountain, river channel) was noted between genders and seasons. In general, female grizzly bears made greater use of mountain habitats than did male bears. Conversely, and especially in the late season, male bears moved much more extensively throughout the tundra and river channel land types. We did not detect any changes in bear use of the land types when adjacent to, or while crossing the road. When bears did cross the road, they most typically moved from the mountains on one side of the road, to mountains on the opposite side.

The number and timing of road crossings by bears may indicate whether given traffic volumes are sufficient to impede normal movement across road corridors. Theoretically, at low traffic volumes, bears may cross a road corridor unimpeded. As traffic volumes increase, bears may shift their movement patterns to favor periods of the day when traffic is low. However, there is a theoretical threshold in traffic volume and road corridor configuration beyond which bear crossings are not possible. At extremely high traffic volumes, and in areas where multiple traffic lanes exist, bears find it nearly impossible to cross. Such was the case along the Trans-Canada highway were traffic volumes exceeded 20,000/day (Gibeau 2000), and along a 4-lane highway in Slovenia at traffic volumes of 7,500/day (Kaczensky et al. 2003).

In Waller's (2005) study, approximately half of his 43 study bears crossed a 2-lane highway and railroad corridor at least once. Most crossings were at night when traffic levels were approximately 10 vehicles/hr. McKoy (2004) reported similar night crossings for black bears in Montana. Waller (2005) suggested a traffic volume threshold of approximately 100 vehicles/hr. Graves et al. (2006) also demonstrated a preponderance of nighttime crossings for grizzly bears along the Sterling Highway, Alaska.

We documented 444 road crossings by 11 grizzly bears during this four-month study. Bears crossed at all hours of the day, regardless of sex or season. Peak times of crossing occurred during the period when traffic levels were moderate to high. No selection for the mountain, tundra, or river channel land types was noted during road crossings.

Grizzly bears significantly increased their movement speed while crossing the Denali Park Road. Average movement speeds in the hour preceding a crossing ($\bar{x}$ = 700 m/hr), and following a crossing ($\bar{x}$ = 611 m/hr) were slower than speeds during the hour of crossing ($\bar{x}$ = 985 m/hr). The increase in movement speed while crossing suggests that bears were cognizant of human activity along the road, and used speed to minimize the duration of contact with humans or vehicles.

This study was not without limitations. It was not designed as a "treatment-control" study where comparable samples were collected near and far from the road. Although most bears were captured within 10 km of the road, several bears ventured outward as far as 38 km.

The movement patterns of bears in this study were sampled at hourly increments. Our results show that on average, bears moved at a rate of over 400 m/hr. As a result, we were unable to ascertain whether vehicular traffic on the Denali Park Road influenced bear movements at finer spatio-temporal scales. Using our techniques, we would be unable to document short-term and/or short-distance negative responses to road traffic. Further, it is probable that some road crossings, or instances of bears actually walking on the road bed, occurred between sampling intervals.

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Appendix A. Tables and Figures

Table 1. Characteristics and telemetry sample sizes of radio-instrumented grizzly bears in Denali National Park and Preserve, 2006. Characteristics include male (M) or female (F); adult (Ad) or subadult (Sub) and the total number of GPS locations received (*n*).

Bear ID	Gender	Age class	Dates followed	*n*	Nunber of young (last date young observed[a])
601	M	Ad	5/9 - 9/20	2927	
602	F	Ad	5/9 - 9/20	2755	1, 2 yr old (5/23/2006)
603	F	Ad	5/9 - 9/20	2830	0
604	F	Ad	5/9 - 9/20	2946	2, 1 yr olds (8/27/2006)
605	F	Ad	5/10 - 9/20	2986	1, 3 yr old (7/19/2006)
606 (Not focal)	M	Sub	5/10 - 9/20	2882	
607	F	Ad	5/10 - 9/20	2930	3, 1yr olds (8/27/2006)
609	F	Ad	5/11 - 9/20	2986	3, 2 yr olds (5/31/2006)
610	F	Ad	5/11 - 9/20	2931	2, 1yr olds (7/19/2006)
611	M	Ad	5/11 - 9/20	2910	
612	F	Ad	5/11 - 9/20	2930	1, 2 yr old (8/27/2006)
613	M	Ad	5/12 - 9/20	2849	
614 (No collar)	F	Ad	5/12 -	0	
615	M	Ad	5/13 - 8/09	1828	
616	F	Ad	5/13 - 9/20	2976	1, 3yr old (7/19/2006)

Table 1. Characteristics and telemetry sample sizes of radio-instrumented grizzly bears in Denali National Park and Preserve, 2006, continued.

Bear ID	Gender	Age class	Dates followed	*n*	No. young (last date young observed[a])
617 (Not focal)	M	Sub	5/13 - 9/20	2901	
618	F	Ad	5/13 - 9/20	2814	1, 2 yr old (8/27/2006)
619	F	Ad	5/13 - 9/20	2900	1, 1 yr old (8/27/2006)
620	F	Ad	5/13 - 9/20	2956	2, 3 yr olds (5/23/2006)
621	F	Ad	5/13 - 9/20	2891	2, 3 yr olds (9/19/2006)

[a] The latest aerial flight of the year when young were observed with mother. The last flight of the year was on 9/19/2006

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Table 2. Duration of grizzly bear inactive bouts by gender and season in Denali National Park, 2006.

Gender	Season	Mean hours inactive	*n*	SD	Min-max
Female	Early	1.8	1442	1.45	1-13
	Late	2.0	951	1.38	1-8
Male	Early	2.0	451	1.57	1-12
	Late	2.7	327	2.24	1-14

Table 3. Distribution of male and female grizzly bear inactive bouts per land type by season, Denali National Park, 2006.

Gender	Season	Percent of inactive bouts per land type (Selection Ratio)			Significance
		Mountain	Tundra	River channel	
Female	Early	83.0 (+28.0)[a+]	10.0 (-30.0)[-]	7.0 (+3.0)[+]	$X^2 = 524.75$ $p = 0.00$
	Late	73.0 (+18.0)[+]	20.0 (-20.0)[-]	7.0 (+3.0)[+]	$X^2 = 167.40$ $p = 0.00$
Male	Early	61.0 (+6.0)[+]	35.0 (-5.0)[0]	4.0 (-1.0)[0]	$X^2 = 6.04$ $p = 0.047$
	Late	28.0 (-27.0)[-]	51.0 (+11.0)[+]	21.0 (+16.0) [+]	$X^2 = 56.11$ $p = 0.00$
Both		71.0 (+16.0)[+]	21.0 (-19.0)[-]	8.0 (+3.0)[+]	$X^2 = 630.66$ $p = 0.00$

[a] : + use > expected; 0 use as expected; - use < expected

Table 4. Mean elevation and slope for grizzly bear inactive bouts in Denali National Park, 2006.

Gender	Season	*n*	Mean elevation (m) (SD)	Mean % slope (SD)
Female	Early	1442	1160 (165)	20.4 (17)
	Late	951	1131 (180)	17.3 (15)
Male	Early	451	1109 (330)	19.1 (18)
	Late	327	847 (132)	10.5 (11)
Both		3171	1114 (219)	18 (16)

Table 5. Distribution of grizzly bear inactive bouts by aspect class in Denali National Park, 2006. Bear locations in flat habitats (*n* =7) were omitted due to low sample sizes.

Gender	Season	Percent of inactive bouts per aspect class (Selection Ratio)				Significance
		Northerly	Easterly	Southerly	Westerly	
Female	Early	26(-20) [-a]	25 (+3) [o]	15 (-4) [-]	34 (+21) [+]	$X^2 = 620.98$ $p = 0.00$
	Late	33 (-13) [-]	23 (+1) [o]	14 (-5) [-]	30 (+17) [+]	$X^2 = 243.55$ $p = .00$
Male	Early	25 (-21) [-]	20 (-2) [o]	15 (-4) [-]	41 (+28) [+]	$X^2 = 307.27$ $p = 0.00$
	Late	36 (-10) [-]	18 (-4) [0]	20 (+1) [o]	26 (+13) [+]	$X^2 = 567.55$ $p = 0.00$
Both		29 (-17) [-]	23 (+1) [o]	15 (-4) [o]	33 (+20) [+]	$X^2 = 1038.38$ $p = 0.00$

[a] : + use > expected; 0 use as expected; - use < expected

Table 6. Speed of grizzly bears during one hour steps in Denali National Park, 2006.

Gender	Season	*n*	Average step speed (m/hr)	SD
Female	Early	15498	298.5	404.6
	Late	16604	465.7	478.8
Male	Early	4420	588.8	851.9
	Late	3703	504.1	591.3
Both		40225	418.4	529.1

Table 7. Length and duration of seasonal moves between inactive periods for grizzly bears in Denali National Park, 2006.

Gender	Season	*n*	Mean length (m), SD	Mean duration (hrs), SD
Male	Early	501	5450, 10494	13, 12
	Late	302	6383, 7274	15, 12
Female	Early	1646	2852, 4089	13, 12
	Late	1147	6958, 7782	16, 14
Both		3596	4820,7085	12,12

Table 8. Mean percent of land types used by grizzly bears during early and late season movements in Denali National Park, 2006.

Gender	Season	Percent of inactive bouts per land type (Selection Ratio)			Significance
		Mountain	Tundra	River channel	
Female	Early	71.0 (+16)[+a]	19.0 (-21) [-]	10.0 (+5)[+]	$X^2 =$ 2930.69 $p =$ 0.00
	Late	64.0 (+9)[+]	24.0 (-16) [-]	12.0 (+7)[+]	$X^2 =$ 3055.72 $p =$ 0.00
Male	Early	55.0 (0)[o]	38.0 (- 2) [-]	7.0 (+2)[+]	$X^2 =$ 54.42 $p =$ 0.00
	Late	29.0 (-26) [-]	66.0 (+26)[+]	5.0 (-1)[o]	$X^2 =$ 120.38 $p =$ 0.00
Both		61.0 (+6)[+]	28.0 (-12) [-]	10.0 (+5)[+]	$X^2 =$ 3649.31 $p =$ 0.00

[a] : + use > expected; 0 use as expected; - use < expected

Table 9. Use of four aspect classes by grizzly bears during movement bouts in Denali National Park, 2006.

Gender	Season	Percent of inactive bouts per aspect class (Selection Ratio)				Significance
		Northerly	Easterly	Southerly	Westerly	
Female	Early	45 (-1)[a] o	26 (+4) +	15 (-4) -	14 (+1) +	$X^2 = 299.13$ $p = 0.00$
	Late	49 (+3) +	21 (-1) -	17 (-2) -	13 (0) o	$X^2 = 168.00$ $p = 0.00$
Male	Early	54 (+8) +	20 (-2) o	14 (-5) -	12 (-1) o	$X^2 = 54.71$ $p = 0.00$
	Late	65 (+19) +	9 (-13) -	13 (-6) -	13 (0) o	$X^2 = 44.02$ $p = 0.00$
Both		58 (+12) +	16 (-6) o	13 (-6) -	12 (-1) o	$X^2 = 390.64$ $p = 0.00$

[a] : + use > expected; 0 use as expected; - use < expected

Table 10. Average path length of male and female grizzly bears in Denali National Park, 2006.

Gender	*n*	Average path length (km)	Min-max	SD
Female	13	975	765-1369	165
Male	4	1165	736-1381	292
Both	17	1020	736-1381	208

Table 11. Number of grizzly bear road crossings per bear and month in Denali National Park, 2006. Individual bears were classified as either having home ranges that abutted the road, straddled the road, or were far from the road. Gender of the individual bears is noted by the letter in front of the ID number; male (M) or female (F).

Bear	Home range relation to road	Number of road crossings					Total
		May	June	July	Aug	Sept	
M601	abut	0	0	0	0	0	0
F602	straddle	11	0	0	0	0	11
F603	straddle	2	10	16	7	3	38
F604	straddle	3	6	4	23	4	40
F605	straddle	3	24	7	19	13	66
F607	straddle	29	37	18	39	13	136
F609	straddle	15	18	10	4	10	57
F610	far	0	0	0	0	0	0
M611	straddle	5	4	0	0	0	9
F612	straddle	0	5	0	0	0	5
M613	abut	0	0	0	0	0	0
M615	straddle	13	12	2	1	0	28
F616	far	0	0	0	0	0	0
F618	abut	0	0	0	0	0	0
F619	abut	0	0	0	0	0	0
F620	straddle	8	12	8	20	4	52
F621	straddle	0	0	2	0	0	2
Total		89	128	67	113	47	444

Table 12. Distribution of road crossings by season and gender for grizzly bears in Denali National Park, 2006.

Gender	Number of road crossing (percent of total)		
	Early season	Late season	Total
Female	203 (46%)	204 (46%)	407 (92%)
Male	36 (8%)	1 (0.2%)	37 (8%)
Both	239 (54%)	205 (46%)	444

Table 13. The distribution of 444 road crossings by grizzly bears by month and hour in Denali National Park, 2006.

Hour	No. of road crossings					
	May	June	July	Aug	Sept	Total
0	1	6	1	0	0	8
1	0	5	2	0	0	7
2	2	4	1	0	0	7
3	1	2	0	0	0	3
4	1	4	1	1	0	7
5	2	6	1	5	0	14
6	1	3	6	5	4	19
7	4	8	6	10	2	30
8	2	5	2	8	3	20
9	5	6	4	12	3	30
10	4	9	3	4	2	22
11	1	4	3	3	6	17
12	2	7	5	4	1	19
13	4	8	2	5	1	20
14	5	4	3	5	3	20
15	5	7	2	2	5	21
16	7	6	1	8	3	25
17	5	6	4	5	5	25

Table 13. The distribution of 444 road crossings by grizzly bears by month and hour in Denali National Park, 2006, continued.

Hour	No. of road crossings					
	May	June	July	Aug	Sept	Total
18	2	1	1	7	2	13
19	5	9	1	6	3	24
20	10	2	4	7	1	24
21	11	6	9	6	2	34
22	7	3	3	6	1	20
23	2	7	2	4	0	15
Total	89	128	67	113	47	444

Table 14. Distribution of grizzly bear road crossings by season and traffic diel in Denali National Park, 2006.

Season	Number crossings by traffic diel (Percent of total)			
	Low traffic	Moderate traffic	High traffic	Total
Early season	60 (14%)	69 (16%)	110 (25%)	239 (54%)
Late season	24 (5%)	71 16%)	110 (25%)	205 (46%)
Both	84 (19%)	140 (32%)	220 (50%)	444

Table 15. Comparisons of bear movement rate within the road corridor (< 3 km) to rates outside of the road corridor in Denali National Park, 2006.

Gender	Season	Land type	Average movement rate (m/hr)		*P*	Interpretation
			<3 km	>3 km		
Female	Early	Tundra	501.68	484.21	0.26	
	Late		610.68	669.82	<0.01	Slower within
Female	Early	Mountain	470.56	509.90	<0.01	Slower within
	Late		289.66	315.98	<0.01	Slower within
Female	Early	River	439.23	542.35	<0.01	Slower within
	Late		601.27	642.80	0.05	Slower within
Male	Early	Tundra	941.90	767.92	<0.01	Faster within
	Late		618.31	542.59	0.19	
Male	Early	Mountain	783.78	659.28	<0.01	Faster within
	Late		523.77	595.14	0.31	
Male	Early	River	1835.85	1043.97	<0.01	Faster within
	Late		1494.06	726.12	<0.01	Faster within

Table 16. Movement speed (m/hr) of grizzly bears during one hour steps before road crossing, while crossing the road, and immediately after crossing the road in Denali National Park, 2006.

Movement relative to road	Movement speed (m/hr)	*n*	SD
Pre-crossing	700	364	690
Road crossing	985	444	756
Post-crossing	611	328	691

Table 17. Initial and final land types used by grizzly bears along movement paths that cross the road in Denali National Park, 2006.

Land types		Percent by season		Percent of total
Initial	Final	Early	Late	
Mountain	Mountain	56.8	43.2	51.8
Mountain	River	56.3	43.8	6.3
Mountain	Tundra	48.2	51.9	10.6
River	River	0.0	100.0	0.8
River	Tundra	37.5	62.5	3.1
River	Mountain	57.1	42.7	5.5
Tundra	Tundra	44.4	55.6	7.1
Tundra	Mountain	43.8	56.3	12.6
Tundra	River	16.7	83.3	2.4

Table 18. Land types used by grizzly bears while crossing the road in Denali National Park, 2006.

Season	Percent of road crossings within land type (Selection ratio)			Significance
	Tundra	Mountain	River channel	
Early	45.7 (-4.3)^{o} [a]	45.7 (-0.3)^{o}	8.5 (+4.5)$^{+}$	$X^2 = 11.46$ $p = 0.00$
Late	53.3 (+3.3)^{o}	40.5 (-5.5)^{o}	6.2 (+2.2)^{o}	$X^2 = 0.71$ $p = 0.70$

[a] : + use > expected; 0 use as expected; - use < expected

Table 19. Distance of grizzly bear inactive bouts to the road, for bouts ≤2 km from road in Denali National Park, 2006.

Gender	Season	*n*	Mean distance (m) (SD)
Female	Early	412	842.1 (585.2)
Female	Late	225	990.0 (597.0)
Male	Early	53	1052.4 (564.3)
Male	Late	6	1164.6 (700.4)
Both		696	911.3 (593.4)

Table 20. Percent of inactive bouts of grizzly bears by land type within the 3 km road corridor.

Gender	Season	Percent of inactive bouts per land type (Selection Ratio)			Significance
		Mountain	Tundra	River channel	
Female	Early	71.0 (+16.0) +[a]	12.0 (-28.0) -	17.0 (+12.0)+	X^2 = 215.34 p = 0.00
	Late	65.0 (+10.0)+	24.0 (-16.0) -	10.0 (+5.0)+	X^2 = 31.81 p = 0.00
Male	Early	47.0 (-8.0)o	51.0 (+11.0)o	2.0 (-3.0)o	X^2 = 3.20 p = 0.00
	Late	33.0 (-22.0)o	67.0 (+27.0)o	0.0 (-5.0) -	X^2 = 1.87 p = 0.00
Both		66.0 (+11.0)+	20.0 (-20.0) -	14.0 (+9.0)+	X^2 = 192.33 p = 0.00

[a] : + use > expected; 0 use as expected; - use < expected

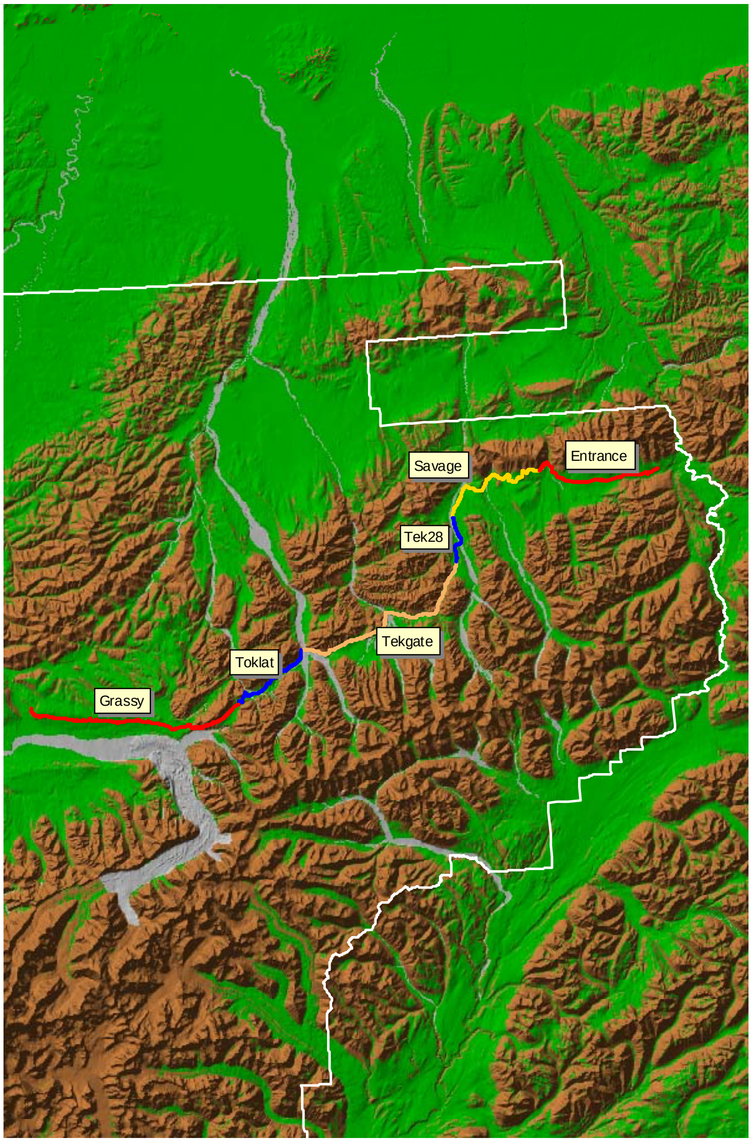

Figure 1. Location of road segments of the road in Denali National Park. Traffic data were collected along all but the entrance segment in 2006. Background map represents the 3 land types: mountains (brown), tundra (green), and river channels (grey).

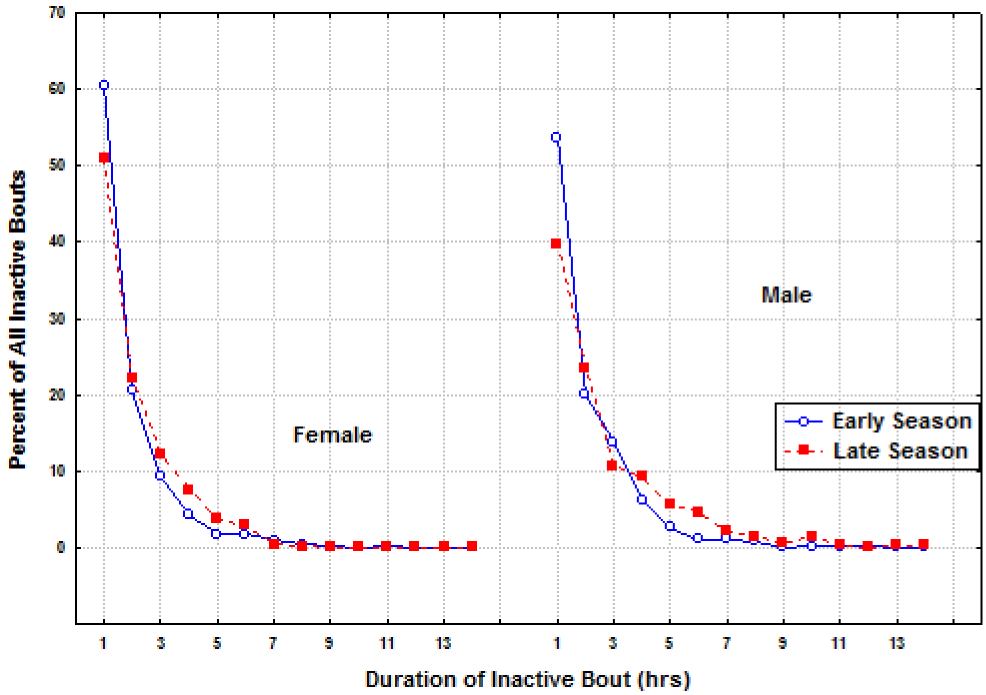

Figure 2. Duration of inactive bouts for male and female grizzly bears in Denali National Park during early and late season, 2006.

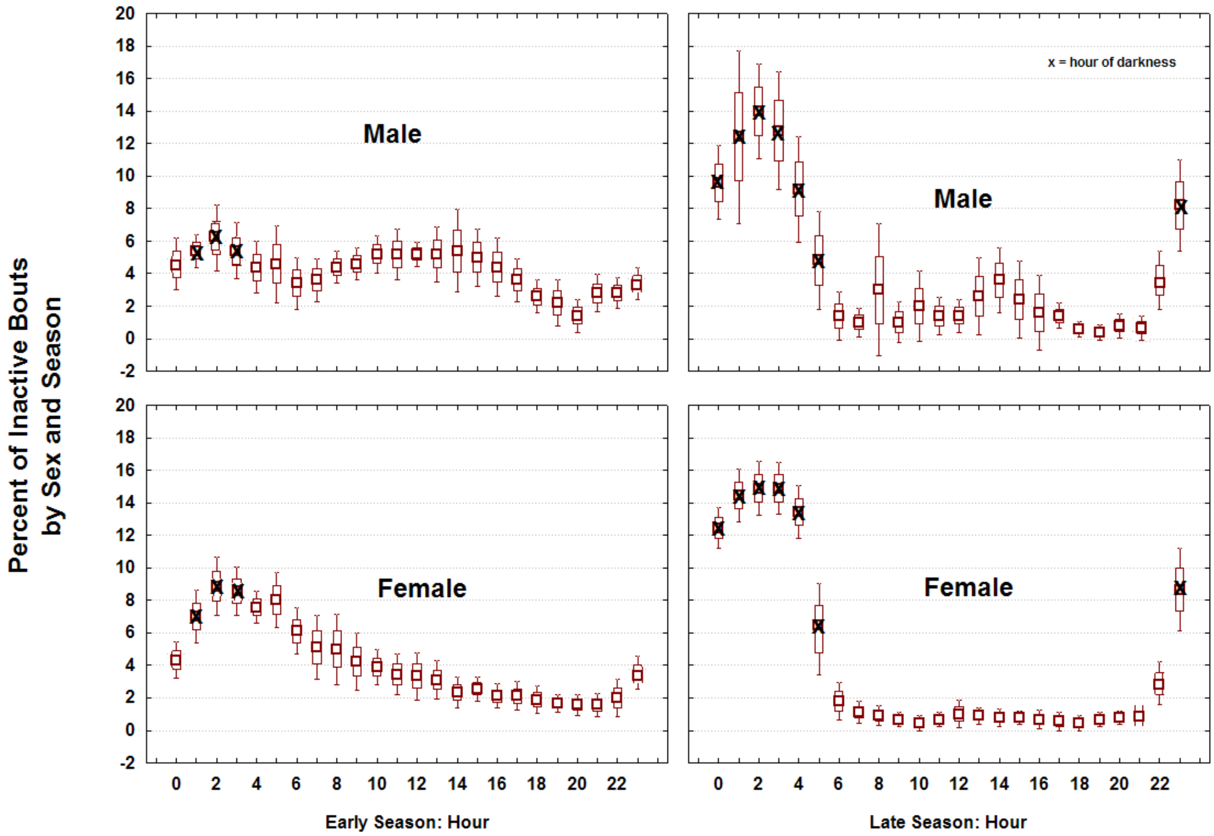

Figure 3. Percent of grizzly bear inactive bouts by season, sex, and hour of day in Denali National Park, 2006. Maximum daylight is at 14:00, minimum at 02:00 AKDT.

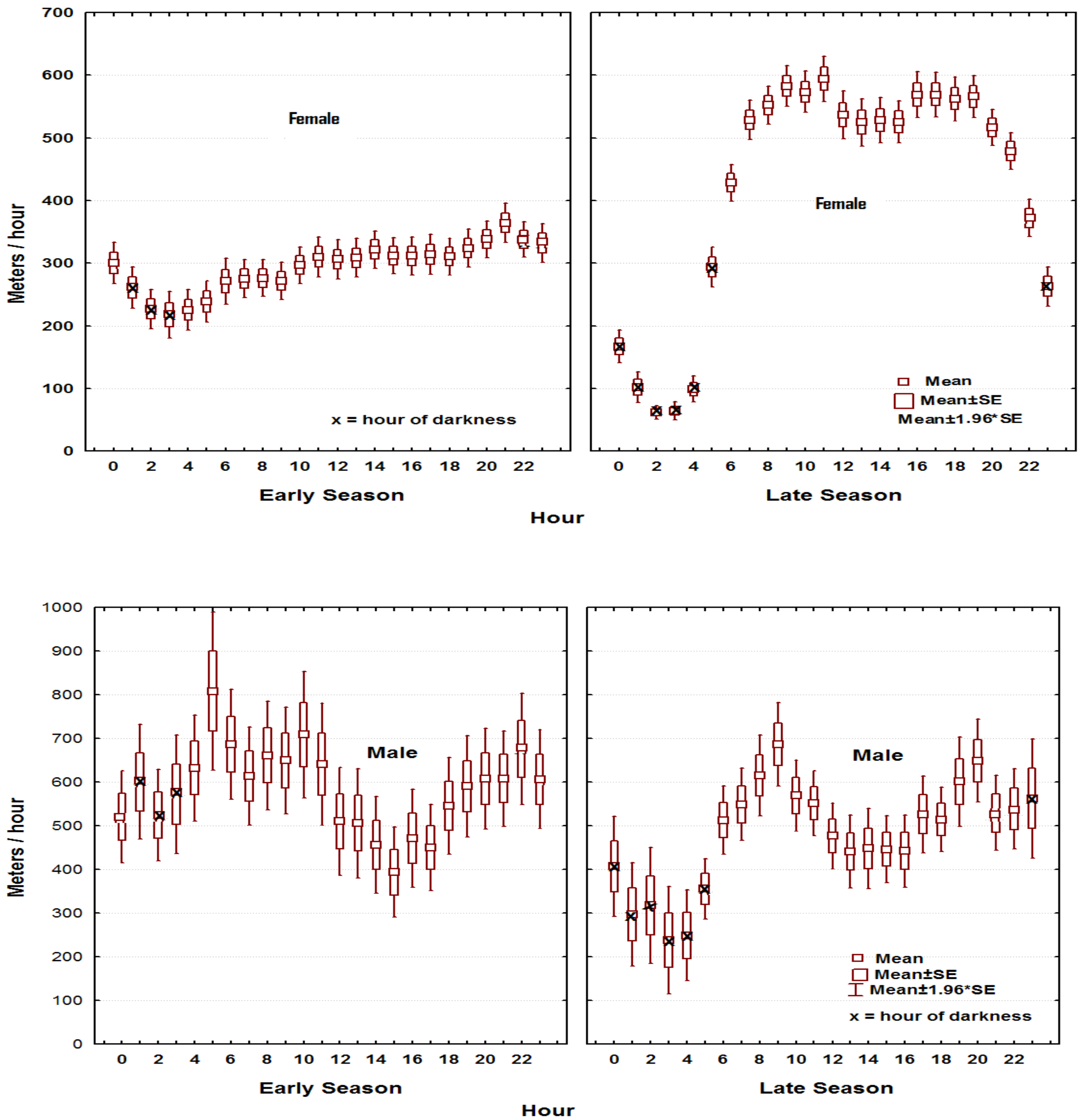

Figure 4. Speed (m/hr) of male and female grizzly bear moves during each season and hour in Denali National Park, 2006. Maximum daylight is at 14:00, minimum at 02:00 AKDT.

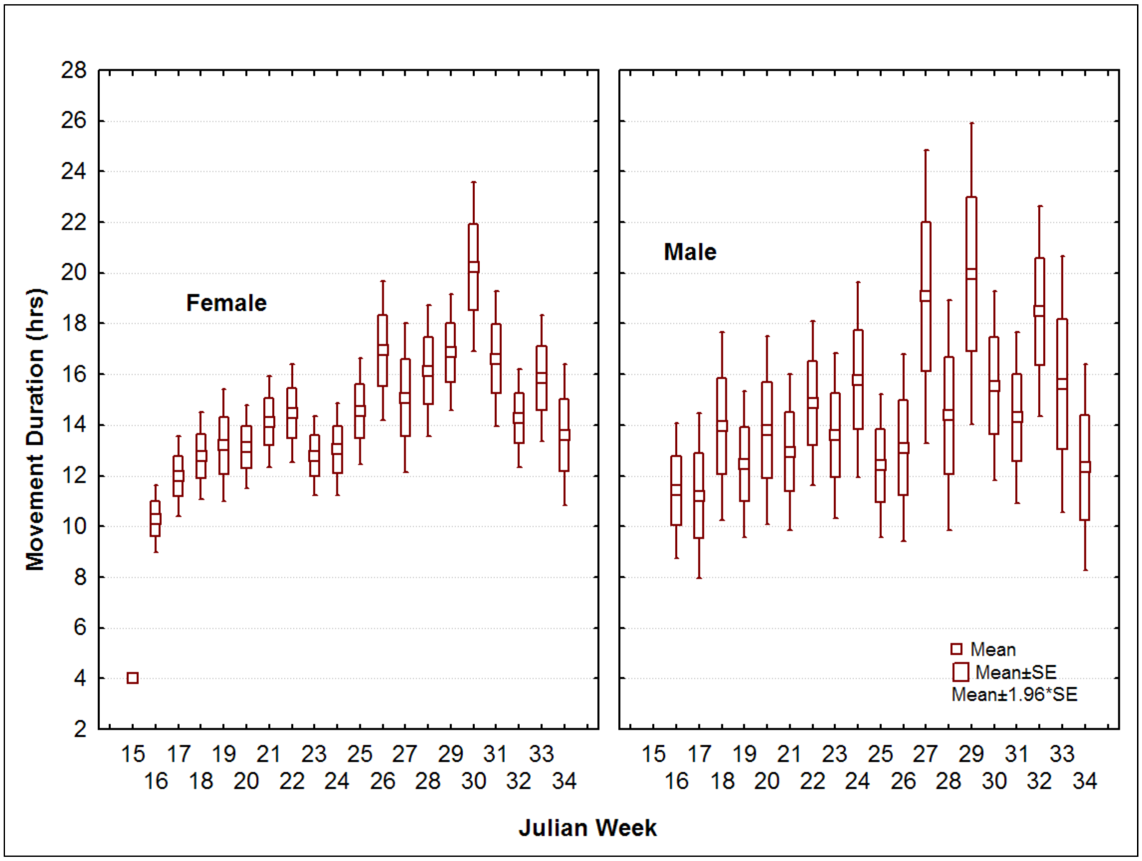

Figure 5. Duration of movement path (hr) of grizzly bears in Denali National Park by week, 2006.

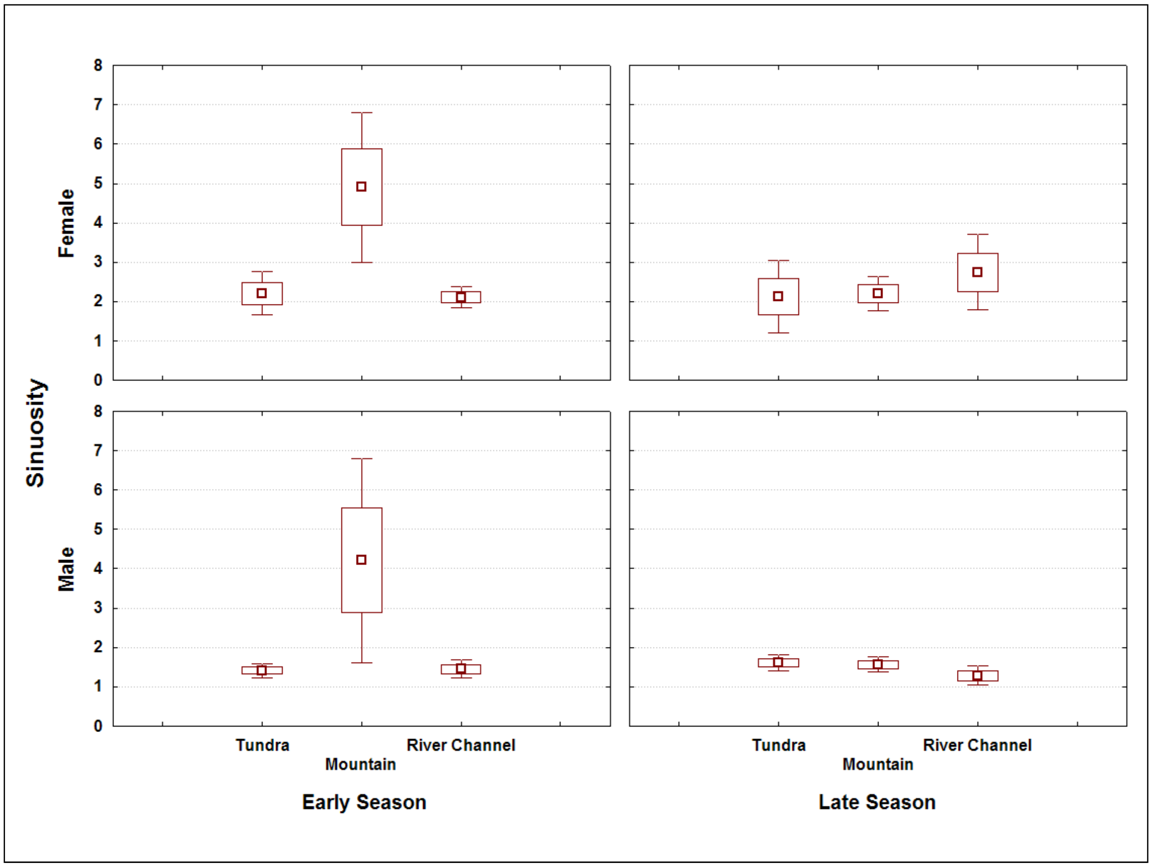

Figure 6. Sinuosity of movement paths of grizzly bears by season and habitat type in Denali National Park, 2006.

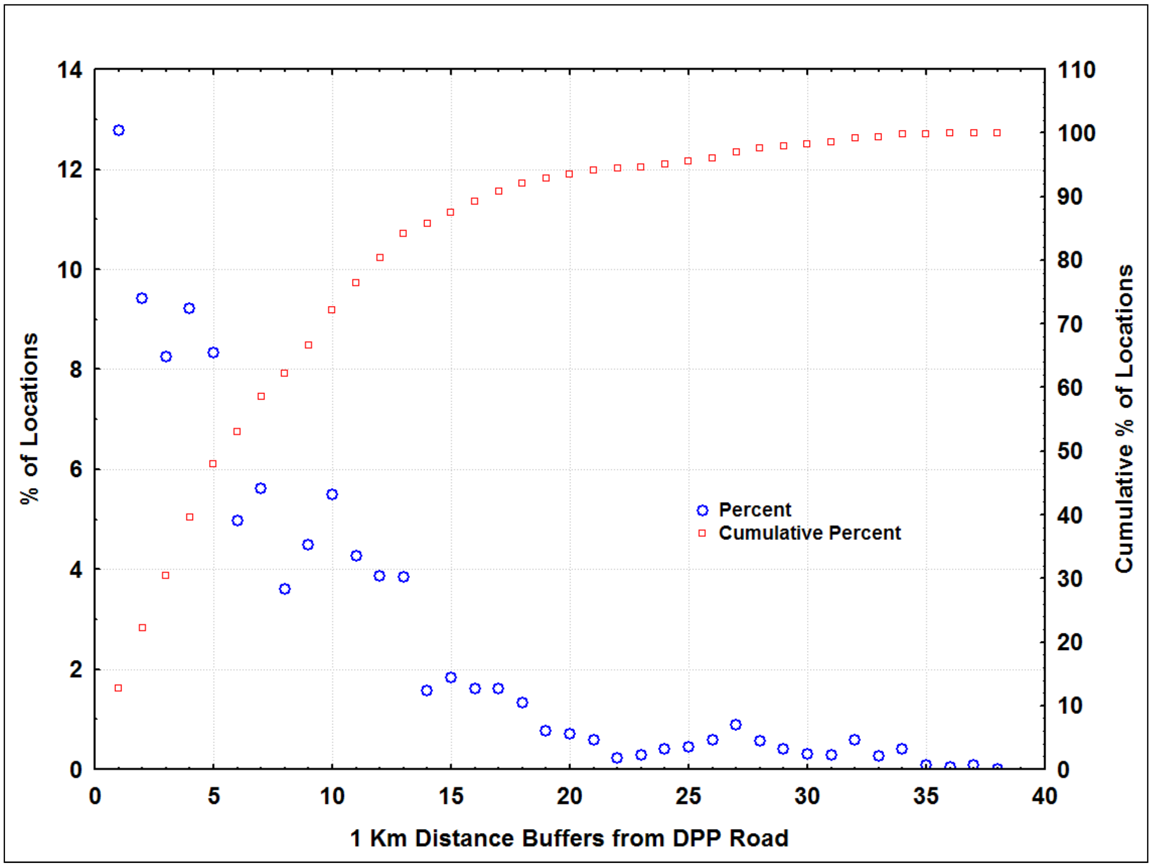

Figure 7. Distance of grizzly bear telemetry locations from the road in Denali National Park, 2006.

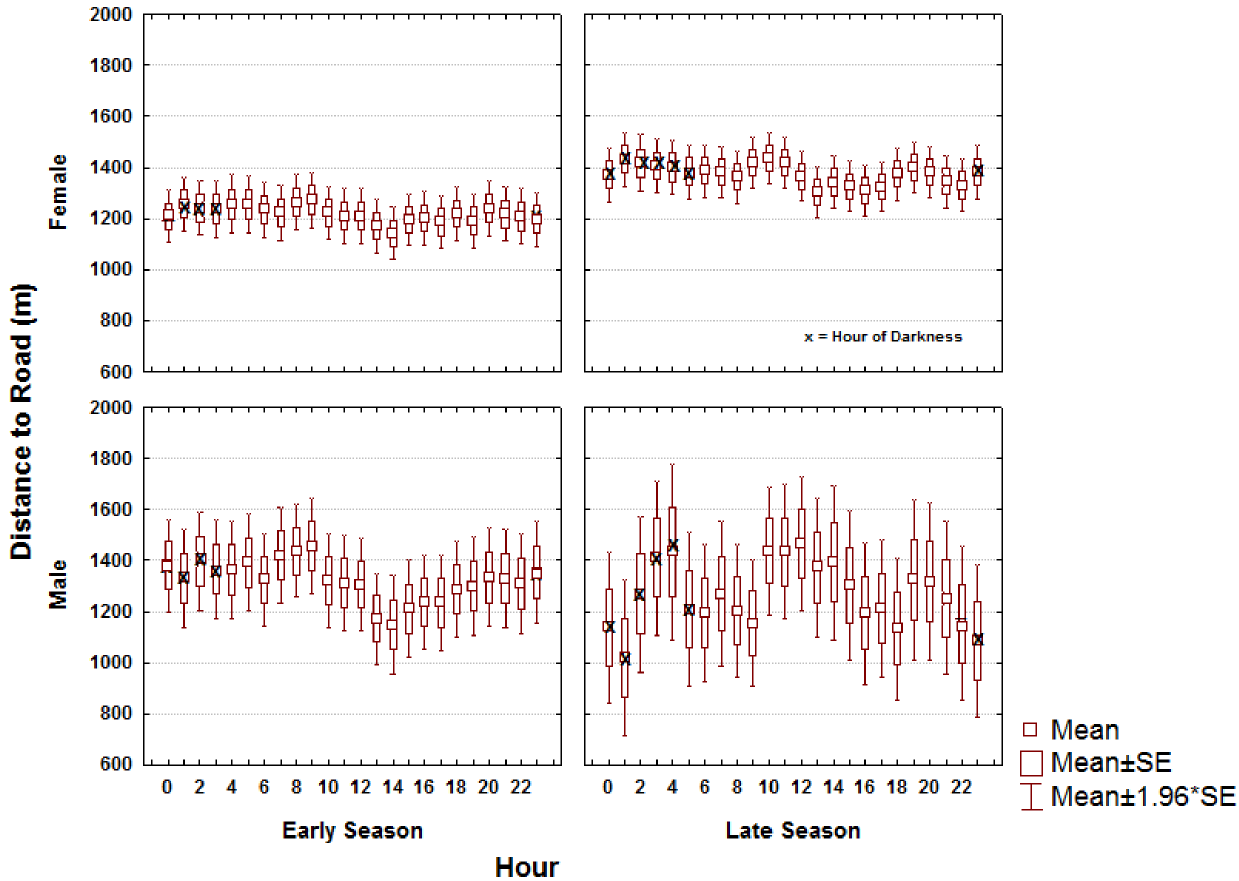

Figure 8. Average distance of grizzly bears to the road by hour during early (15 May – 15 July) and late (16 July – 20 September) seasons in Denali National Park, 2006. Includes only locations of bears within 3 km of the road. Maximum daylight is at 14:00, minimum at 02:00 AKDT.

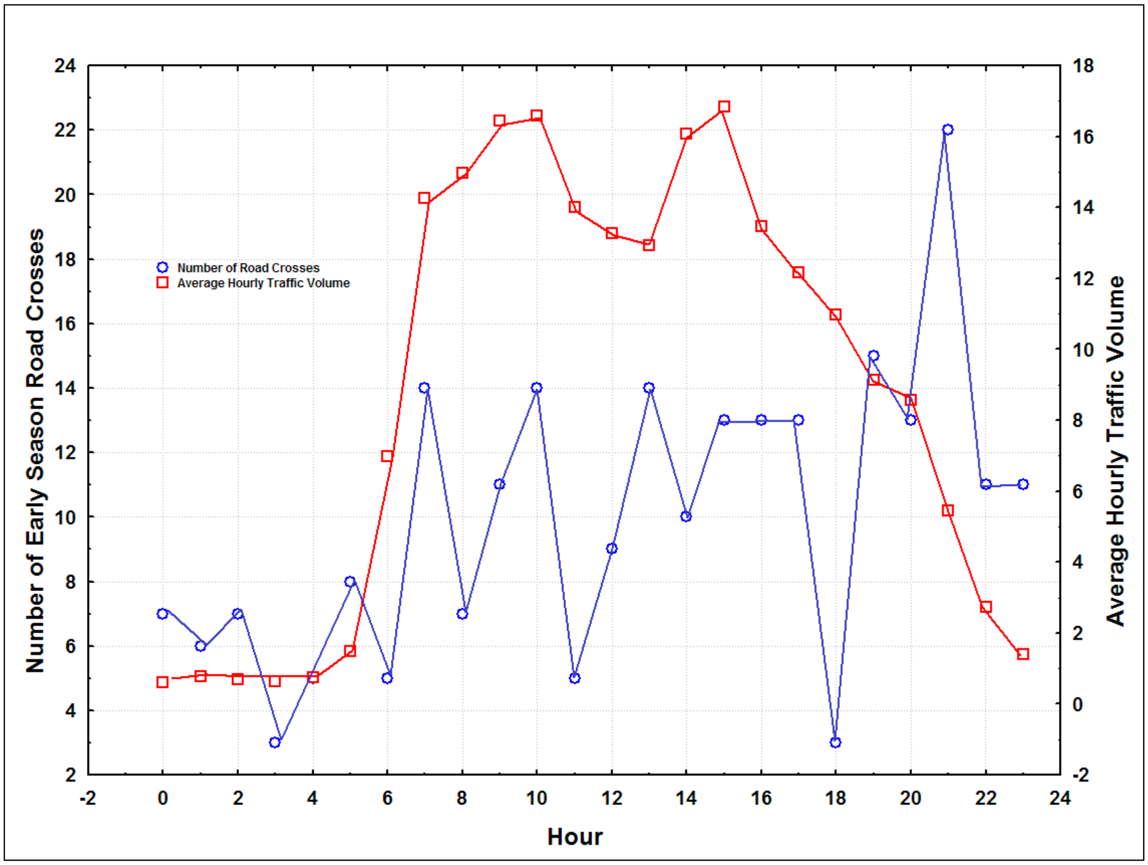

Figure 9. The relationship between hourly road crossings of grizzly bears and hourly traffic volume along sections of the road during the early season, 15 May – 15 July 2006, Denali National Park.

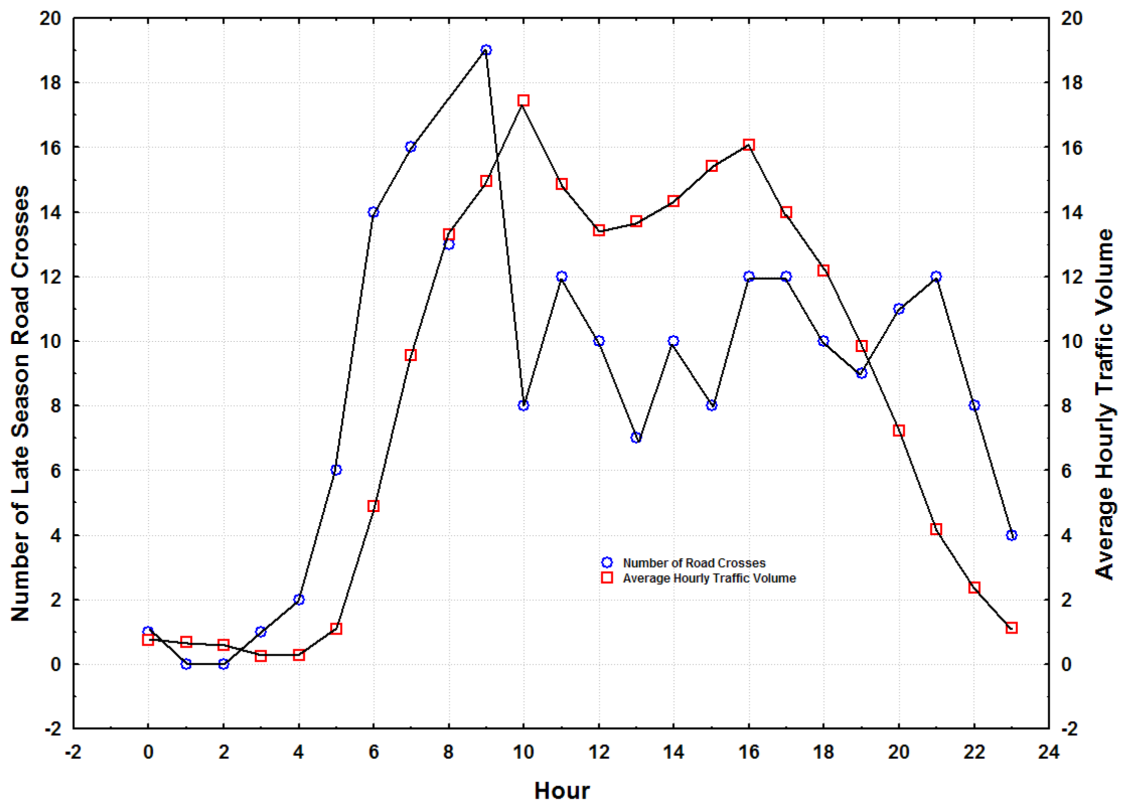

Figure 10. The relationship between hourly road crossings of grizzly bears and hourly traffic volume along the road during the late season, 16 July – 20 September 2006, Denali National Park.

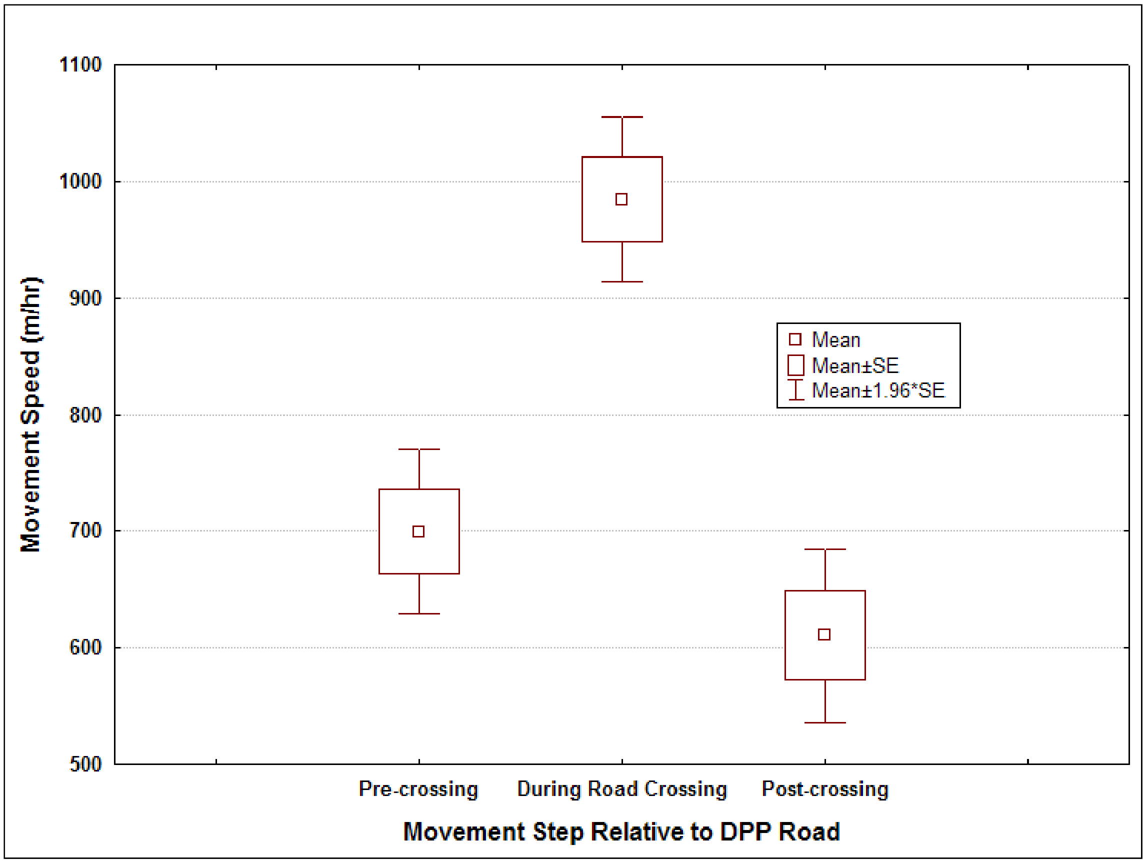

Figure 11. Movement speed (m/hr) of grizzly bears during one hour steps before road crossing, while crossing the road, and immediately after crossing the road within Denali National Park, 2006.

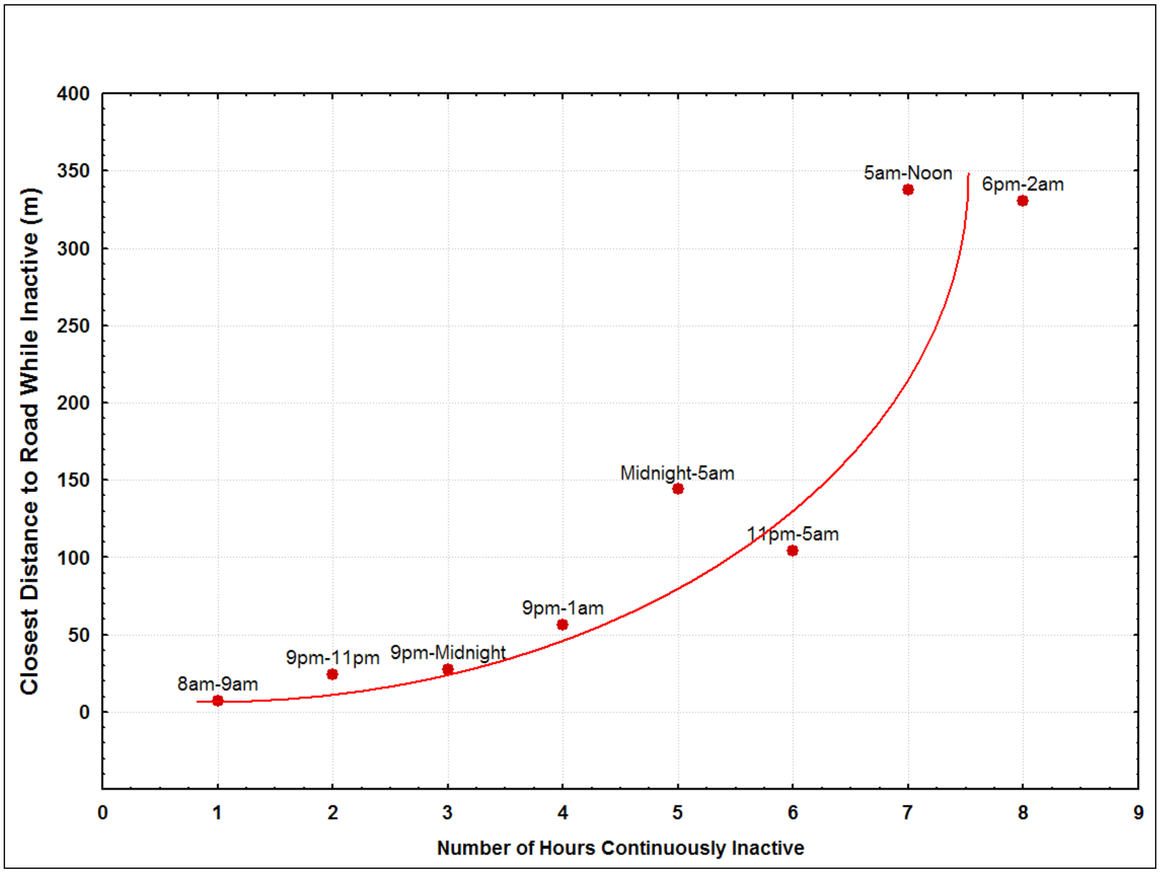

Figure 12. Relationships between number of hours grizzly bears were inactive and their closest distance to the road in Denali National Park, 2006.

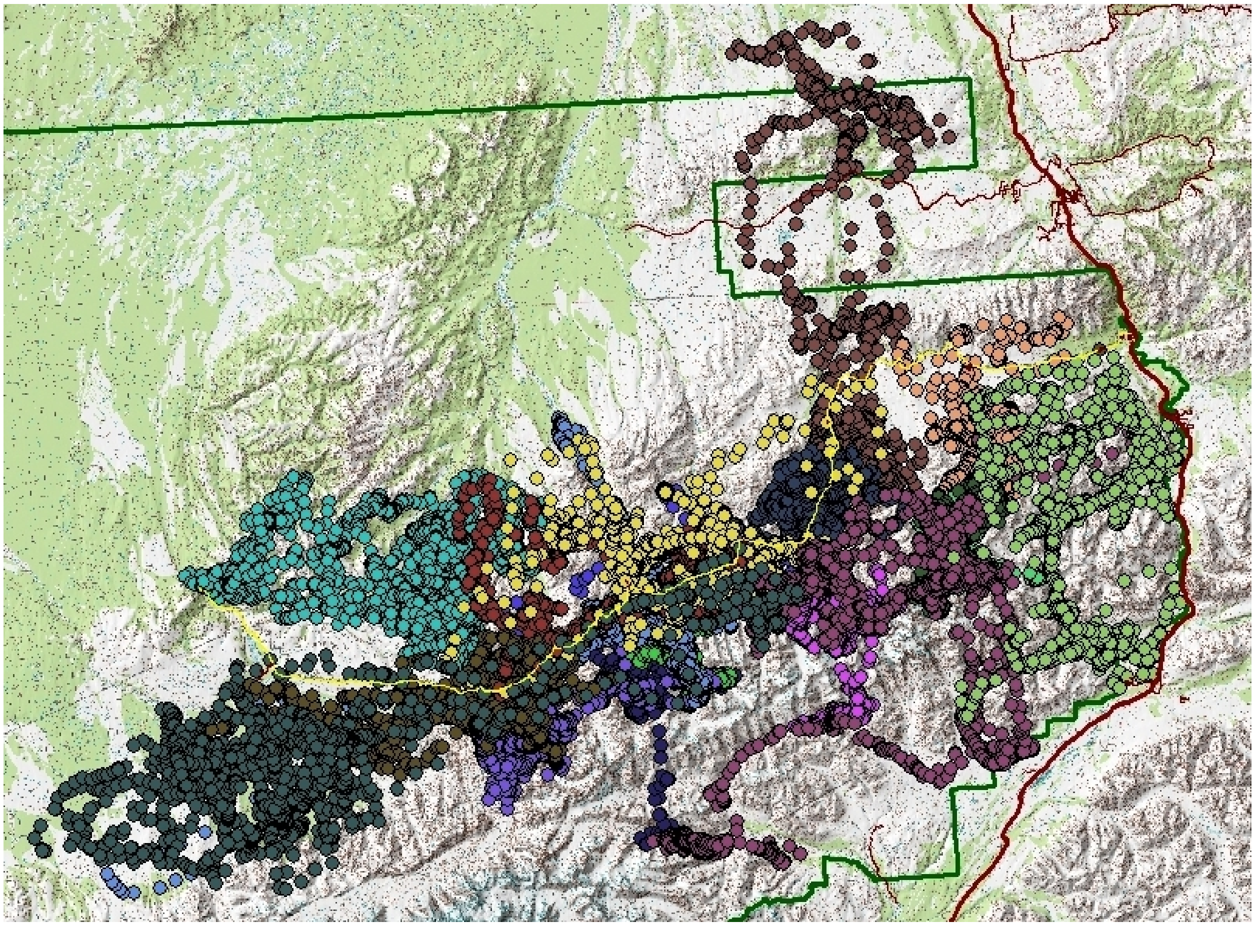

Figure 13. Locations of radio-collared bears in summer 2006, showing the Denali National Park and Preserve boundary (green) and the Denali Park Road (yellow).

Appendix B. Multi Variable Analysis of Grizzly Bear Habitat in Denali National Park and Preserve

Introduction

Grizzly bear habitat selection was modeled using several topographical and vegetation variables with the goal of providing a basic map of bear distribution across Denali National Park and Preserve (Denali). A separate map of resource use was developed for bears while in the inactive state and the active state. For this modeling effort, we used the potential vegetation map, derived from the soils map for Denali as the primary vegetation layer. This vegetation map was used as an alternative to the land type map described elsewhere in this report, to assess its value as a predictor of bear habitat selection.

Methods

We used logistic regression to estimate the probability of occurrence of male and female grizzly bears on the Denali landscape based on map variables. We calculated resource selection probability functions (RSF) based on used and available resources (Manley et al. 1993). Bear telemetry points (used) that corresponded to inactive bouts or active movement paths were compared to an equal number of random points (available) within Denali. RSF values represented the relative probability of grizzly bears using a unique set of resources. RSF values were calculated using the following formula:

$$w(x) = \exp(B_1x_1+\ldots B_px_p) /1+ \exp(B_1x_1+\ldots B_px_p)$$

where w(x) was the RSF and $B_1x_1+\ldots B_px_p$ were the available resource units. RSF values were scaled between 0 and 100% by dividing each un-scaled value by the largest un-scaled RSF value. Models were derived by pooling the 2 sexes and 2 seasons.

We randomly selected 20% of the sample as a “holdout” or cross-validation sample. Logistic regression models were built using 80% of the sample. Model fit (% of points correctly classified as available or bear telemetry points) was then assessed with the holdout sample.

Elevation classes were derived from the Digital Elevation Model (DEM) for Denali as follows: 1) < 1000m, 2) 1000-1100 m, 3) 1100-1200, 4) 1200-1300, 5) 1300-1400, 6) 1400-1500, and 7) >1500 m. Elevation class 7 was used as the standard class for this variable. Aspect, also derived from the DEM, was categorized into the following classes: northerly (0^o- 45 ^{o} and 315 ^{o}- 360 ^{o}), easterly (46 ^{o}- 135^o), Southerly (136 ^{o}- 225 ^{o}), westerly (226 ^{o}- 269^o), and flat. The flat aspect was very rare in the study area, and there was no bear use of this aspect class. Therefore, the flat aspect was set to zero in RSF models. The south aspect class was used as the standard class for this variable.

Vegetation classes were derived from the soils map of Denali (U.S. Department of Agriculture, Natural Resources Conservation Service 2004). We combined vegetation classes, derived from a classification of potential vegetation into 7 classes. The standard variable was Snow/Ice and Glaciers. Water showed no use by bears and was set to zero in RSF maps. These classes were defined as follows:

1. Black Spruce Bog: Dwarf needle-leaf permafrost woodland is dominated by black spruce (Picea mariana), which is often less than 5 meters tall but may be over a century old. Numerous ponds, bogs, and fens dot this extensive area.

2. Low Trees/Tall Shrubs:
a. Mixed paper birch – white spruce forest. Paper birch (Betula neoalaskana) forest, sometimes mixed with white spruce (Picea glauca) and with an under story of green alder (Alnus viridis ssp. crispa), dominates warm slopes of the low Kuskokwim Mountains.

b. Riparian white spruce mixed hardwoods_mixed scrub. Well-drained floodplains associated with major rivers, of very limited extent, support narrow, productive forests of white spruce and poplar (Populus balsamifera ssp. balsamifera), with associated communities of alder (Alnus spp.) and willow (Salix spp.) scrub.

c. White spruce/mixed scrub woodlands. Warmer low slopes, especially in the Kantishna Hills and Park headquarters areas, support white spruce/mixed scrub woodlands.

d. Mixed paper birch-white spruce forest. Forested communities of paper birch, some mixed with white spruce, are limited to lower slopes.

e. Riparian alder scrub and wet meadow. Poorly drained lowlands, underlain by glacial drift, support a mosaic of alder scrubs and wet herbaceous meadows.

3. Non- or Sparsely Vegetated Areas

4. Water

5. Snow/Ice and Glaciers

6. Alpine Dwarf Shrub:
a. Mountain avens-ericaceous dwarf alpine scrub. Mountain vegetation of the Alaska Mountains Section is dominated by white mountain avens (Dryas octopetala)- dwarf ericaceous shrub scrubs.

b. Shrub birch/sedge scrub ericaceous dwarf scrub. On cooler, more northerly aspects these scrubs sometimes have high percentages of sedge and other herbaceous vegetation

7. Medium Shrubs
a. Shrub birch-ericaceous scrub. medium-sized scrubs dominated by shrub birch and ericaceous shrubs such as blueberry (Vaccinium uliginosum), Labrador tea (Ledum palustre ssp. decumbens and L. groenlandicum) and crowberry (Empetrum hermaphroditum).

b. Barclay willow scrub/medium herbaceous meadow mosaic. Barclay willow (Salix barclayi) forms a mosaic with medium-sided herbaceous meadows between the dwarf alpine communities and the tall Sitka alder/ (Alnus sinuata) tall herbaceous meadow mosaics of the lower slopes-alpine.

Results

Inactive State

The logistic regression model for grizzly bear inactive bouts was significant (-2LL = 7198.2, X^2 = 1025.67, df = 14, $P < 0.01$, Figure B-1). Cross-validation showed that 67% and 66% of the telemetry locations and available points were correctly classified. The variable season (early: < 15 July, late: >16 July) was not significant (P = 0.78) and was omitted from the final model. Bear use of all elevation classes was significant in logistic regression models (Table B-1). Bears were positively correlated with all lower elevation classes relative to the highest elevation class (>1500 m). The greatest positive coefficients were observed for those elevation bands between 1000m and 1300m. The highest mean RSF value was for the elevation class 1100-1200 m (Figure B-2)

While in the inactive state, bears were negatively associated with Black Spruce Bog potential vegetation type, relative to the standard variable of Snow/ice-Glaciers. All other potential vegetation types were significant, and were selected for by bears. The Low Tree/Tall Shrub vegetation type exhibited the largest mean RSF value (Figure B-3).

Bear selection was strongest for the westerly and easterly aspects, relative to southern aspects. Use of northerly aspects was not significant (Table B-1). Bear selection was strongest for westerly aspects (Figure B-4).

Active State

The logistic regression model for brown bear active bouts was significant (-2LL 97775.09, X^2 =13127.09, df = 14, $P < 0.01$, Figure B-5). Cross-validation showed that 64% and 68% of the telemetry locations and available points were correctly classified. The variable season was not significant (P = 0.16) and was omitted from the final model.

Bear use of all elevation classes was significant in logistic regression models (Table B-2). Bears were positively correlated with all lower elevation classes relative to the highest elevation class (>1500 m). The greatest positive coefficients were observed for those elevation bands between 1000m and 1400m. The highest mean RSF value (approximately 70% relative probability of use) was for the elevation class 1100-1200 m (Figure B-6)

While in the inactive state, bears were positively associated with all potential vegetation types, relative to the standard variable of Snow/ice-Glaciers. The Low Tree/Tall Shrub vegetation type exhibited the largest mean RSF value (Figure B-7).

Bear selection was positive and significant for all aspect classes relative to the southerly standard aspect (Table 2). Bear selection was strongest for westerly aspects (Figure B-8).

Conclusions

The sample of radio-instrumented brown bears utilized the area between the Nenana River (the park boundary) on the east and the Wonder Lake area on the west (Figure 13). Bears occupied habitats on both sides of the park road and into the southern portion of the Kantishna hills. We documented several bears crossing the Alaska Range, following several different passes. Although we had several bears utilize the McKinley River area below the Muldrow Glacier, these individuals did not use the higher elevation habitats surrounding Mount McKinley.

RSF values were generally lower for the Snow/Ice and Glacier potential vegetation type (mean RSF values between 20-30%) than other vegetation types. Vegetative food resources important to bears are scarce within this type. Relatively low selection was also seen for the Black Spruce Bog vegetation type. The mean relative probability of use was approximately 17% for this type, which was rare within the confines of the road corridor.

Grizzly bears favored the 3 vegetation types dominated by shrubs. The Low Tree/Tall shrub type was found predominantly north of the Denali park road along major river channels. Peak use of this type by bears occurred in June. Vegetative food resources in the type included Equisetum arvense, Boykinia richardsonii, and Rumex arcticus. The Non/Sparsely vegetated type was used by bears predominantly during May and June. The roots of Hedysarum alpinum americanum would be available for bears to dig within this type.

The Medium Shrub type was well distributed throughout Denali and was favored by grizzly bears. The ericaceous shrubs Vaccinium uliginosum and Empetrum hermaphroditum are common in this type, and the fruits of these species are actively sought by bears from mid-July through September.

The Alpine Dwarf Shrub type was primarily used in June and July by radioed bears. This type was common in open tundra along the road corridor and along lower mountain slopes.

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U.S. Department of Agriculture, Natural Resources Conservation Service. 2004. Soil survey of Denali National Park and Preserve area, Alaska

Table B-1. Logistic regression coefficients, standard errors (SE), Wald Statistics, and P values for grizzly bears while in the inactive state in Denali National Park, 2006.

Model Variable	Coefficient	SE	Wald Statistic	*P*
Intercept	-1.98	0.23	74.3	<0.001
Elevation: < 1000m	0.14	0.19	0.5	0.460
Elevation: 1000-1100m	1.16	0.19	35.7	<0.001
Elevation: 1100-1200m	1.38	0.19	53.2	<0.001
Elevation: 1200-1300m	1.31	0.18	50.9	<0.001
Elevation: 1300-1400m	0.98	0.17	32.2	<0.001
Elevation: 1400-1500m	0.50	0.20	6.5	0.011
Black Spruce Bogs	-0.63	0.35	3.2	0.074
Low Tree/Tall shrub	1.43	0.29	23.7	<0.001
Medium Shrubs	1.01	0.28	13.2	<0.001
Alpine Dwarf Shrub	1.61	0.27	36.2	<0.001
Non-/sparsely Vegetated	0.65	0.25	6.834292	0.008
West	0.47	0.09	30.33669	<0.001
East	0.22	0.09	6.032213	<0.001
North	0.14	1.61	2.577184	0.108

Table B-2. Logistic regression coefficients, standard errors (SE), Wald statistics, and P values for grizzly bears while in the active state in Denali National Park, 2006.

Model Variable	Coefficient	SE	Wald Statistic	*P*
Intercept	-2.51	0.08	876.8	<0.001
Elevation: < 1000 m	0.37	0.053	50.3	<0.001
Elevation: 1000-1100 m	1.38	0.054	644.6	<0.001
Elevation: 1100-1200 m	1.60	0.054	883.8	<0.001
Elevation: 1200-1300 m	1.51	0.053	819.6	<0.001
Elevation: 1300-1400 m	1.20	0.052	532.4	<0.001
Elevation: 1400-1500 m	0.49	0.06	74.2	<0.001
Black Spruce Bogs	0.28	0.11	7.2	<0.001
Low Tree/Tall shrub	1.98	0.10	417.4	<0.001
Medium Shrubs	1.45	0.09	240.9	<0.001
Alpine Dwarf Shrub	1.94	0.09	443.1	<0.001
Non-/sparsely Vegetated	0.90	0.09	102.4	<0.001
North	0.14	0.02	30.4	<0.001
West	0.27	0.02	119.1	<0.001
East	0.12	0.03	19.2	<0.001

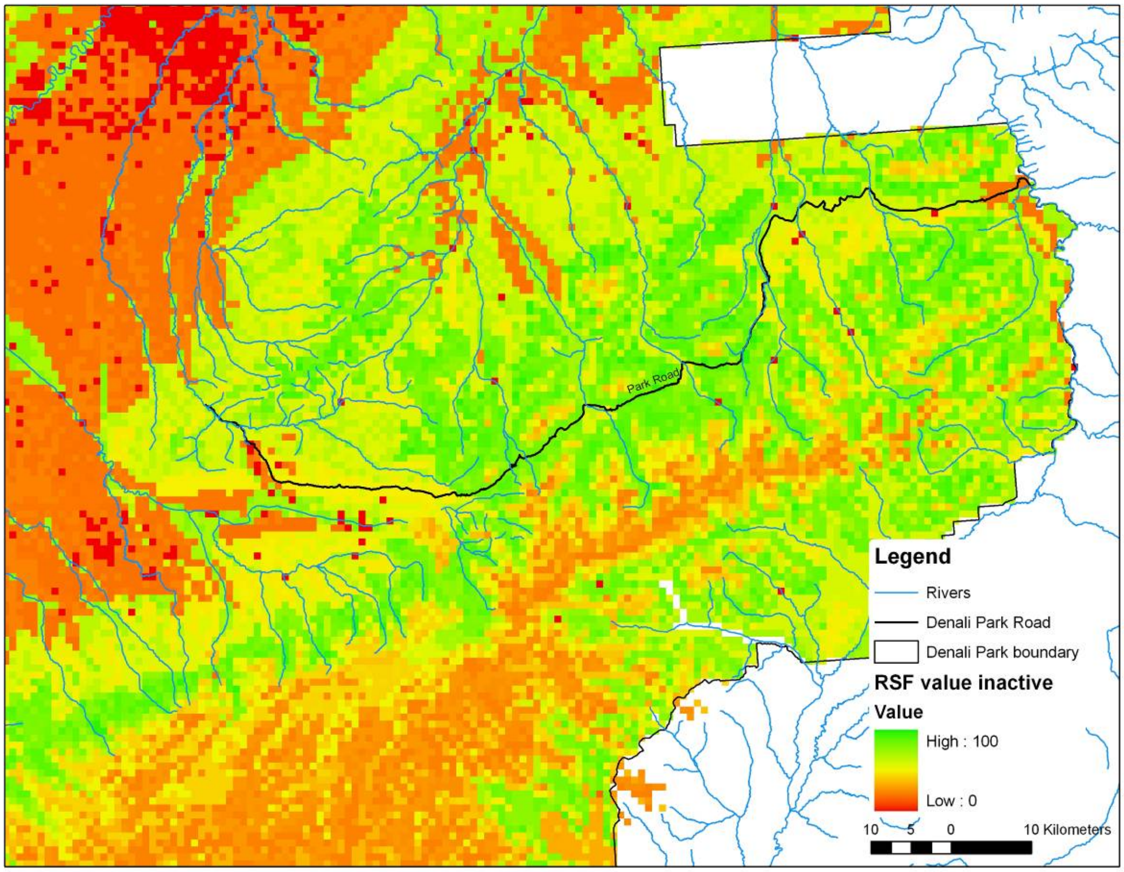

Figure B-1. Probability of occurrence of inactive grizzly bears in Denali National Park based on resource selection function (RSF) values. Higher RSF values represent an increased probability of use.

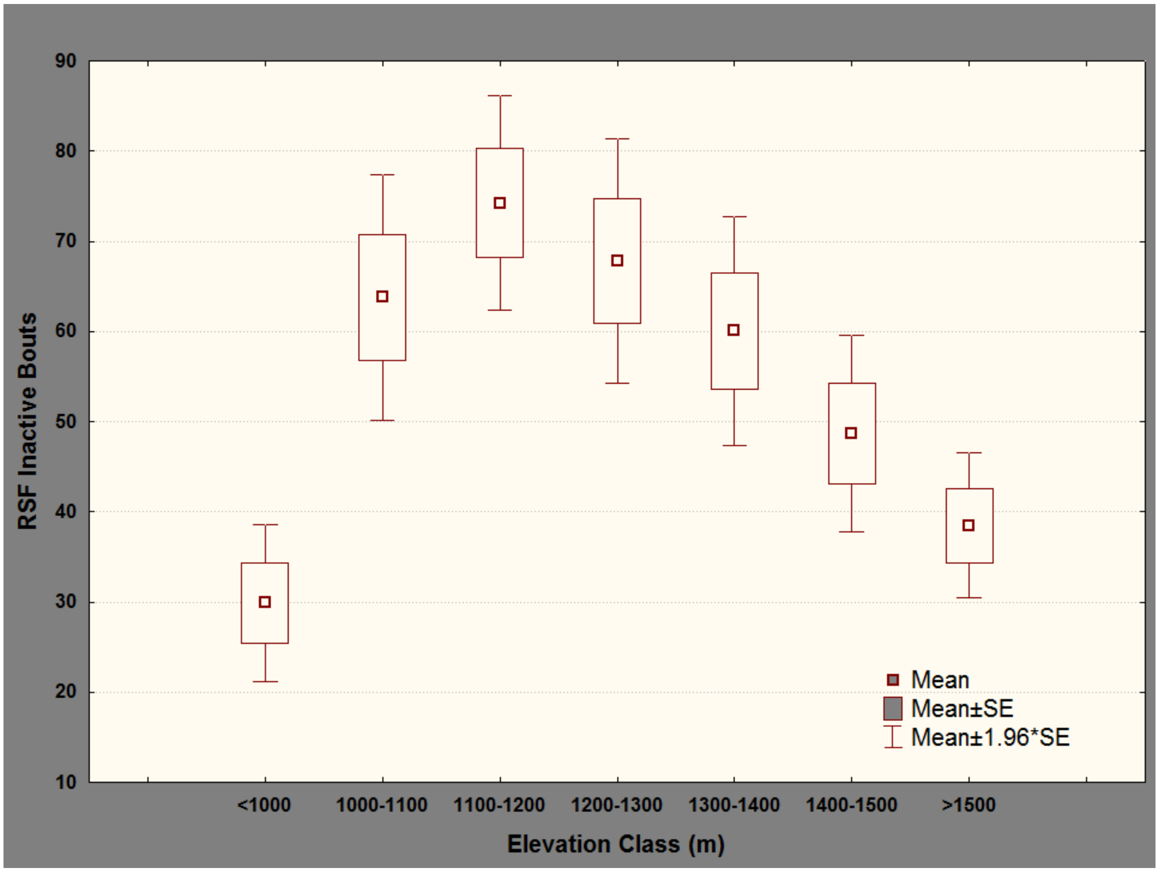

Figure B-2. Mean resource selection function (RSF) values for 7 elevation classes for grizzly bears while in the inactive state in Denali National Park, 2006.

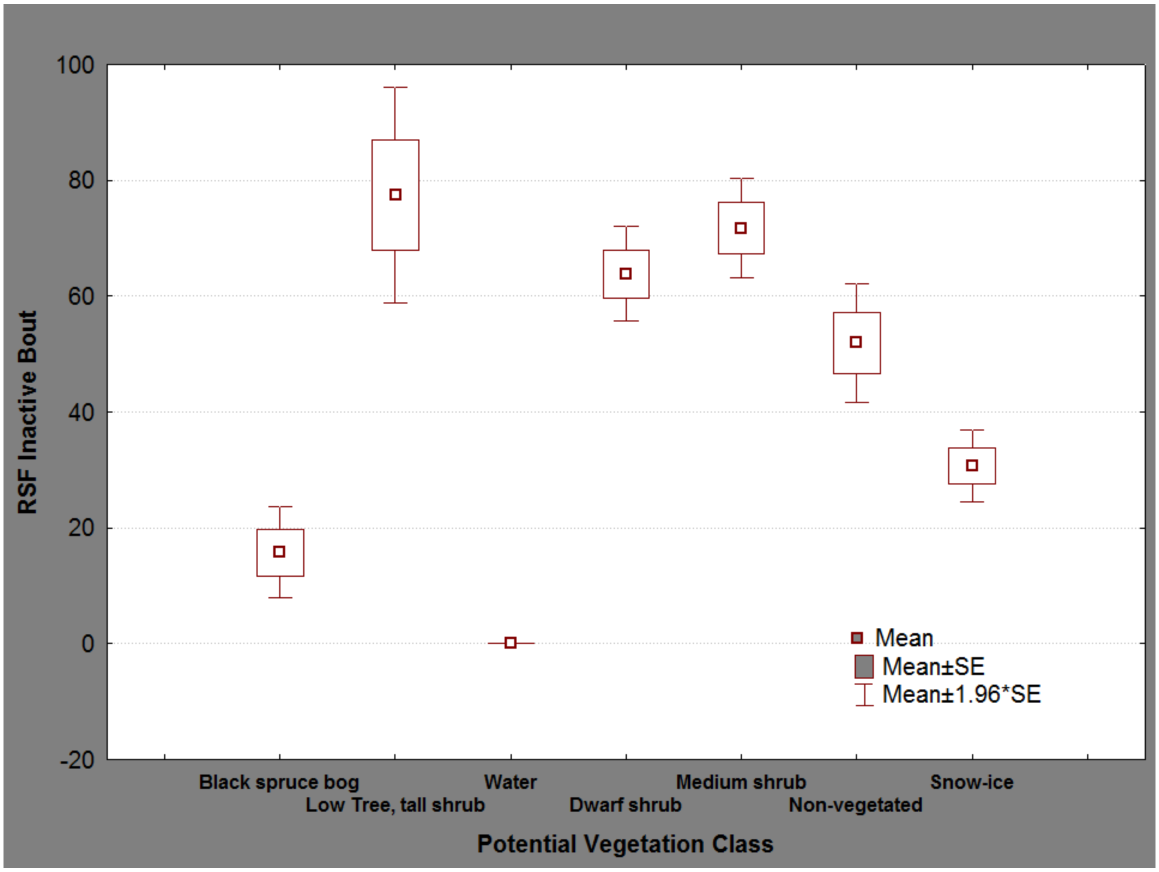

Figure B-3. Mean resource selection function (RSF) values for 7 potential vegetation classes for grizzly bears while in the inactive state in Denali National Park, 2006.

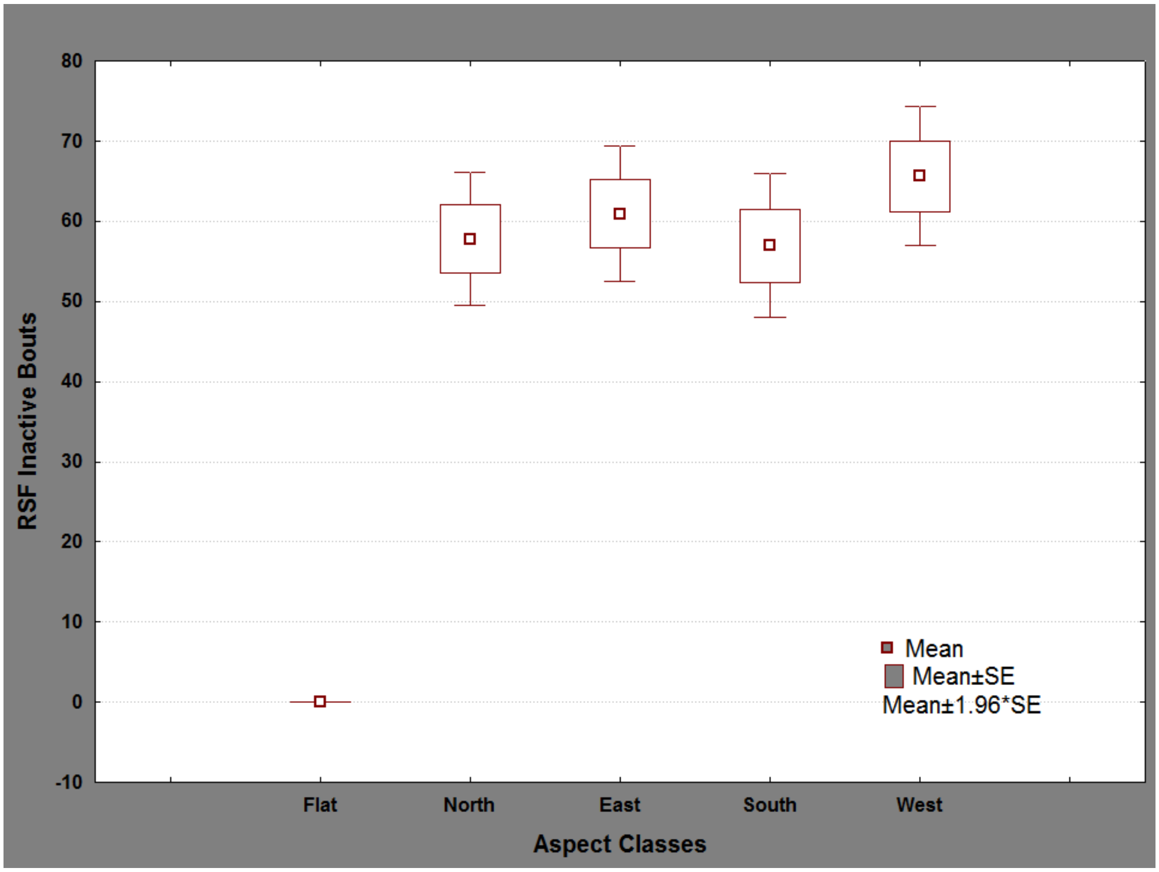

Figure B-4. Mean resource selection function (RSF) values for 5 aspect classes for grizzly bears while in the inactive state in Denali National Park, 2006.

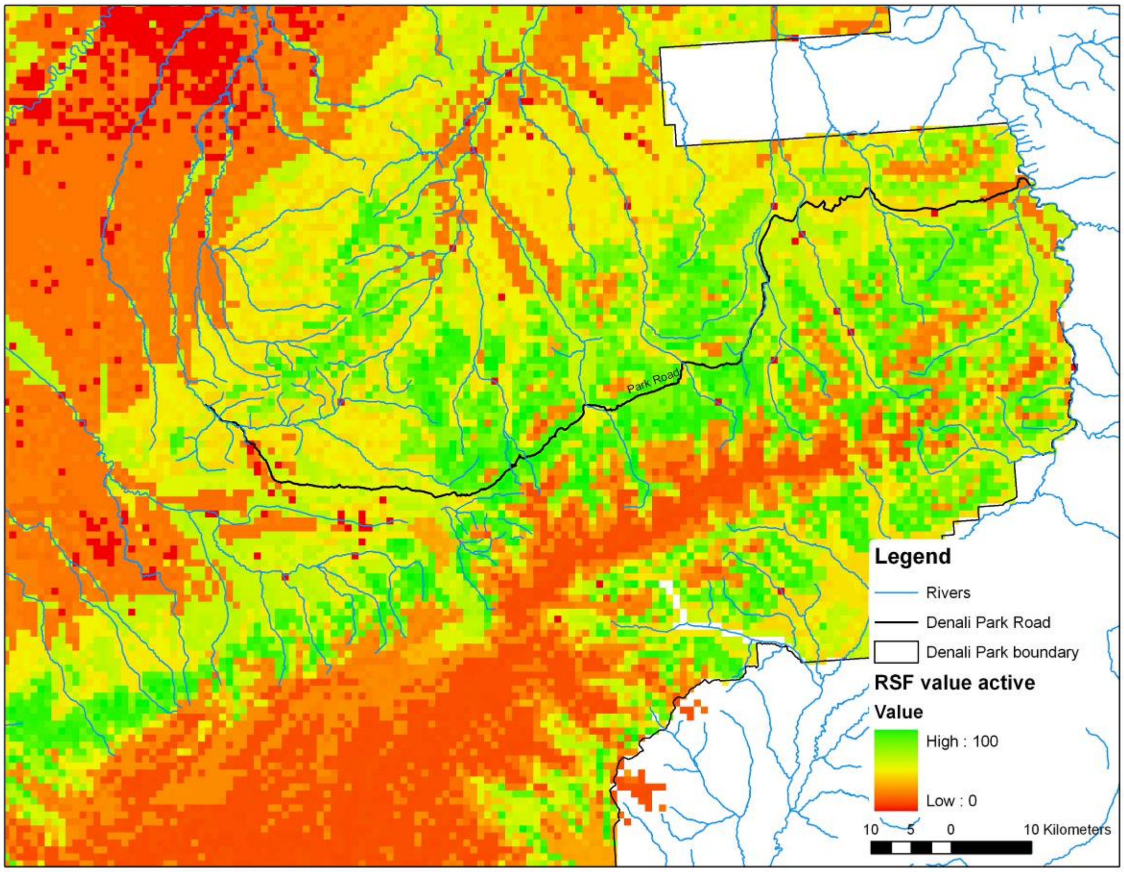

Figure B-5. Probability of occurrence of active grizzly bears in Denali National Park based on resource selection function (RSF) values. Higher RSF values represent an increased probability of use.

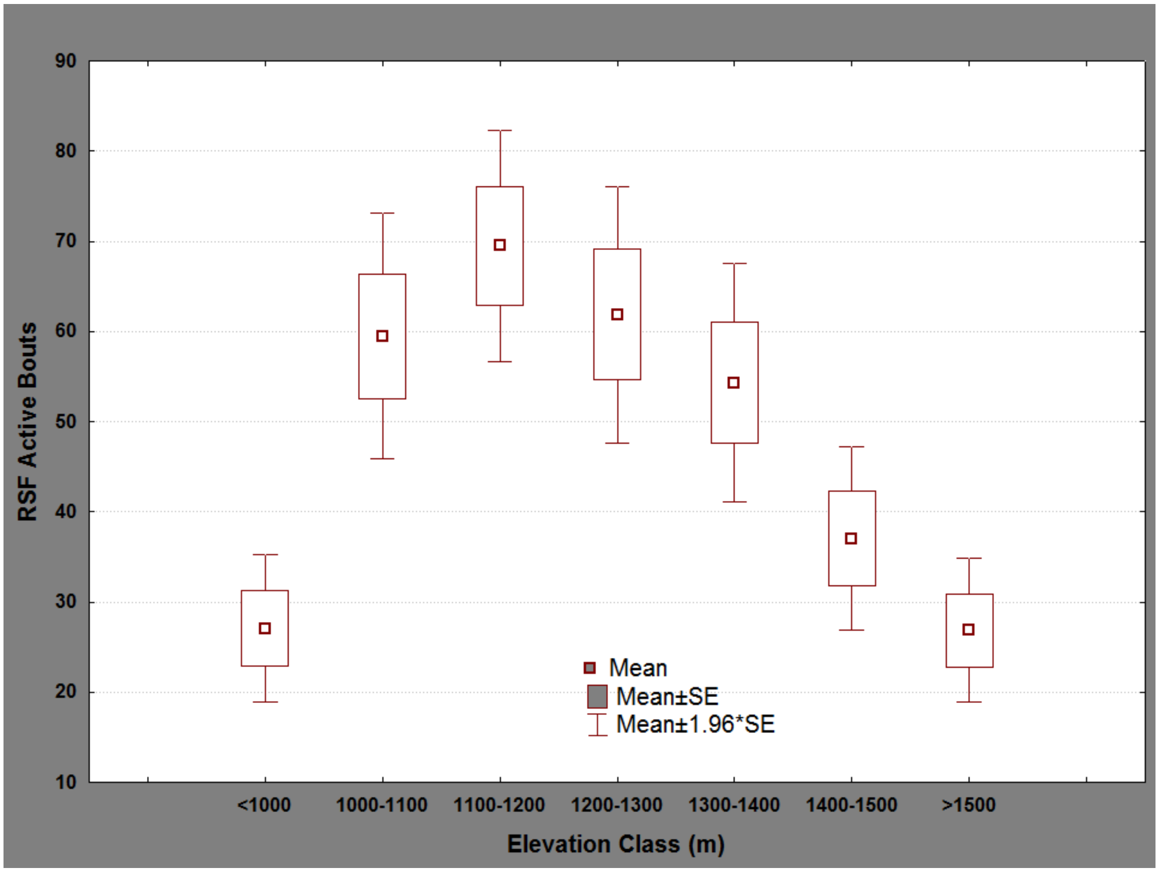

Figure B-6. Mean resource selection function (RSF) values for 7 elevation classes for grizzly bears while in the active state in Denali National Park, 2006.

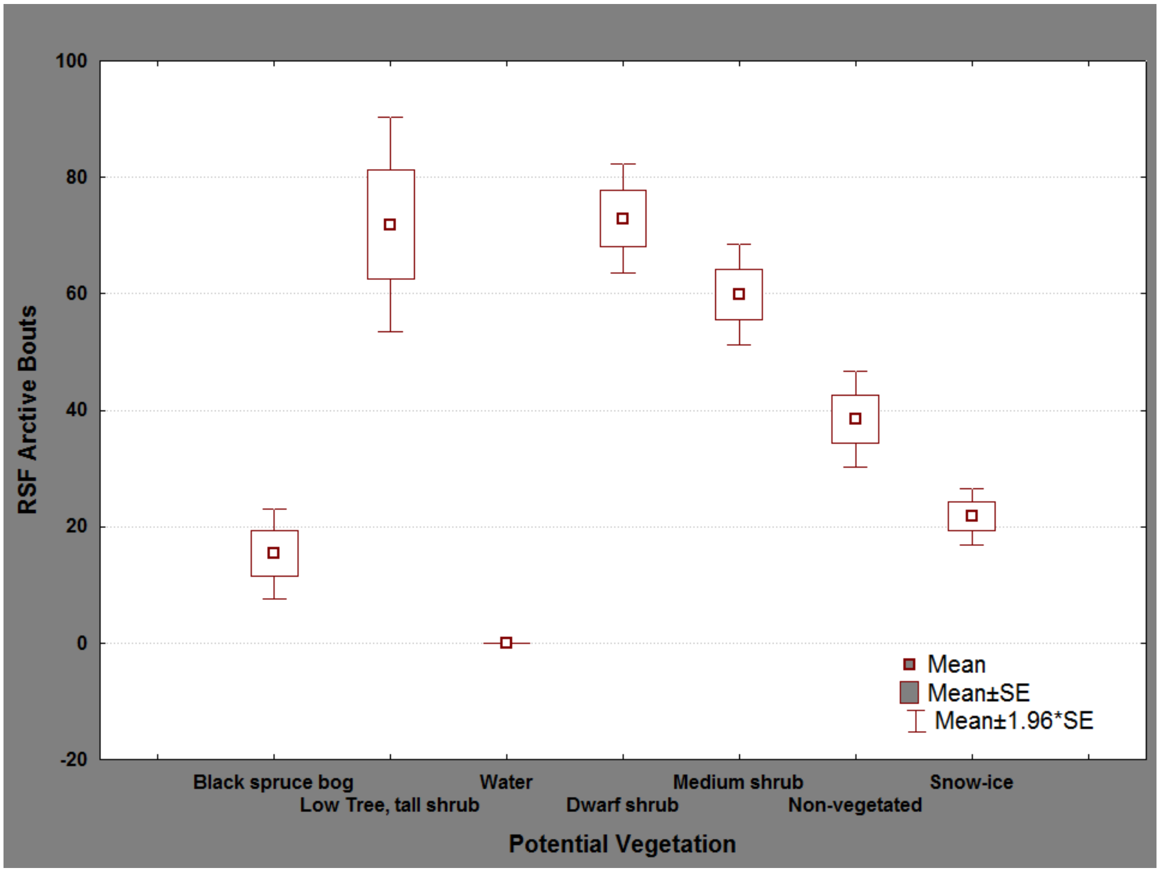

Figure B-7. Mean resource selection function (RSF) values for 7 potential vegetation classes for grizzly bears while in the active state in Denali National Park, 2006.

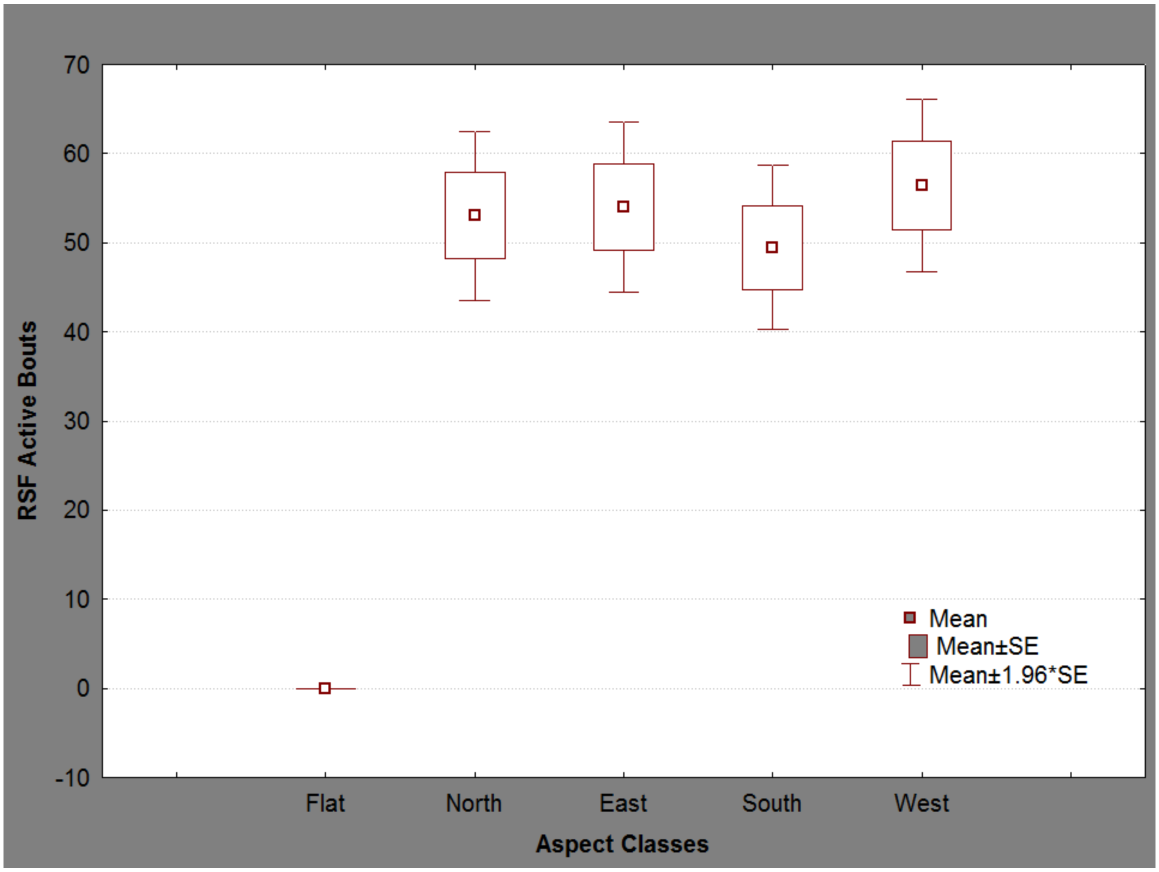

Figure B-8. Mean resource selection function (RSF) values for 5 aspect classes for grizzly bears while in the active state in Denali National Park, 2006.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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