Final Wildlife Research Report ADF&G/DWC/WRR-2017-2

Movements and Sightability of Moose in Game Management Unit 21E

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2017

Alaska Department of Fish and Game Division of Wildlife Conservation

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Cover photos: (front) View north from Innoko-Yukon Rivers floodplain; (back) Moose concentrated on island in Yukon River in late March during period of deepest snow, western Interior Alaska.

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Abstract

Understanding movements and seasonal dispersion of moose (*Alces americanus*) and estimating their detection during aerial surveys is important to design surveys for abundance and age-sex composition, ultimately to provide sustainable hunting opportunity. We obtained GPS telemetry fixes every 4 hours from 21 female and 28 male moose during March 2010–March 2014 to estimate detection probability in late-winter surveys, twinning rate in early summer, and describe annual movements in the lower Innoko River and middle Yukon River region. This report focuses on movements and dispersion. To gauge moose vulnerability during potential hunting periods (September–March), we examined proportions of locations ≤0.8 km and ≤1.6 km of navigable rivers, recognizing that moose hunting in winter is closed ≤0.8 km of the Innoko and Yukon rivers. We also conducted post hoc evaluations of constrained female movements indicative of parturition and male movement as correlated to temperature during mid-August to mid-October, when reduced movement might reduce detection by hunters and thus moose vulnerability to harvest.

Seasonal dispersion of moose verified the boundary of the late-winter survey area was appropriate and suggested population coverage for fall age-sex composition surveys was also adequate. Both sexes were slightly more prevalent within 0.8 km of rivers for boat access in October (52%) than in September (50%) or November (45%). For boat access to 1.6 km (September–November), moose prevalence increased by 39–55% for males and 19–29% for females. Considering potential (predominantly antlerless) hunts by snowmachine in winter, we found a slight increase in male (25–34%) and female (20–29%) prevalence from November to March in areas open to hunting. Females were substantially more prevalent over winter months (39–47%) compared with males (17–31%) in areas closed to hunting, validating the regulatory protection during a period of high harvest vulnerability. Patterns in net squared displacement (NSD) suggested that 56% of females over 41 moose-years and 60% of males over 52 moose-years had movement patterns indicating migration, but no movements exceeded 20 km beyond of the Unit 21E boundary. Weekly averages of changes in NSD identified optimal periods for VHF telemetry to define constrained range use and detect relatively rapid movements for this population. Behavioral change point analysis of movements during 49 female-years validated positive and negative evidence of parturition. Male movement rate was not consistently correlated with ambient temperature in fall, but we did not evaluate whether changes in movement patterns or habitat selection during warmer periods of the hunting season may reduce moose detection by hunters, thus potentially lowering moose vulnerability to harvest.

***Key words*:** Alaska, *Alces*, behavioral change point analysis, climate change, GPS telemetry, harvest, migration, movements, net squared displacement, parturition, snow, survey.

♦ ♦ ♦

Introduction

Residents of the lower Innoko River and middle Yukon River primarily from the communities of Grayling, Anvik, Shageluk, and Holy Cross (GASH) rely on moose (*Alces americanus*) for subsistence, and guiding of nonlocal moose hunters in fall provides seasonal employment to local residents. In 1994 the intensive management (IM) of moose populations to produce a high yield for consumptive use was defined and mandated in Alaska Statute[3]. Objectives were set for Unit 21E moose in 2000 by the Alaska Board of Game for a population of 9,000–11,000 and a harvest of 550–1,100[4].

Land managers and local residents have perceived large-scale seasonal movements of moose to riparian winter habitat, particularly south of Anvik (Yukon-Innoko Moose Management Plan[5]; Yukon-Innoko Moose Management Working Group 2006:10). An unpublished study of moose movements in Unit 21E by Alaska Department of Fish and Game (ADF&G) and the U.S. Fish and Wildlife Service (USFWS) during the late 1980s was based on limited VHF relocations but indicated common seasonal movements of 60 km and extreme movements of 100 km (male) and 225 km (female) in opposite directions from the study area (Appendix A). Whether these movements were migration or dispersal movements is unknown due to limitations of data collection. Local residents perceived a decline in moose abundance during the fall hunting season that was not reflected by late-winter abundance estimates. Early-winter aerial surveys soon after the hunting season are rarely feasible in this area due to frequent poor flying weather and unreliable snow conditions.

The Yukon-Innoko Moose Management Plan (Yukon-Innoko Moose Management Working Group 2006:i) described the intent of local residents to “establish a proactive management program that will help to maintain an abundant moose population to provide for high levels of human consumptive uses. This approach is designed to help prevent a decline in the moose population to a low level that would be very difficult to reverse.” In 2010 the Alaska Board of Game authorized an IM plan for Unit 21E moose[6] with a decision framework to implement wolf control if the abundance of observable moose (not corrected for sightability) declined to $\leq 0.4/km^2$ ($\leq 1/mi^2$) in a 12,980 km^2 (5,070 mi^2) late-winter survey area that bounded the Yukon-Innoko floodplain and adjacent hills. ADF&G-Division of Wildlife Conservation (DWC) recognized a need for biological information about moose in Unit 21E to better understand moose seasonal movements and sightability for design of aerial surveys, moose nutritional condition as a possible factor limiting abundance, and the potential to manage moose population growth through harvest if wolf control allowed the population to increase.

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[3] Title 16, Sections 05.255(e)–(g) and (k).

[4] Alaska Administrative Code, Title 5, Chapter 92, Section 108.

[5] http://www.adfg.alaska.gov/static/research/plans/pdfs/yukon_innoko_plan.pdf

[6] Alaska Administrative Code, Title 5, Chapter 92, Section 124.

In addition to the earlier movements study, the biological data available for design of a Unit 21E IM program for moose in 2010 consisted of 3 abundance estimates without sightability correction (range: 0.35–0.47/km^2) from late winter since 2000 (Kellie Seaton 2014:Appendix A), 3 estimates of November age-sex composition and 7 estimates of twinning rate since 1998 (Peirce and Seavoy 2010), and 1 browse survey from 2006 (Paragi et al. 2008). McGrath area managers sought to verify whether the current sampling boundary for the geospatial population estimator (GSPE) used to estimate late winter abundance is large enough and appropriately shaped to contain most of the moose available in the area during the fall hunting season for moose (5–25 September and additionally 25 August–4 September and 26–30 September on federal lands).

The research goals for a field project during March 2010–March 2014 included a better understanding of moose ecology in Unit 21E that would aid with planning and conducting aerial surveys and managing for sustainable moose harvest (e.g., Osborne and Spindler 1993). A memorandum of understanding among ADF&G, the federal Bureau of Land Management (Anchorage District), and USFWS-Innoko National Wildlife Refuge (McGrath, Alaska) regarding moose research was signed in July 2010. The memorandum specified goals, objectives, roles, and responsibilities of each party in this cooperative project that centered on acquisition of data using GPS telemetry, and it was amended in March 2015 for data sharing.

ADF&G research goal 1 was to estimate a sightability correction factor with associated precision for late-winter estimates of moose abundance as the primary metric to implement or suspend wolf control. Results were reported in 2 research memos (Kellie Seaton 2014:Appendices A and B). Survey data sheets were scanned to PDF, and both the hard and electronic copies were sent to McGrath for storage. Electronic data were entered in ADF&G's Wildlife Information Network (WinfoNet) server application for geospatial population estimator (GSPE) that serves as the archive.

Goal 2 was to increase sample size and estimated precision of twinning rate as an index to nutritional condition of adult females. If predator control led to moose population growth, twinning rate can guide recommendations for antlerless harvest to maintain productivity and reduce risk of excessive browsing pressure on winter range (Boertje et al. 2007). Results were reported in Paragi et al. (2015a), and productivity data are archived in this report (Appendix B).

Goal 3 was to describe seasonal movements and dispersion of moose for optimal design of aerial surveys to estimate population-level parameters (abundance, composition, etc.). Typical fall abundance surveys are impractical because of irregular snow cover, so we first sought to affirm for estimating the harvestable surplus (sustainable yield) that the survey boundary for late-winter (March) abundance estimates corresponds to the population hunted in September. Second, we wanted to understand the proportion of moose that are surveyed in late winter that are also categorized by age and sex during a November survey. Third, we sought to understand male and female distribution during September–March to evaluate potential access by hunters and vulnerability to harvest. Fourth, we attempted to better characterize the proportion of male and female moose that are resident and migratory in the population. Finally, we desired to define seasonal periods of rapid range shift by sex to optimize planning of VHF telemetry flights in the future.

In addition to the planned research goals, we conducted 2 post hoc analyses of the fine-scale movement data (≥1 location per day) to evaluate biological questions germane to moose management. First, we sought to identify a behavioral pattern of constrained movements by adult females in spring that indicates parturition in a remote population that is rarely observed. Second, we desired to correlate ambient temperature with male movements in fall to identify whether warm weather is associated with reduced movements, thus potentially lowering detection by hunters (vulnerability to harvest).

The research was conducted under Federal Aid in Wildlife Restoration project 1.69 as jobs/activities 1c and 1d (Paragi et al. 2015a). Information from our 3 goals was intended to aid creation of the initial IM operational plan under the IM Protocol (ADF&G 2011) for Unit 21E moose when the IM plan (regulatory: 5 AAC 92.124) is submitted to the Alaska Board of Game for reauthorization in spring 2017. Additional research goals to be addressed by federal cooperators included estimation of habitat selection and home range size. This report addresses ADF&G goal 3 and our post hoc analyses.

Study Area

Fieldwork was conducted in Game Management Unit 21E and included the western portion of Innoko National Wildlife Refuge (Fig. 1). Within Unit 21E the Innoko lowlands (30 m above sea level) contain abundant meandering sloughs and oxbow lakes in recently abandoned floodplain primarily between the Innoko and Yukon rivers east of the Nulato Hills and west of the Kuskokwim Mountains (Wahrhaftig 1965) with peaks to ca. 850 m. Wildland fire is prevalent but stochastic in spruce (*Picea* spp.)-dominated upland forest (Gabriel and Tande 1983), whereas flooding is the more common disturbance in the lowlands that distributes nutrients for plant growth in primary succession (Kielland and Bryant 1998) and helps maintain graminoid meadows within the forested floodplain. These disturbance agents, including ice scouring in the active floodplain during spring break-up, rejuvenate willow (*Salix* spp.) shrubs and young deciduous trees (*Betula neoalaskana*, *Populus balsamifera*, *P. tremuloides*) that provide concealment cover and winter forage for moose.

Paragi and Kellie (2011) characterized snow depths in the western Interior as exceeding in some years the thresholds affecting moose habitat use (70 cm) and high energy expenditure including possible reduced calf survival (90 cm) (Coady 1974). Snow depths were commonly >70 cm in the study area during a mid-April 2006 browse survey (Appendix C).

The Paradise controlled use area (CUA) has existed since 1977 and was implemented to reduce conflicts between user groups. This CUA, which lies primarily in Unit 21E between the Yukon and Innoko rivers (Fig. 1), is closed to the use of aircraft for hunting moose, including the transportation of moose hunters and their gear. This restricts access in the CUA primarily to the floodplain by residents with boats (Peirce 2014) or to floodplain or upland habitat by snowmachine if winter hunts occur.

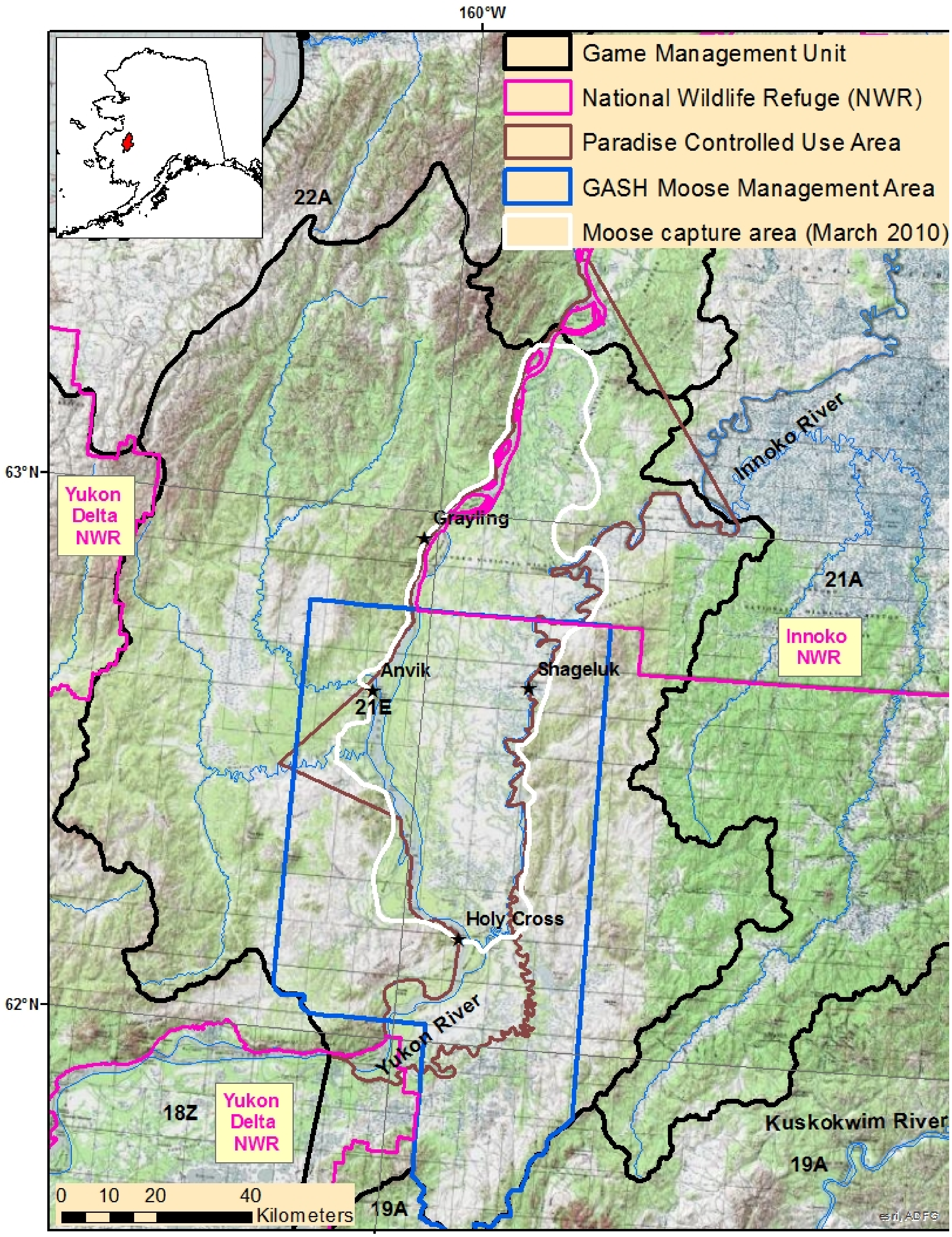

Figure 1. Location of moose study area in the lower Innoko and middle Yukon rivers region composing Unit 21E, western Interior Alaska.

Methods

SNOW DEPTH

We gauged March snow depth from ground measurements during moose captures (2010) and a moose survey (2012). We also obtained readings of vertical gauges from fixed-wing aircraft done at the start of winter months at 2 sites in the northern part of the study area (courtesy Innoko National Wildlife Refuge).

Moose Capture and GPS Acquisition

We had Telonics, Inc. (Mesa, Arizona) fit Generation IV model CLM-340 GPS transmitters to 3-inch wide butyl belting that weighed 1,900 g for adult females (n = 20). The same transmitter was fitted to 3-inch wide expandable butyl belting that weighed 2,000 g for adult males (n = 24) to accommodate 50% increase in neck circumference during the rut and return to the normal circumference outside the rut. Female collars had the GPS antenna in the dorsal position, whereas the GPS antenna on male collars was a side-mounted prototype to permit collar expansion with minimal effect on antenna position. We had transmitters programmed to collect GPS locations every 4 hours and transmit stored data to the ARGOS satellite every 7 days. GPS transmitters were synchronized on a duty cycle to transmit during a single 6-hour period to the ARGOS satellite, thus achieving a cost efficiency over requiring >1 period. GPS collars contained temperature and mortality sensors, the latter causing a reduced VHF pulse period for inactivity >5 hours. VHF transmitters on GPS collars were set to transmit for 10 hours daily starting at 15:00 Universal Time (07:00 local in summer, 06:00 in winter) for real-time observations of moose as necessary while conserving battery life. Battery life for these transmitter duty cycles were estimated to be approximately 5 years for GPS and 6 years for VHF. We also fitted Telonics MOD-600 VHF transmitters with 2-inch wide butyl belting that weighed 1,200 g for female moose (n = 10).

Our capture objective was to mark approximately an even proportion of adult male and female moose across high density areas of winter range based on prior surveys. We deployed collars during 14–18 March 2010. Moose were spotted from Piper PA-18 fixed-wing aircraft and immobilized by darting from a Robinson R-44 helicopter. Adult moose were immobilized with carfentanil citrate (3.6 mg for adult females, 3.9 mg for adult males) and xylazine hydrochloride (160 mg for adult females, 50 mg for adult males), administered intramuscularly via 3 cc or 4 cc darts. Induction typically occurred in <5 minutes, and handling took about 15 minutes. Moose were fitted with a collar after a blood sample was drawn and measurements taken, with a canine extracted from male moose to establish the relationship between neck circumference and age for a low-density population (i.e., good nutritional condition with potentially larger body size). We administered Procaine Penicillin G at a concentration of 300,000 units per ml (3 ml/100 lb [45 kg]) intramuscularly as a prophylactic against susceptible infections by *Clostridium* bacteria. We administered Naltrexone (100 mg/mg of carfentanil) intramuscularly to reverse the effects of carfentanil and Tolazoline (0.5 mg/lb [0.23 mg/kg]) intramuscularly to increase respiration and reverse the effects of xylazine. We listened for mortality signals (caused by collar inactivity) daily once collar deployment began but found no evidence of capture myopathy or other capture-related mortality during field operations. GPS and VHF function were tested before deployment, but 1 VHF collar (ID 41) was never detected after deployment or subsequent searches, presumably because of failure. Blood samples were tested for *Brucella* titer on all moose, and trace minerals were determined for the first 25 moose handled. Concentration of pregnancy-specific protein B in blood indicated 28 of 30 females were pregnant. Capture metrics were archived in a Microsoft®Access (Redmond, Washington) database for moose (ADFG_Moose_Interior) stored on the regional computer server.

On 12 October 2010 we recaptured 5 older males to verify collar expansion and examine their necks for signs of collar abrasion from neck swelling during the rut. On this date we also recovered 2 male collars for subsequent refurbishment because GPS transmission had failed (we temporarily fitted 1 male with a VHF collar and the other with a GPS collar opportunistically retrieved from a recovered poaching mortality of a collared male without salvage on the same trip). On 21 April 2011 we redeployed these 2 refurbished collars: 1 on the male with the VHF collar, and 1 on a new female. During 19–24 March 2014, we recaptured live moose with GPS collars and recovered 3 GPS mortalities; a single male remained collared because capture was infeasible due to high winds and dense cover. Collars from mortalities were also retrieved during associated fieldwork in April 2011, July 2012, and June 2014. Moose were captured and handled under the ADF&G Institutional Animal Care and Use Committee permit 2010-02 and subsequent renewals 2011-05 and 2013-035.

For obtaining GPS data in near real time, we initially downloaded GPS locations via the Internet approximately once per week from the ARGOS distributor (CLS America, Lanham, Maryland), processed them with the Telonics data converter, and appended them to a Access 2007 database. We used a filter in Access to verify unique moose ID and date-time record (hh:mm:ss) of each satellite-acquired record to prevent duplication during successive downloads. Beginning in November 2012 we contracted with Alaska Biological Research, Inc. (Fairbanks, Alaska) to create a program that automatically downloaded ARGOS data for multiple GPS projects in our region and coded data by animal ID (thus reducing potential for error in manual entry) into an Access database maintained on the Alaska Biological Research, Inc. server. Weekly downloads were expected to adequately overlap transmission periods, but we also obtained electronic data summaries from the ARGOS distributor once per month on compact disc (CD) as a safeguard against failure of Internet downloads and second backup against premature failure of transmitters. Display of data during the acquisition phase was done utilizing an open database connectivity interface between Access and ArcGIS™ 10.3 (Environmental Systems Research Institute, Inc. (Esri), Redlands, California). Of 203 VHF locations acquired during the study (0–8 per individual moose; Appendix D), we obtained 80 (39%) during sightability trials for both sexes in March 2012 with the remainder primarily from females during calf observations from fixed-wing aircraft in June, November, and March. VHF data were also stored in Access for separate query but not analyzed with the GPS data.

Raw GPS data were processed using Telonics Data Converter software. We recovered 39 GPS collars for downloading datalog files, including 2 of 8 male collars where GPS failed prematurely but VHF transmission continued long enough for recapture. Two additional male collars were not recovered (we could not capture 1 moose and we could not retrieve 1 collar underwater in a gravel pit near a village, likely a hunting mortality). For the 8 male collars that were not recovered, plus a collar from a female mortality early in the study for which the datalog could not be located, we used Access queries to compare the date and time of successful GPS acquisitions we downloaded weekly from the ARGOS distributor with those obtained on CD from the ARGOS distributor. GPS locations were filtered manually by date and time of deployment and the estimated mortality or retrieval from live animals. Capture locations from the helicopter GPS were excluded because animals may travel substantial distances from the time spotted to immobilization, which would bias inference on spatial use of an undisturbed animal. We then screened data following Bjørneraas et al. (2010), where locations were removed if they were >100 km from the median of a 21 point moving window, centered on that location, or if the speed of the segments immediately preceding and following that location was >1.5 km/h and the cosine of the turning angle was <−0.97. We did not screen locations using the mean of the moving window, as described in Bjørneraas et al. (2010), because this proved to be overly conservative, owing to occasional intervals between successive locations greater than 2 hours. Mortality sensors sometimes gave false positives, so to estimate time and date last alive we plotted location clusters near the recovery site.

Our USFWS collaborator (Steve Kovach) utilized 3 refurbished collars (2 M, 1 F) in McGrath prior to redeployment in April 2011 to evaluate collar positional error. Reference position was obtained using a survey-grade Trimble GeoXT GPS with external antenna. We expect this evaluation of positional error from stationary collars to be conservative because it occurred in a single terrain cover type (flat, nonforested) and did not include animal behaviors, both of which influence acquisition success of 3-D locations and positional error (Cain et al. 2005; Frair et al. 2010; Mattisson et al. 2010). Collar temperature was calibrated to ambient temperature readings within 30 minutes from the National Weather Service station 1.1 km away, with April 2011 ambient temperature prior to redeployment ranging from −25°C to 9°C.

Moose Movements and Seasonal Dispersion

We plotted moose locations during age-sex composition surveys (November) and spring abundance surveys (March) overlaid on November and March survey boundaries to evaluate suitability of boundaries for including the target population. Although the sample size of GPS collared moose declined during the study, we used the number of collared individuals present within these 2 survey boundaries to assess sex composition (M:F ratio) during hunting season (September), composition surveys, and abundance surveys for comparison to aerial surveys of random moose in November surveys. We also used presence of 1–2 calves at heel during November and/or March telemetry flights over the core wintering area to grossly assess young to adult female (Y:F) ratio for collared moose during these 3 periods, using November data as a conservative proxy for the prior September. All females were not located during all telemetry flights, but we did not perceive a consistent individual bias prior to mortality or censoring, and we included calves observed in adult female groups for which assignment to the marked dam was infeasible (Appendix B). We recognize that visual detection of moose during aerial surveys may vary substantially by season (typically lower and more variable in late winter than in early winter; Gasaway et al. 1986), but we merely report ratios of GPS collared moose for comparison of what would be available to be seen.

A winter hunt for moose in Unit 21E currently occurs only on federal lands (15 February–15 March) with the restriction that moose may not be taken ≤0.5 mile (0.8 km) on either side of the Innoko and Yukon rivers. To assess whether winter hunts would afford greater harvest opportunity than fall hunts if the moose population increased following wolf control, we first calculated the proportions of male and female locations that were within 0.8 and 1.6 km (0.5 and 1.0 mi) of rivers and sloughs. We judged 1.6 km as the maximum distance hunters would pack moose during the open water period in September (the present moose hunt) and October (Fig. 2). We had 2 local residents verify extent of river use by hunters from surface waters visible at 1:750,000 scale in the National Hydrography Dataset[7] and digitized these segments for analysis. We extended the evaluation to November on the assumption that open water may occur later in fall in the future due to present climatic trends (Chapin et al. 2014). We also evaluated moose locations for the same 0.8 and 1.6 km buffers during periods when rivers are frozen and allow snowmachine access on safe ice (November–March); this period may be shortening given current warming trends in northern Alaska (Schneider et al. 2013). We recognize that hunters would be able to travel outside frozen water courses by snowmachine in more sparsely forested upland habitats, so the buffered rivers are a minimal characterization of potential hunter access to moose in winter. However, we also expect moose to be more tightly confined to river corridors that contain abundant forage and potentially shallower snow because of wind compaction and frozen overflow, particularly during winters of deep snow. We used ArcGIS for spatial selection of points (“are within” option that includes point features on boundaries of polygons), clipping polygons, and buffering rivers.

Net squared displacement (NSD) is a scale-independent approach to objectively characterize movement patterns such as migration (Bunnefeld et al. 2011). NSD measures the straight-line distances between a starting location and subsequent locations for the movement path of a given individual. We calculated NSD for individual moose relative to their starting location on 19 March (date all moose were collared in 2010 on winter range, just prior to collar removal in 2014) for each of the 4 years animals were marked (2010–2011 through 2013–2014). This date is approximately the spring equinox when moose are still on winter range (not prone to large movements) and allowed maximum use of our data set. Only those moose alive and logging GPS data at the start and end of a yearly period were included, and we excluded animals with >60 days of gap in GPS locations during April–October that could bias pattern recognition. We used shape of NSD plots (Fig. 3) to categorize the status of moose in a given year as nonmigratory, migratory, mixed migratory, or disperser (Bunnefeld et al. 2011). Nonmigratory or resident moose often have relatively short seasonal movements within a physiographic area (Gasaway et al. 1983:18) that may involve important shifts among habitat types but generally have partial overlap of summer and winter ranges, whereas migration denotes movement between spatially distinct seasonal ranges (LeResche 1974). Regardless of amplitude in distance moved, patterns in NSD over time may be used as evidence of migration behavior (Dettki and Ericsson 2008; Singh et al. 2012).

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[7] U.S. Geological Survey, https://catalog.data.gov/dataset/usgs-national-hydrography-dataset-nhd-downloadable-data-collection-national-geospatial-data-as

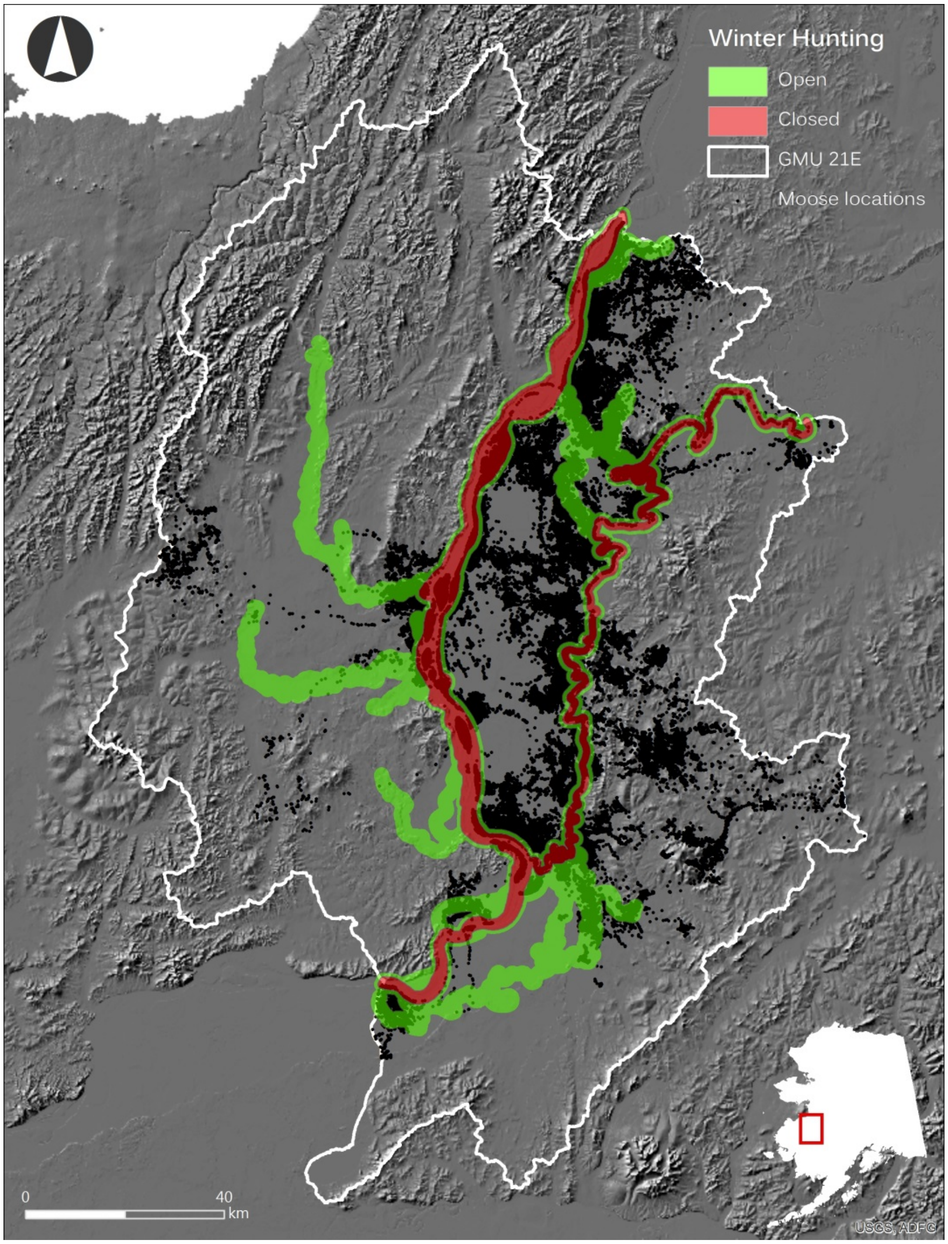


Figure 2. Buffers of 1.6 km (green) and 0.8 km (red) along rivers navigable to motor boats in Unit 21E, western Interior Alaska. Buffers were used for evaluating moose presence (vulnerability to harvest) during potential hunt periods in September through March. The red buffer is closed to winter moose harvest.

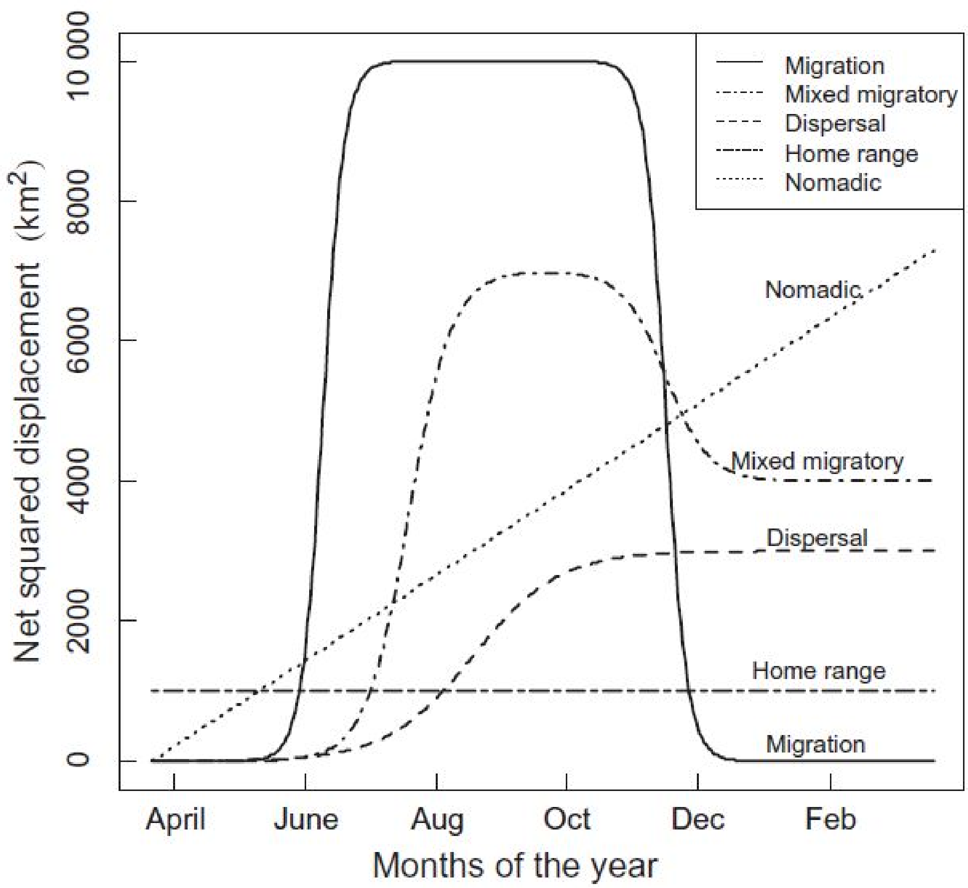


Figure 3. Stylized characterization of movement behaviors for moose using net squared displacement across an annual cycle beginning 21 March (Bunnefeld et al. 2011:467).

We anticipated that defining periods of rapid movement indicative of range transition would aid planning of future VHF telemetry by managers for monitoring biological events or seasonal habitat use (e.g., calving, calf rearing, rut, winter range). To describe degrees of movement by biological period (e.g., Joly et al. 2015a), we also used NSD to calculate weekly average GPS paths of males and females for individual-year combinations with a full 12-month period. We calculated the mean NSD for each week of the year (beginning 19 March) for each individual, and then the absolute value of the difference between the mean for each week and the mean for the subsequent week. Individual differences in weekly means were then averaged, by week, separately for each sex. Differences in means could not be calculated for weeks at the beginning and end of each path, resulting in a gap each year in the last 2 weeks of March. We did not expect dramatic changes in movements in this period because the deepest snow accumulation of the winter occurred in March or April (Appendix E).

Short-term Movements Indicative of Parturition

We used VHF telemetry to observe marked females for presence of ≥1 calf in late May or early June for estimation of twinning rate. Observations of the same females were attempted again in late October or early November to categorize maternal status during the summer and fall and in late March for overwinter status. The infrequency of visual relocation and unequal sample sizes between years (Appendix B) did not warrant estimates of calf survival but provided evidence of maternal status if calf observations were missed during spring twinning surveys.

To identify parturition dates, we used behavioral change point analysis (BCPA; Gurarie et al. 2009) to search for a restricted movement pattern characteristic of calving female moose. Within a specified analysis window in a time series, movement pattern may be described with parameters derived from changes in location and distance, such as mean $\mu(t)$, variance $\sigma^2(t)$, and continuous autocorrelation $\rho(t)$. We expect BCPA to identify where changes in a movement metric were abrupt before calving, given that female movements change considerably before parturition (Testa et al. 2000; Poole et al. 2007; Wattles and DeStefano 2013). We analyzed GPS paths of 21 females in Alaska between 1 May and 1 July for 1–4 years each for a total of 47 female-years. GPS paths with data gaps in excess of 72 hours were eliminated from analysis. To evaluate the behavioral break point change in moose movement, we used persistence velocity as the representative movement metric. Persistence velocity (V_p) decomposes an animal's movement into the velocity (V) and turning angle (Ψ) between subsequent locations, defined as:

$$V_p = V * \cos(\Psi)$$

BCPA is an empirical distillation of movement data (Gurarie et al. 2009) with 3 algorithm parameters that must be user specified: size of analysis window, sensitivity to change detection, and cluster width. First, we set a moving window of 50 data points over which to search for change points. Second, following exploratory analysis we settled on a sensitivity parameter for the adjusted Bayesian information criterion (K) of 0.3, which produced a reasonable balance between reliably identifying a change point while minimizing spurious structural shifts in the plot of V_p. K is generally conservative with respect to selecting the most parsimonious BCPA; increasing its value increases the sensitivity to detect change in movement pattern. In the event that no change point corresponding to the calving period could be identified, we increased K to 0.5 and repeated the analysis. Third, to filter out minor change points we used a 48-hour cluster width within which neighboring change points were clustered. We saved plots for each individual by year to archive information used for interpreting BCPA (Fig. 4).

As a complement to BCPA, we estimated parturition date based on contraction in size of home range for adult females over a moving window of time. McGraw et al. (2014) described the 'localization' behavior of female-calf pairs in Minnesota, where the area used following parturition dropped to 1.72 ± 0.48 ha for approximately 7 days. We calculated the area of the minimum convex polygon (MCP) in a moving window using our GPS location interval of 4 hours. These windows are overlapping and are not the same as daily movement: the first window consisted of the first 6 locations, the second window consisted of locations 2–7, etc. By using a ~24-hour rolling window we included daytime and nighttime locations. When the area of the rolling MCP is plotted against the date of the last location in the window, the parturition date becomes clear as a sudden and sustained contraction in the area used (Fig. 5). Based on mean localization area (McGraw et al. 2014), we identified the earliest date where the mean of the "rolling" MCP remained equal to or less than 1.7 ha for approximately 72 hours. We assumed the date of the first location in a window that meets this criterion should correspond to calving. Female moose commonly make relatively long-distance movements immediately preceding parturition (McGraw et al. 2014). To weed out false positives, the window was not initialized until a threshold area, designed to represent this spike in movement, had been reached. We used an 18-point moving window for the search algorithm with a threshold area of 100 ha.

Male Movements Related to Fall Temperature

In recent years hunters have reported reduced harvest success for male moose during relatively warm conditions in September and attributed the change to possibly limited movements or apparent absence of male moose from traditional hunting areas (McNeeley and Shulski 2011; McNeeley 2012). We sought to address this issue for the current dates of the fall hunting season in Unit 21E by testing for an inverse relationship between fall ambient temperature and movement rates of male moose. We estimated 4-hour movement rates of 25 males during 15 August–15 October 2010–2013 and obtained the closest hourly temperature at the Anvik airport (91 m above sea level), which is in the westcentral portion of the study area (Fig. 1). We also compared these male movement rates to the 4-hour average of real-time temperature recorded on the individual collars (i.e., the 2 data points that define the movement period).

Data Management

GPS locations filtered for analyses were stored in an Access database and an Esri geodatabase. Plots of annual NSD to characterize movement patterns, female BCPA during calving, and male movements in fall were stored by year and individual ID. Large GPS data files (>75 MB) are archived on the DWC server in directory of the lead author in folder <archive\moose_movements_sightability_Unit 21E_2010_2014>. Smaller data files and the results of analyses, memos, and reports are in the WinfoNet Data Archive under the project name "Unit 21E moose movements and sightability" along with metadata on Microsoft®Excel, Access, and Esri files.

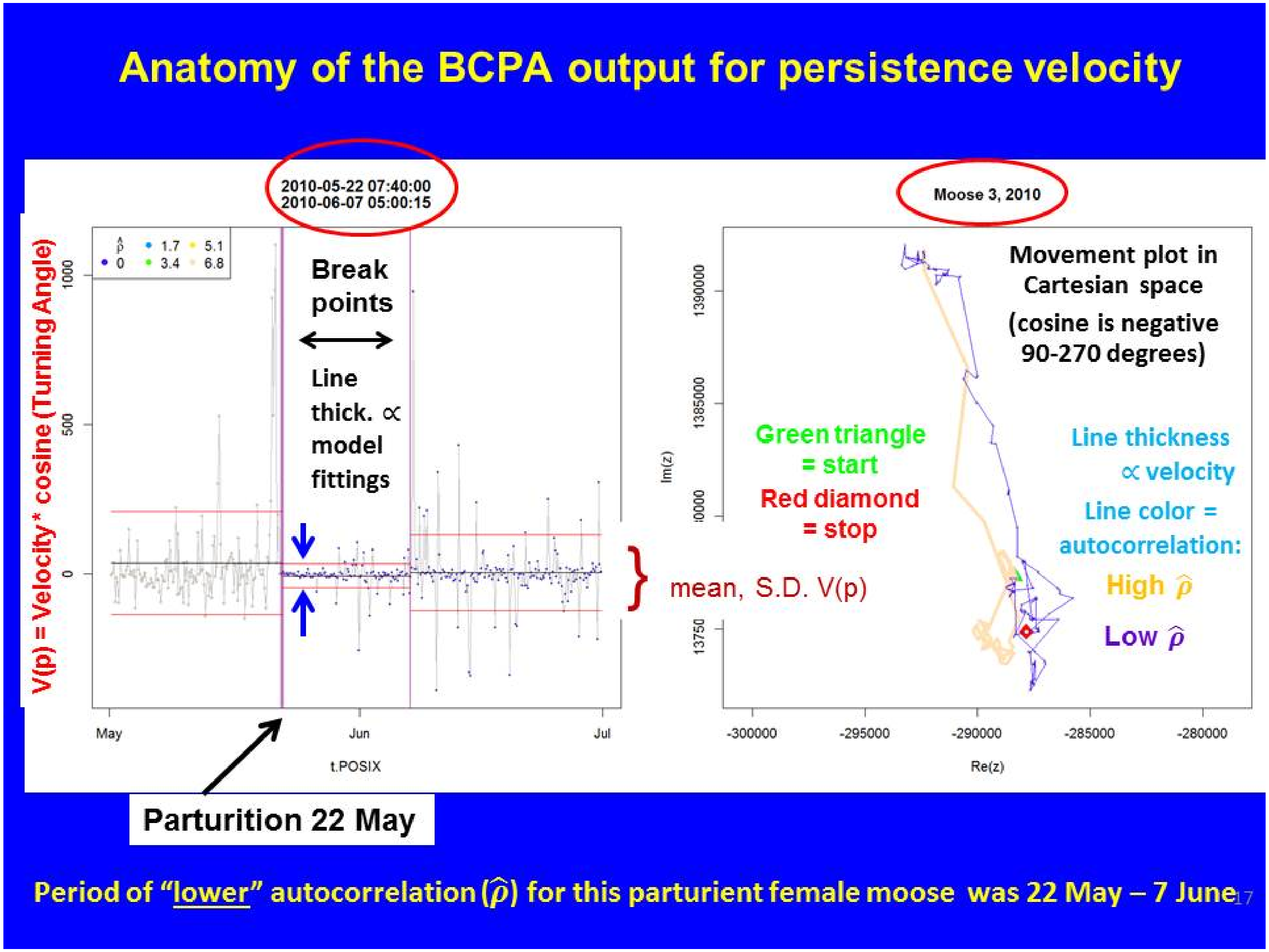


Figure 4. Illustration from a scientific presentation of modeling output for behavioral change point analysis on a parturient female moose.

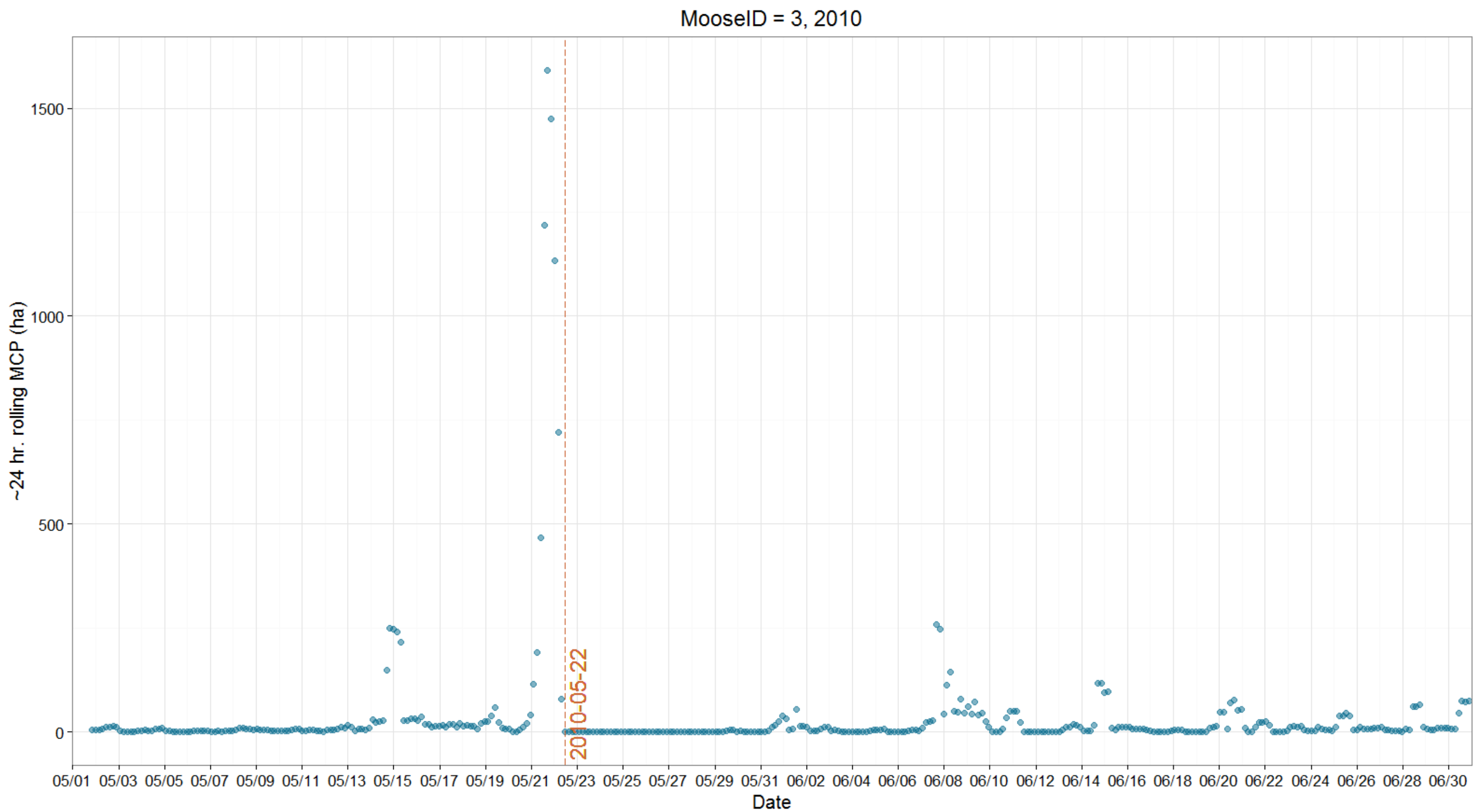


Figure 5. Modeling output of rolling minimum convex polygon (MCP) range size based on GPS locations in a rolling window spanning approximately 24 hours for a parturient female moose (same individual as in Fig. 4) that illustrates preparturition movement, estimated parturition date (22 May, vertical dashed line), and dramatic contraction of range size for several days postparturition.

Results

SNOW DEPTH

In March 2010 the snow depth recorded from 3 measurements within reach at 49 moose capture sites visited by helicopter averaged 70 cm (range: 45–100 cm; Fig. 6). Snow depth recorded from 3 measurements at 5 landing sites by fixed-wing airplane during a 12–16 March 2012 moose survey averaged 80 cm (range: 38–108 cm; T. F. Paragi, K. A. Kellie Seaton, and B. D. Taras, ADF&G, 2014, Unit 21E moose population estimate with sightability correction - March 2012, memorandum, Fairbanks). Snow depth measured at 2 vertical gauges in the northern third of the capture area indicated potential to influence habitat selection by adult female moose in all winters of our study and posed substantial energetic demands in some winter months (Appendix E). Observations at vertical gauges installed by ADF&G in the southern portion of the capture area were inconsistent because gauges frequently required maintenance, but depths were generally lower than those observed on the northern gauges (Appendix F).

Performance of Male and Female Collars

Four males (including a recent mortality that was likely poached) had no rubbing or only broken hair beneath the expandable collar, whereas 2 had skin abrasions because the collar had expanded to only half the full extent of travel (Appendix G). The small number of males we examined precluded inference on the relationship between neck circumference and age.

Successful GPS acquisition to 3-D position tended to be higher for both sexes during spring and summer compared with fall and winter (Appendix H). GPS transmission failed before the end of the study for 8 of 24 male collars and none of 20 female collars. CD records were more complete for these 8 males ($\bar{x}$ = 3,323 locations, range: 951–5,446) than the data we downloaded manually ($\bar{x}$ = 10% more locations, range: 7–15), so we used the CD data for analyses. We averaged 29 months (range: 7–48) of continuous GPS data for male collars and 32 months (range: 13–48) for female collars (Appendix I). Two male collars had acquisition gaps of 7 and 27 months that began after mortality events, but they resumed consistent GPS acquisition prior to collar retrieval. After filtering we had 286,733 GPS locations suitable for analysis from 46 moose, averaging 6,064 for females (n = 21, SD = 3,439, range: 951–16,702) and 5,903 for males (n = 25, SD = 4,848, range: 1,238–18,080). Positional accuracy during 68 trials under ideal conditions averaged 7 m for the female collar (max. = 21 m) and 9 m and 12 m (max. = 40 and 44 m) for the 2 male collars, with directional bias predominantly south of actual location (Appendix J). Temperature calibration showed collars within 2°C of NWS readings in 90% of trails (n = 30, male and female collars combined), tending to be slightly higher than ambient, with maximum positive bias on 10 occasions ranging 7–18°C (Appendix K).

Moose Movements and Seasonal Dispersion

We collared female and male moose throughout the study area to ensure geographic coverage with a representative sample (Fig. 5). The March 2012 GSPE survey boundary included 99% of March relocations during 2010–2014 (Fig. 7), validating the survey boundary for sampling of

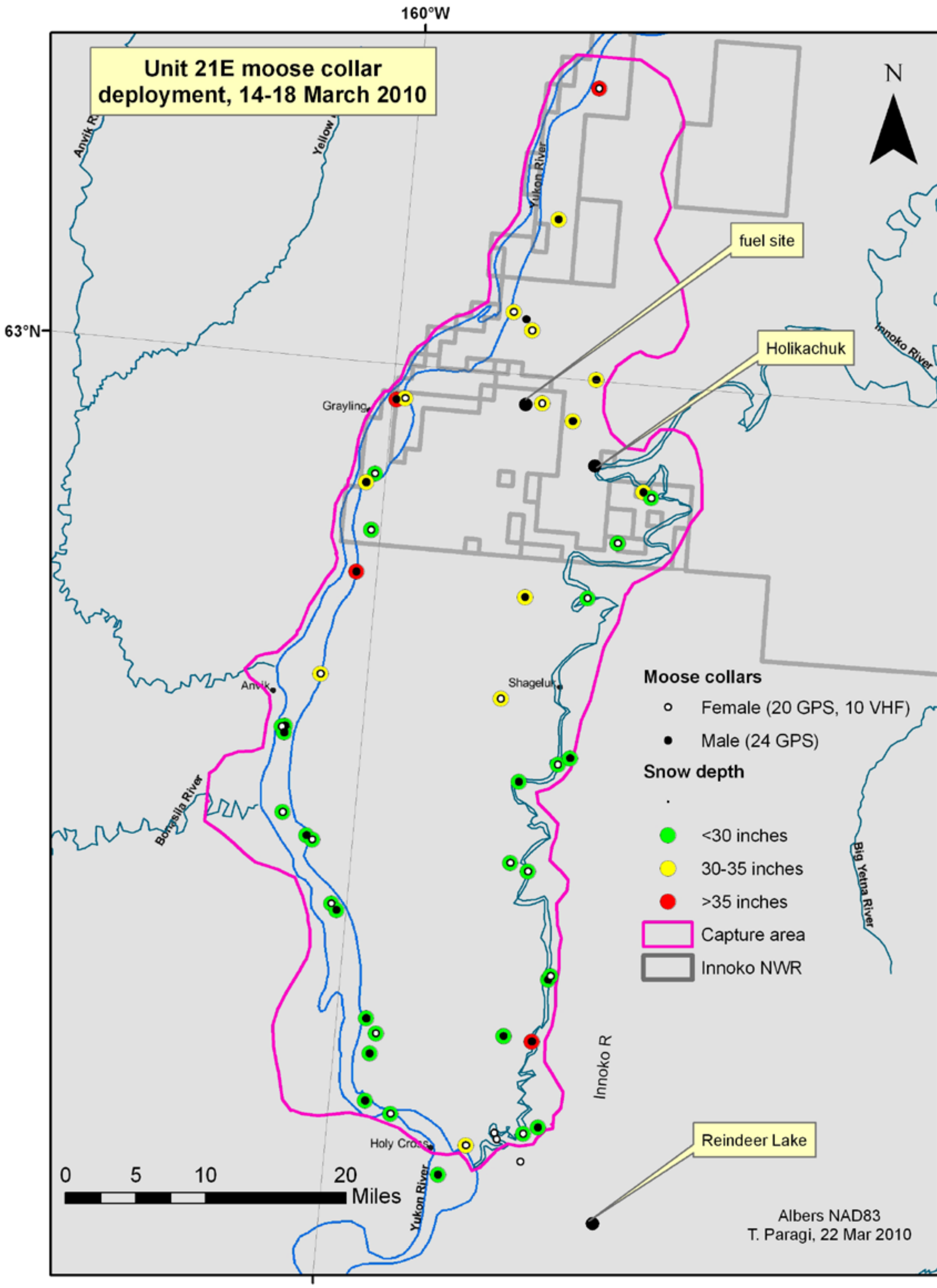


Figure 6. Map from a May 2010 interagency memo on radio collar deployment that depicts snow depth at locations of moose captures in Unit 21E, western Interior Alaska.

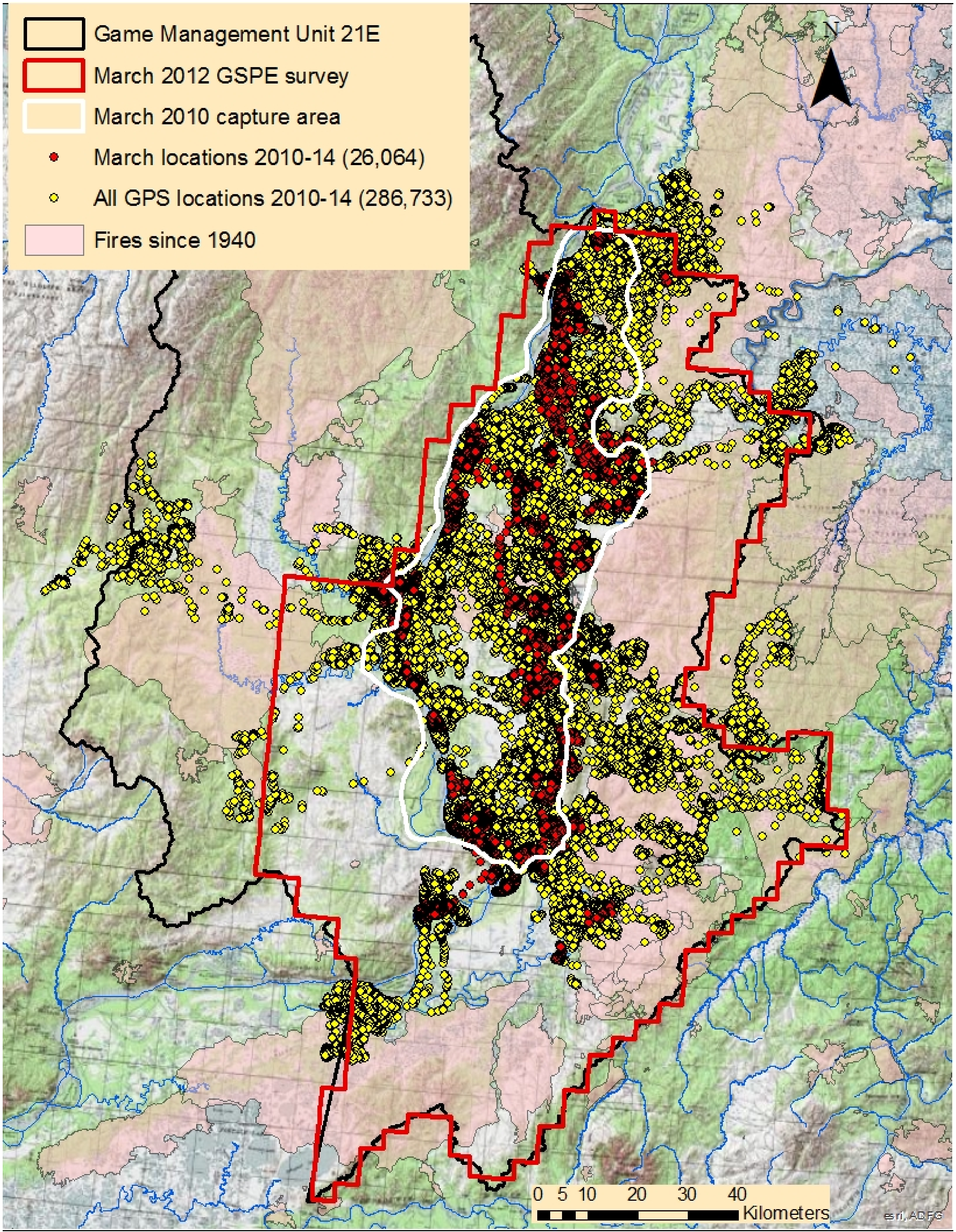


Figure 7. March dispersion compared to fire locations and all GPS locations for 21 female and 25 male moose monitored during 2010–2014 in Unit 21E, western Interior Alaska.

late-winter abundance of moose captured in March 2010. The GSPE boundary also included 95% of September locations (97% of female and 94% of male locations) during 2010–2013 (Fig. 8) when migratory moose were beginning to transition between seasonal ranges (discussed below). The survey area for November composition (1,363 km^2 [526 mi^2]) was only 10.5% of the area of the late-winter GSPE survey boundary yet contained locations from 57% of 21 females ($\bar{x}$ = 88% of November male locations) and from 38% of 24 males ($\bar{x}$ = 58% of November female locations) during 2010–2013 (Fig. 9). Although the sample size of GPS collared moose was small (e.g., far less than the number of random moose observed in the fall 2010 aerial survey) and declined during the study, the November M:F ratio based on collared moose presence was lower in the composition area than in the abundance area for all 4 cohorts (same pattern in September and March except in final year with smallest sample sizes; Table 1). Thus, estimates of bull population size, and related harvest percentages, would be biased low if November composition data were applied to March abundance estimates. The Y:F ratio was higher in the composition area than in the abundance area in the 2 years with data (Table 1), which is a bias suggesting greater calf survival than occurred in the population. M:F and Y:F ratios in the November 2011 composition survey and M:F ratio in the November 2010 composition survey, were less than those calculated from collared moose in the same years (Table 1). Plots of GPS locations showed that some individuals occupied survey areas in defined seasons in all 4 cohorts analyzed, whereas others did not.

For moose occurring ≤0.8 km of rivers that are accessible by motorized boats, the percentage of locations for both sexes was slightly higher in October (52%) than either September (50%) or November (45%) (Fig. 10a). Locations that were ≤1.6 km of rivers (September–November) increased by about 15% for males and 11% for females (Fig. 9a). When we considered potential for winter hunts by snowmachine on antlerless moose, we found a slight increase in the locations of males (25–34%) and females (20–29%) in areas open to hunting from November to March (Fig. 10b). Females were substantially more common and became so from November to March (39–47%) than were males (17–31%) in areas closed to hunting during winter (≤0.8 km of the main rivers; Fig. 10b).

We found movement patterns indicating moose migration in 56% of 41 female-years and 60% of 52 male-years (Table 1), but no movements were >20 km beyond the Unit 21E boundary (see "all GPS locations" in Fig. 7). By including some animals monitored only 1 year, we conservatively estimate that migration occurred at least once for 60% of 20 females and 67% of 24 males. We inferred mixed migratory patterns in 3 instances for females and 5 instances for males, but those behaviors were preceded or followed by migratory or nonmigratory behaviors. For individuals monitored 2–4 years, 50% of 12 females were consistently migratory or mixed migratory and 33% were consistently nonmigratory, whereas 54% of 13 males were consistently migratory or mixed migratory and none were consistently nonmigratory (Table 2). NSD patterns for migration often indicated movements away from winter range before the calving period in mid- to late May and back after the rut in October or November (Fig. 11). However, some females migrated for a short period near calving, and some males migrated for a short period near the rut (maximum displacement: 89 km in 1 male). Straight-line maximum migration extent by individual females averaged 64 km (range: 21–135, n = 12) and occurred almost exclusively within lowland habitats often associated with major river floodplains. Migration extent by individual males averaged 61 km (range: 20–200, n = 16). Individual male patterns remained generally consistent among years: most (10) remaining in lowlands, 4 spent winter and spring in

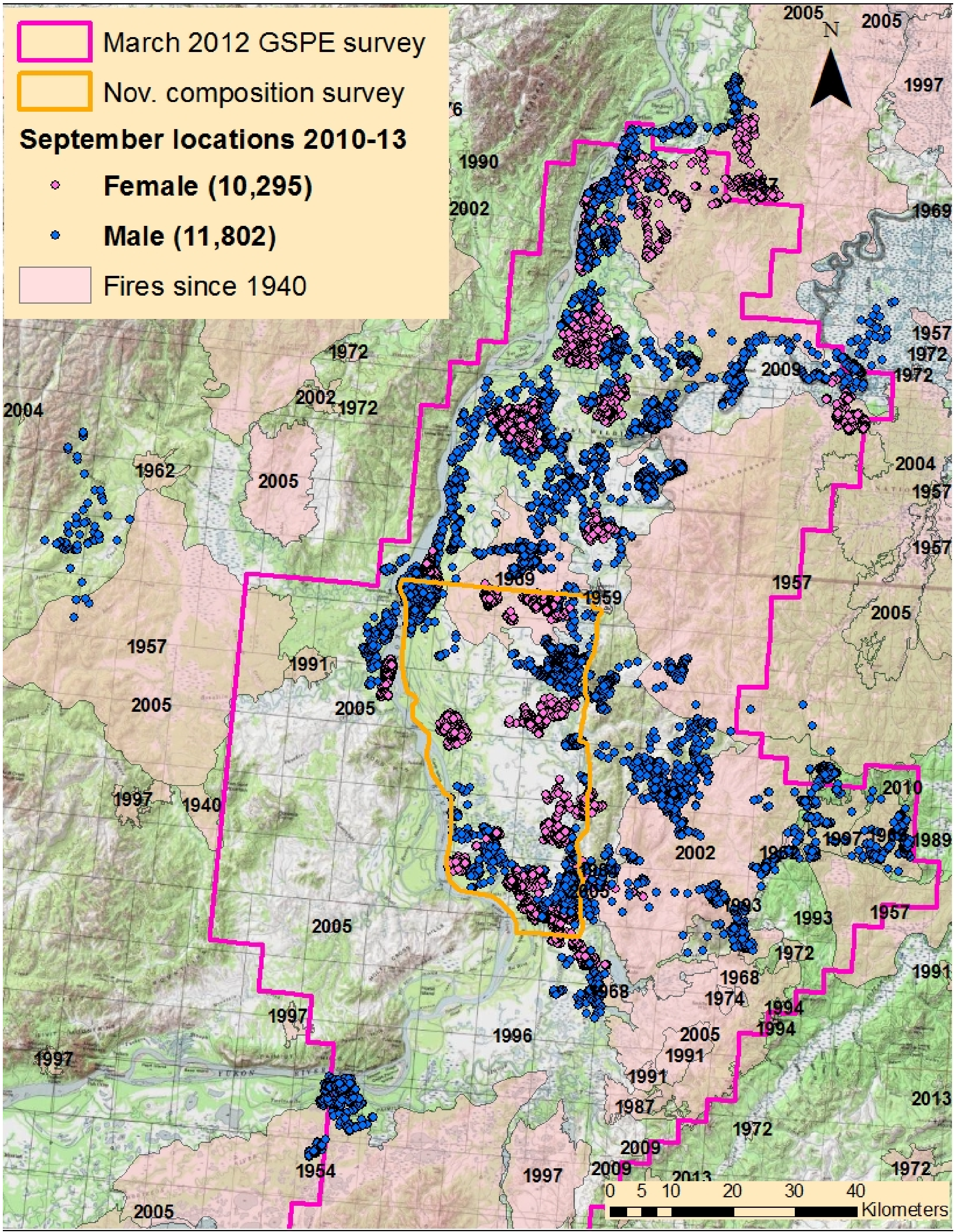


Figure 8. September dispersion of 21 female and 25 male moose monitored during 2010–2013 compared to fire history (year noted) and fall and late-winter survey boundaries in Unit 21E, western Interior Alaska.

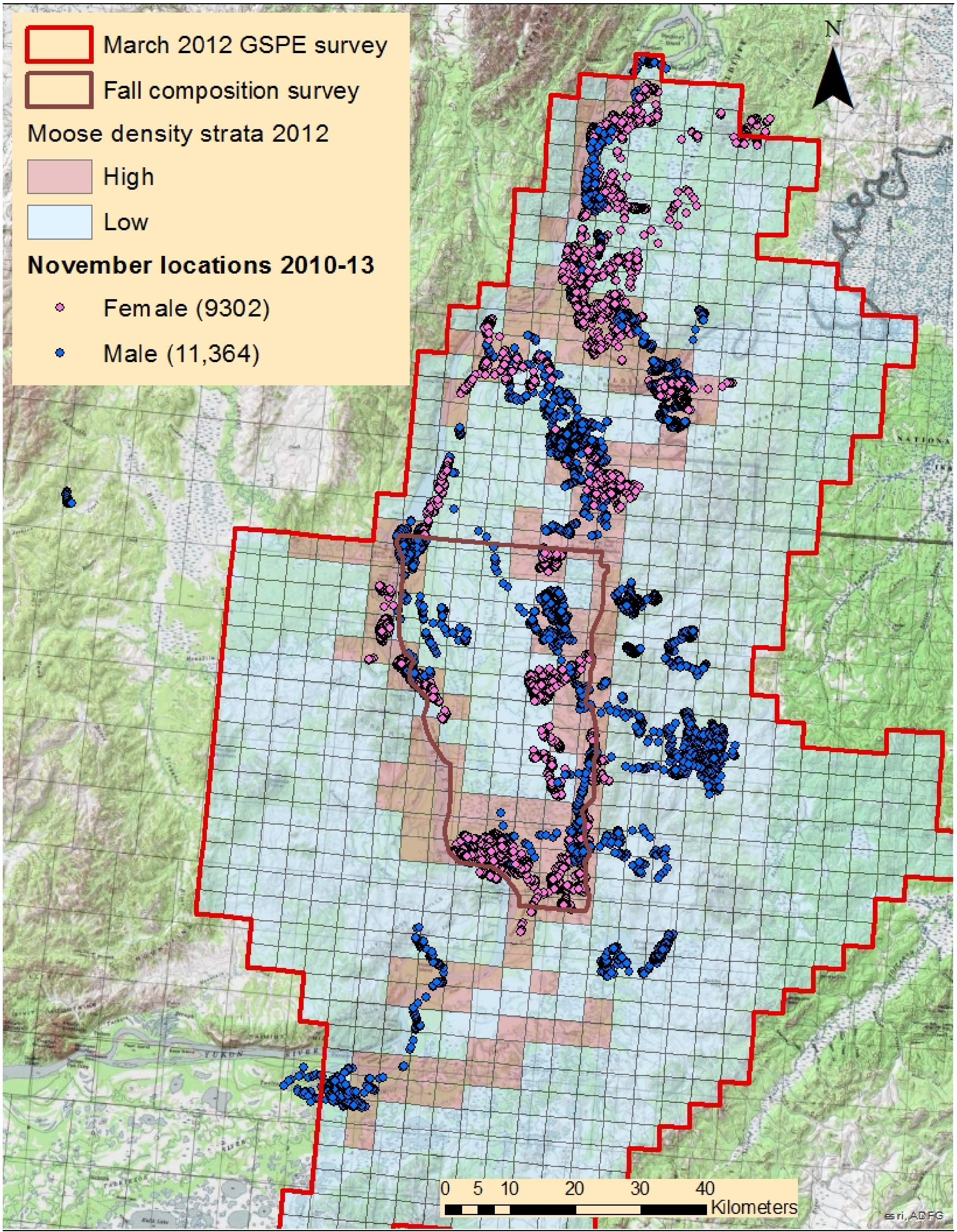


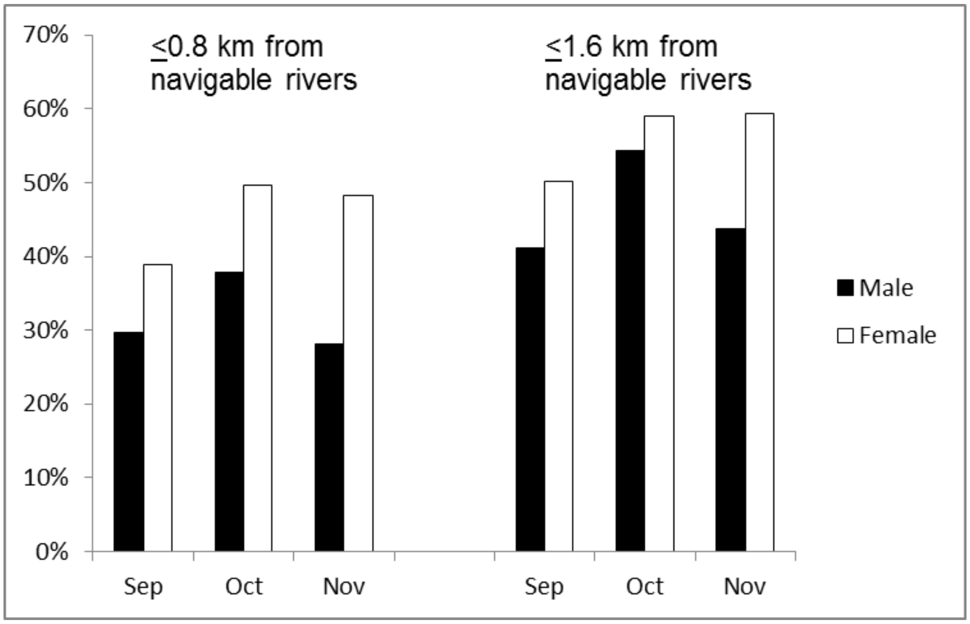
Figure 9. November dispersion of 21 female and 25 male moose monitored during 2010–2013 compared to fall and late-winter survey boundaries in Unit 21E, western Interior Alaska.

Table 1. Sex (M:100F) and age (Young:100F) composition estimated from presence (≥1 location) of GPS-collared moose (≥2 yr old; 24 M, 21 F) and estimation of young (≤10 month old) at heel in the November composition (comp.) and March abundance (abund.) survey areas during 3 biological periods for Unit 21E, western Interior Alaska. See methods for assumptions required to use telemetry data for Y:100F ratio.

	2010–2011 cohort					2011–2012 cohort					2012–2013 cohort					2013–2014 cohort				
Periods and survey areas	M: 100F	Y: 100F	n_M	n_F	n_Y	M: 100F	Y: 100F	n_M	n_F	n_Y	M: 100F	Y: 100F	n_M	n_F	n_Y	M: 100F	Y: 100F	n_M	n_F	n_Y
September (hunting season)[a]																				
Comp. area[b]	75	–[c]	9	12	–[c]	67	44	6	9	4	40	80	2	5	4	150	–[c]	3	2	–[c]
Abund. area[d]	115	–[c]	23	20	–[c]	124	53	21	17	9	109	55	12	11	6	129	–[c]	9	7	–[c]
November (composition survey)																				
Comp. area.	73	–[c]	8	11	–[c]	75	63	6	8	5	40	60	2	5	3	100	–[c]	2	2	–[c]
Abund. area	105	–[c]	21	20	–[c]	94	59	16	17	10	100	45	11	11	5	114	–[c]	8	7	–[c]
Survey results[e]	61	51	218		69	64	47	156		45										
March (abundance survey)[f]																				
Comp. area	88	100	7	8	8	67	83	4	6	5	60	–[c]	3	5	–[c]	150		3	2	0
Abund. area	116	74	22	19	14	93	60	14	15	9	92	–[c]	11	12	–[c]	133	33	8	6	2

[a] Age and sex composition are not feasible to calculate from September aerial surveys because detection rate of moose without snow is low.
[b] Information for the fall survey area (1,363 km^2).
[c] Observation of calf at heel is missing for all females (telemetry flights pre-empted).
[d] Information for the late winter survey area (12,980 km^2).
[e] Ratios and sample size from aerial survey of random individuals in the fall composition area (Peirce 2014).
[f] Age and sex composition are not feasible to calculate from March aerial surveys because males are antlerless, thus confounding counts of females. Tally of sample size for all years excludes the 2009–2010 cohort (individuals from March 2010).

a



b

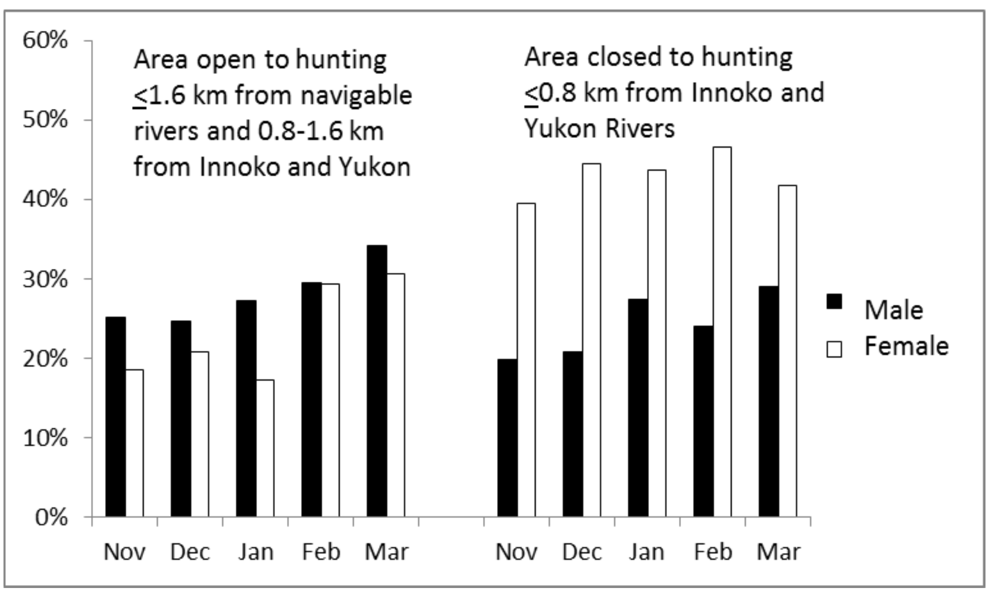


Figure 10. Proportion of moose locations that are within specified distances of navigable rivers during potential hunting periods (months) for access by a) motor boats during open water and b) snowmachines during ice cover. Moose hunting is prohibited at distances ≤0.8 km of the Innoko and Yukon rivers, western Interior Alaska, during winter.

Table 2. Movement behaviors categorized from plots of net squared displacement for female and male moose for 4 annual periods (starting dates 19 March 2010 through 19 March 2013) in Unit 21E, western Interior Alaska. Behaviors are migratory (M), nonmigratory (N), mixed migratory (X), and dispersal (D) per Bunnefeld et al. (2011). An asterisk indicates GPS data for the period but gaps >30 days during April to November or >60 days total.

ID	Age_yr (2010)	2010	2011	2012	2013
F01		N			
F02		N			
F03		N	M	M	
F06		M	M	M	
F10		N	–*	–*	
F11		M			
F12		N			
F15	9	N	N		
F16		N	N	N	–*
F20		M	M	M	–*
F21		N	X	M	
F24		M	M	M	
F27		N	N	–*	
F28		M	X	X	M
F33		M	–*	M	M
F36		M			
F39		N	N	–*	–*
F43		M	M		
F46	8	M	–*		
F56				M	
ID	Age_yr (2010)	2010	2011	2012	2013
M4	4	M			
M5	2	D	M		
M7	2	M	M		
M8	2	N	D		
M13	3	N			
M17	1	X	N	N	N
M18	3	D			
M19	3	M			
M22	4	M	M	M	M
M23	4	M			
M26	8	N	M	N	--
M30	3	M			
M31	3	M			
M34	3	M			
M35	3	M	M	X	
M37	9			N	
M40	1	M	M	M	M
M42	2	N			
M45	6	M	M	M	
M48	3	M	M	X	M
M49	4	N	N	X	X
M51	3	N			
M53	3	M	M	M	M
M55				D	M

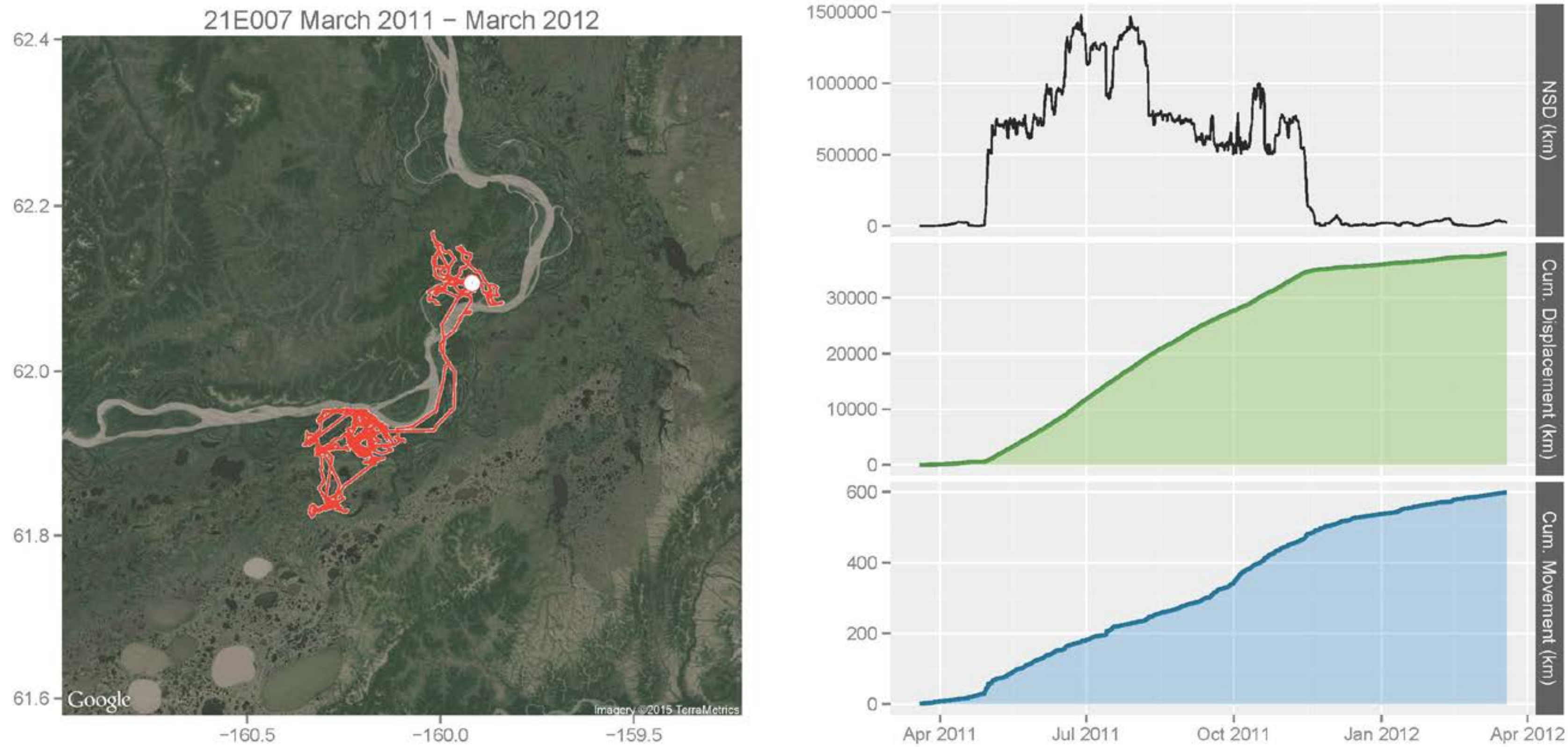


Figure 11. Example of plots for analysis of movement paths and net squared displacement (km^2) illustrating migration for a 4-year-old male moose over 1 year along the Yukon River in Unit 21E, western Interior Alaska. Vertical scale of NSD plot (upper right) is in meters, so peak displacement from 19 March 2011 origin (white dot on left map) was sqrt (1,500,000 m^2) ~ 39 km.

lowlands and summer and fall in the hills, and 2 spent winter and spring in the hills and summer and fall in the lowlands. The last category had a pattern exception in a single male (ID 48) that remained within a 25-km extent; it had a similar pattern for 3 years (March–June in lowlands, remainder of year in hills with infrequent 1–2 day forays to lowlands) but delayed movement to lowlands until May in the fourth year. Four younger males had movements suggesting dispersal: 2 became migratory the next year, 1 died, and 1 was lost from contact (Table 2). We did not find NSD patterns indicative of female dispersal but do not know if the sample of females (age rarely known) was on average older than our sample of males in this male-hunted population.

Male and female moose exhibited nearly a 6-fold range in average weekly movements over an annual period as inferred from NSD (Fig. 12). Male movements generally exceeded female movements in all seasons and were greatest for both sexes prior to calving, prior to hunting season, and after rutting. Mean weekly change in movements ranged 1.7–11.4 km for females and 2.6–16.3 km for males. The aberrant spike in NSD during the second week of March might represent increased movement if a thaw occurred during that period in ≥1 of the 4 winters, but we did not have adequate data on snow depth to evaluate this speculation.

We found 52% of females and 80% of males in our study used burns at least seasonally. For 22 burns since 1940 in the study area, 11 females and 20 males had locations within burn perimeter, with 88% of locations in 8 burns from 3 years (1957, 1969, and 2002) (Appendix L). Males had more prevalent use of burns than females during July to January, with the highest use by females in June to August (Appendix M).

Short-term Female Movements Indicative of Parturition

Calf observations during 1–3 telemetry flights annually over 36 female-years corroborated a pattern of constrained movements suggesting parturition during the suspected peak of calving (20–24 May) that was detected by BCPA (Fig. 4). Conversely for 6 female-years when we failed to see ≥1 calf during telemetry, we did not see a corresponding pattern of constrained female movement (Fig. 13). However, in 7 female-years when we failed to see a calf, the female exhibited constrained movements indicative of parturition (Table 3).

Parturition dates inferred from contraction in area of the rolling-window MCP agreed with the dates inferred using BCPA ±1 day for 39 (91%) of 43 moose-years (Fig. 14). Of the 3 instances where inferred parturition dates differed >2 days between the 2 methods, 2 were ambiguous owing to secondary localization, and 1 was a false positive for rolling MCP on 10 May versus 24 May from BCPA (Fig. 15).

Male Movements Related to Fall Temperature

Pearson's correlation coefficient (r) between Anvik airport temperature (range during analysis period: −7° to 24°C [19° to 75°F]) and male movement rate was significant (P <0.05) for 36 of 67 male-years (5 positive and 31 negative; 25 individuals over 1–4 years, 2010–2013). However, the correlations were variable and overall not strongly negative ($\bar{x}_r = -0.093$, SD = 0.146, range: −0.408 to 0.457; Fig. 16a). We also found significant correlation between collar temperature and male movement rate for 38 of 60 male-years (4 positive and 34 negative), but again, correlations

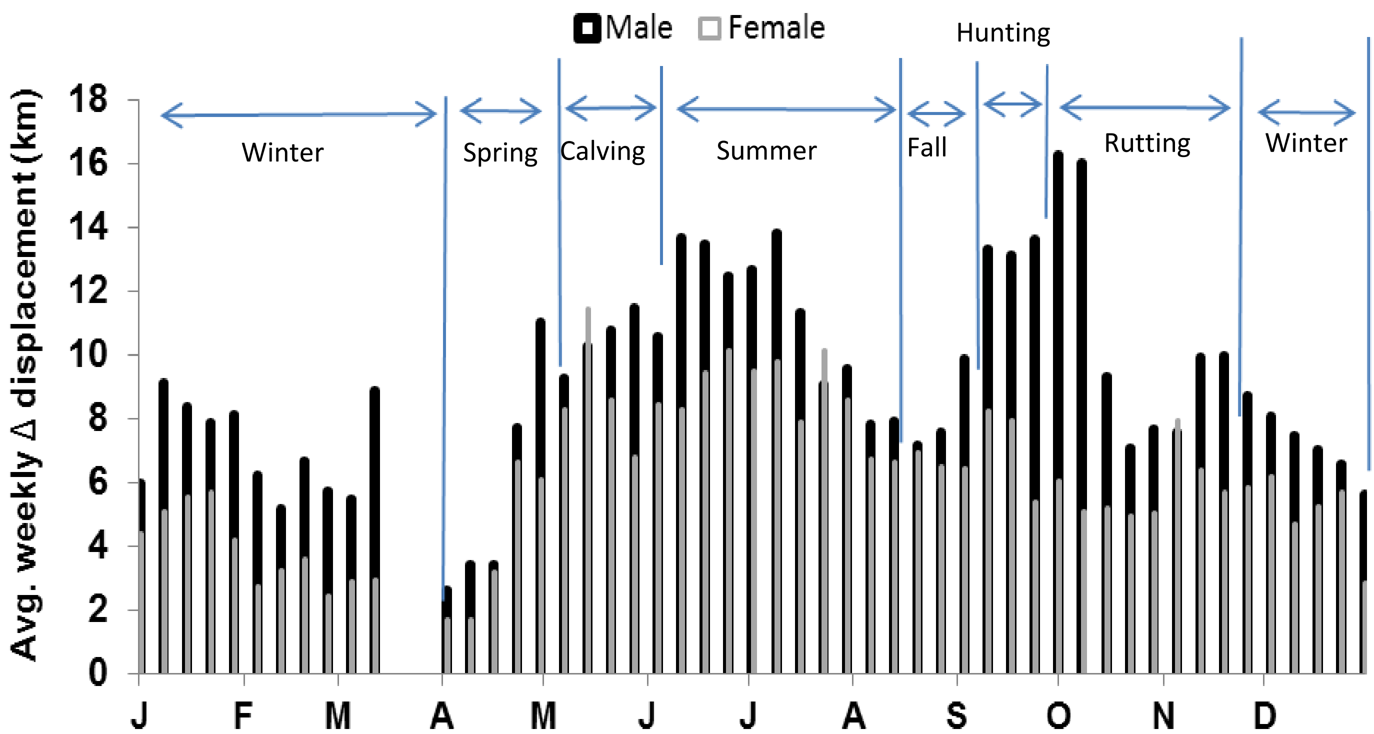


Figure 12. Seasonal movements of female and male moose based on average weekly change in movement paths calculated from net squared displacement. Differences in means could not be calculated for weeks at the beginning and end of each path, resulting in a gap each year in the last 2 weeks of March. Approximate biological or management periods are indicated.

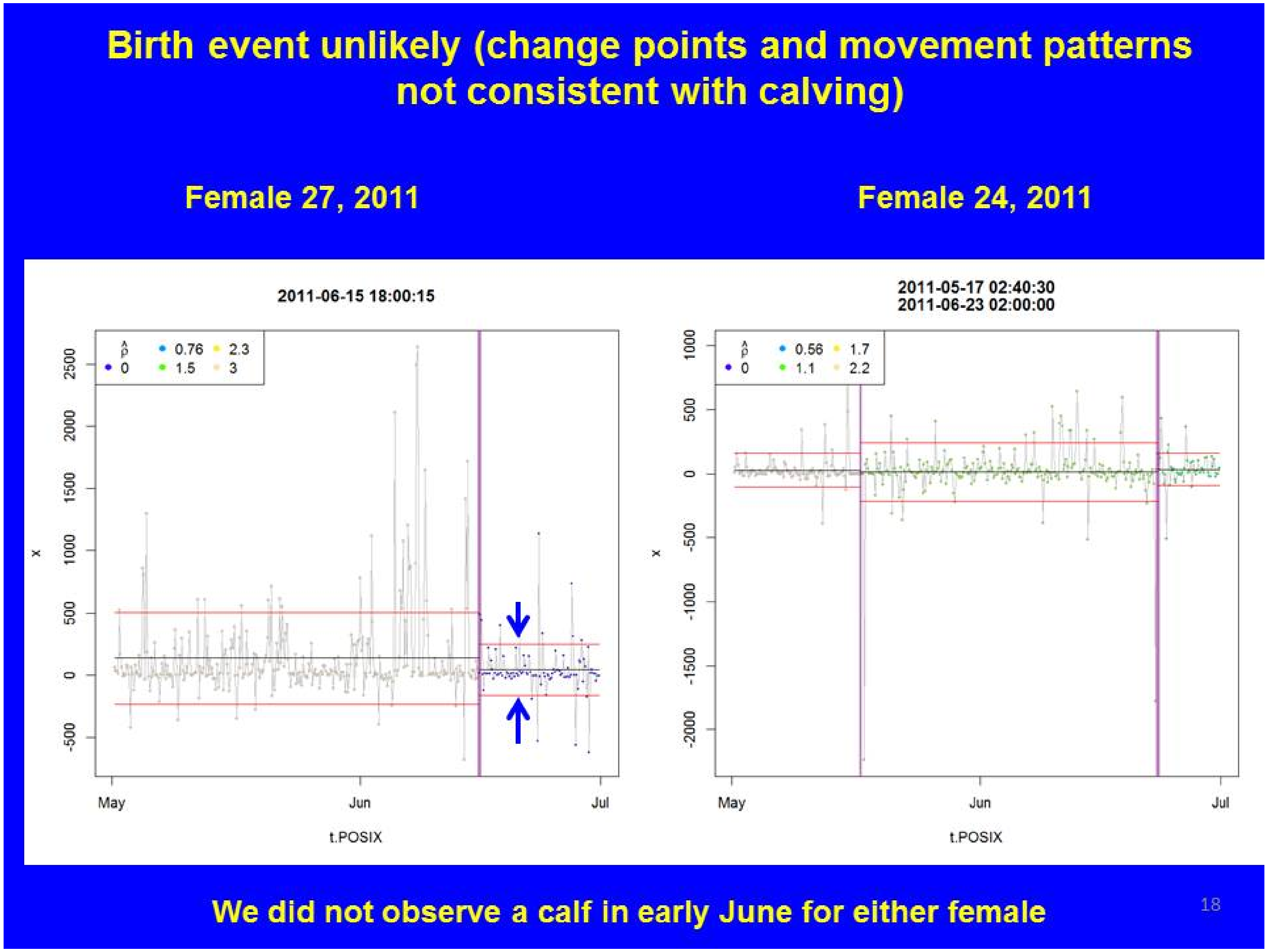
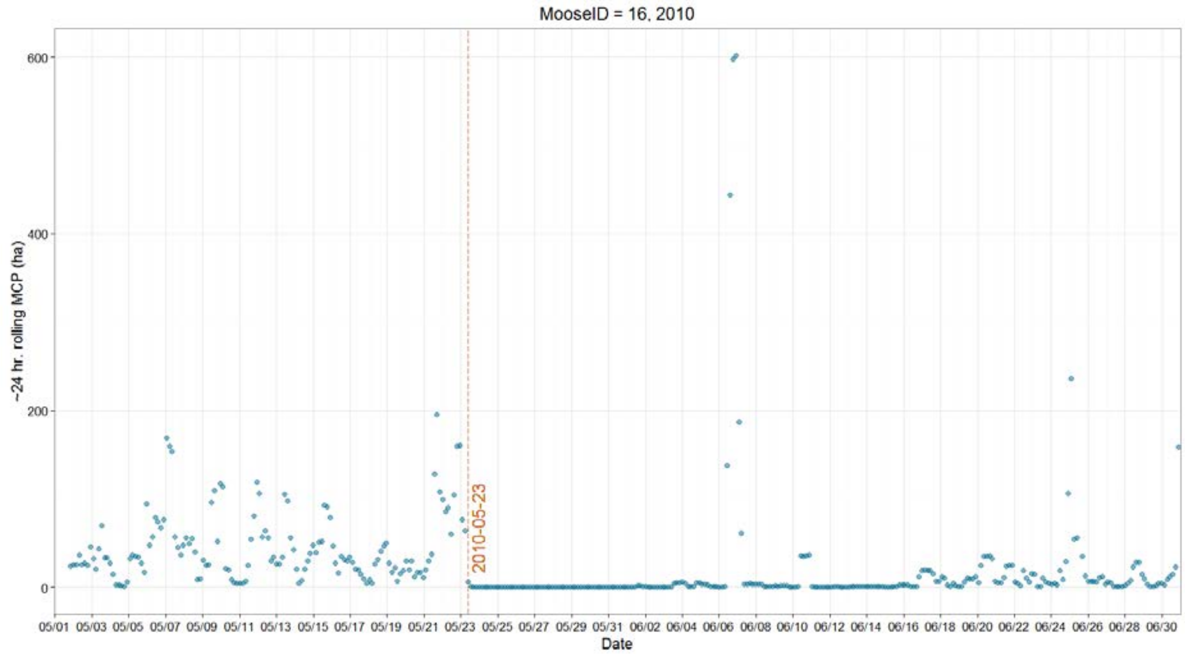


Figure 13. Illustration from a scientific presentation of modeling output for behavioral change point analysis on 2 female moose that did not have a calf.

Table 3. Number of female moose evaluated for parturition using behavioral change point analysis (BCPA) and confirmed as positive or negative based on observations of ≥1 calf at heel during telemetry flights in Unit 21E, western Interior Alaska.

Birth year	No. females	Median calving date	No. observed parturient (% confirmed BCPA)		No. estimated parturient BCPA	No. barren (% confirmed BCPA)	
2010	20	5/22	16	(100)	18	2	(100)
2011	18	5/20	13	(100)	14	4	(100)
2012	7	5/23	5	(100)	7	0	(0)
2013	4	5/24	2	(100)	4	0	(0)
Total	49		36		43	6	

a



b

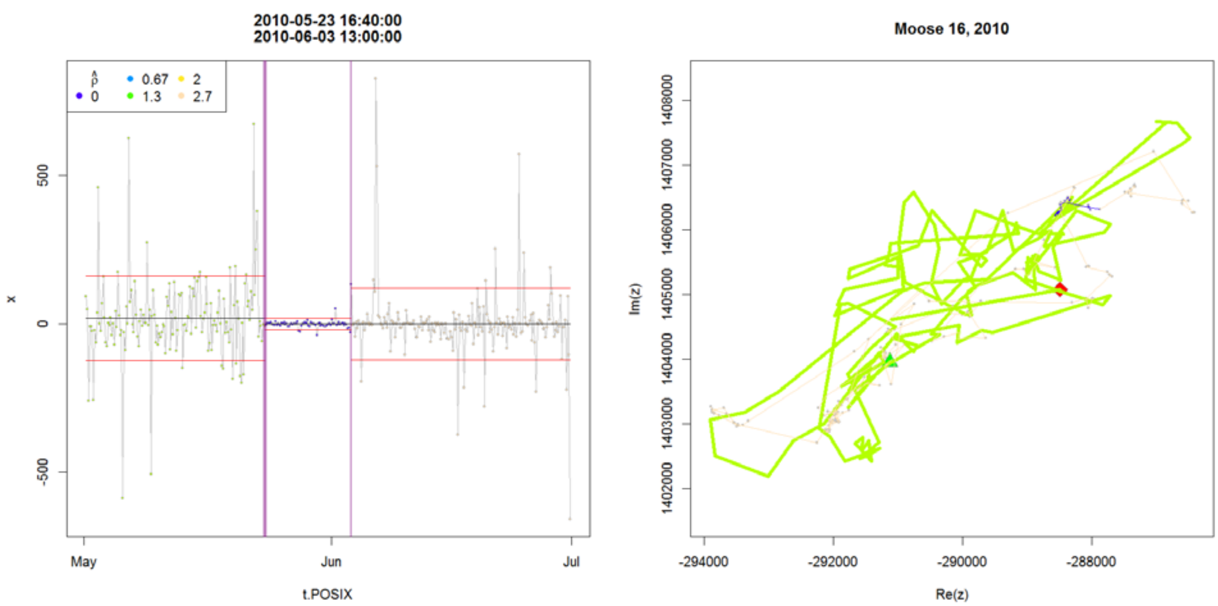


Figure 14. Inferred parturition date (23 May; vertical lines) for a female moose in Unit 21E, western Interior Alaska, based on GPS locations: a) contraction in area of the minimum convex polygon in a rolling window spanning approximately 24 hours, and b) beginning of constrained activity identified using behavioral change point analysis.

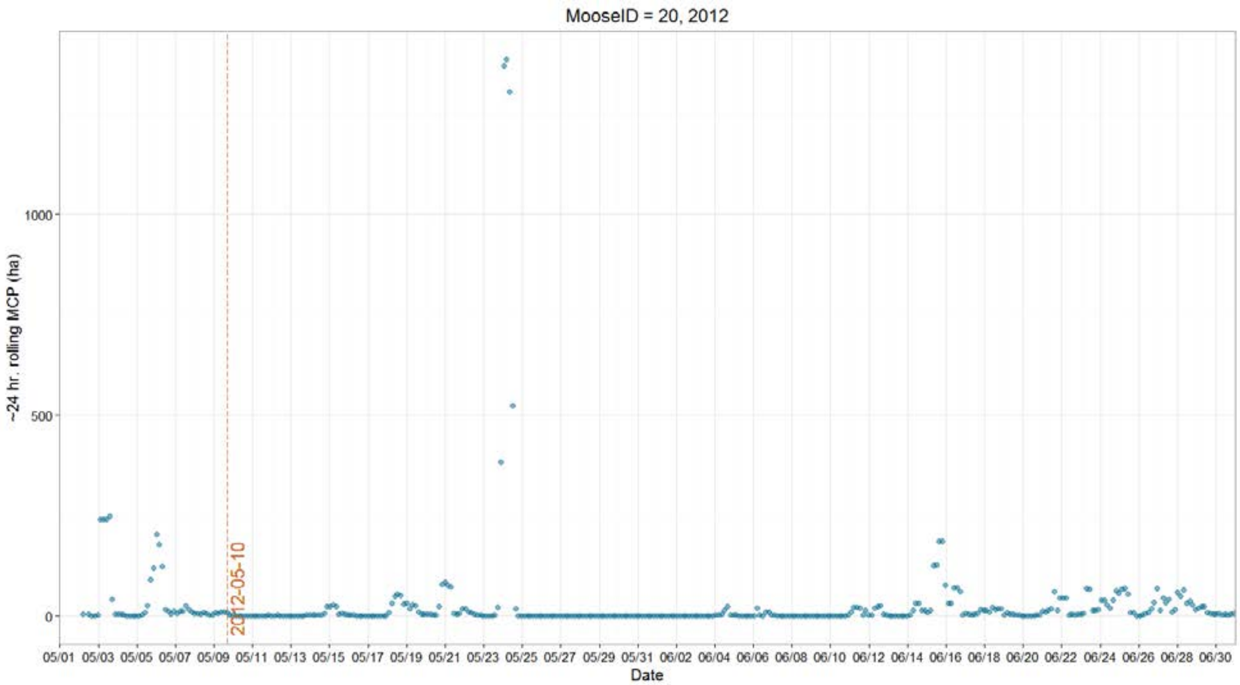
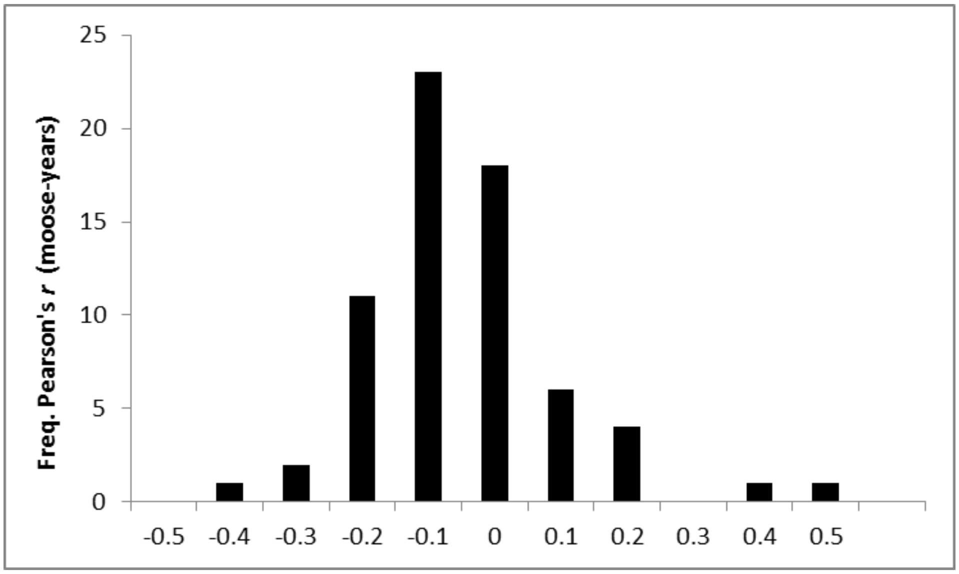


Figure 15. Parturition date (10 May; vertical dashed line) inferred for a female moose in Unit 21E, western Interior Alaska, from the contraction in area of the minimum convex polygon based on GPS locations in a rolling window spanning approximately 24 hours. This date is almost certainly a false positive; the date inferred from behavioral change point analysis appears to be closer to 24 May.

a



b

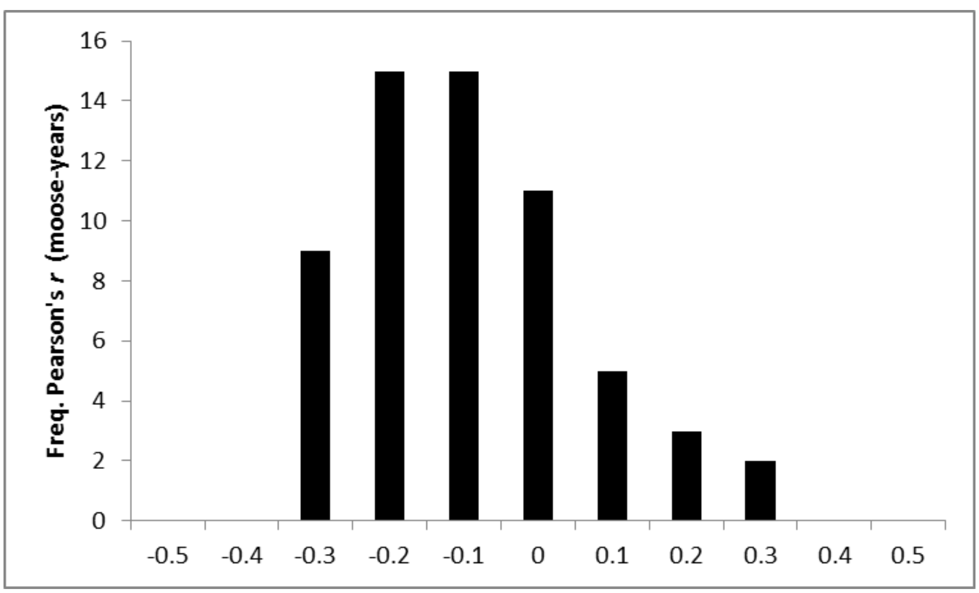


Figure 16. Frequency of correlation (Pearson's *r*) between 4-hour movement rate of male moose during 15 August–15 October, 2010–2013 and a) nearest hourly temperature at the Anvik airport, western Interior Alaska (67 moose-years), and b) 4-hour average of real-time temperature on collars of the individual moose (60 moose-years).

were variable and overall not strongly negative ($\bar{x}_r = -0.140$, SD = 0.143, range: −0.387 to 0.243; Fig. 16b).

Discussion

COLLAR PERFORMANCE

In our small sample we noted 2 instances of an expandable collar causing skin abrasion on a male following a rutting event. Other designs for expandable collars might further reduce potential for abrasion. Subsequent to our collar deployments, Dick et al. (2013) reported on an expandable collar on male elk (*Cervus elaphus*) but noted further testing is warranted to reduce premature failure that results in collar loss. Since only male moose are legal for harvest in many parts of boreal Alaska, collar recovery through harvest is common prior to the end of longer studies (of 24 male collars deployed we recovered 3 via harvest and 1 through failure to salvage). Expandable collars that can persist for 2–3 years may be feasible options for males if recaptures for collar removal are planned into the study design.

Positional accuracy and temporal rate of GPS acquisition were sufficient for purposes of our movements and dispersion study. Further use of our data for estimating habitat use would require assumptions about positional accuracy as affected by behavior (Moen et al. 2001) and habitat types that vary by topography and vegetative cover (which we did not evaluate), plus recognition of seasonal variation in acquisition rate that could affect temporal distribution of samples (Appendix H). We did not evaluate the performance of a single 6-hour upload period on the satellite (for cost efficiency) because it was beyond the need of our study. This could be done for our data set by comparing successful GPS fixes from CDs to the same date and time of filtered datalog fixes from retrieved collars.

Moose Movements and Seasonal Dispersion

Our plots of seasonal locations suggest that the late winter survey boundary seems appropriate for estimating abundance of moose present during the fall hunting season, and we consider winter-resident moose in the GSPE area as a population. We were constrained from collaring moose in early fall because of animal welfare consideration, i.e., potential for drowning or overheating during chemical immobilization. Thus, our study could not sample the fall population for evaluating movements and dispersion germane to estimating harvestable surplus of males in fall. Nonetheless, sampling moose on their late winter range and monitoring them over 4 years allowed us to determine that collared moose largely remained in the late-winter survey area during the fall hunting season. Accordingly, we do not expect harvest quotas to be biased higher than the harvestable surplus, which in Unit 21E had been conservatively calculated from observed moose uncorrected for the proportion not seen during surveys (since the March 2016 survey, quotas now incorporate abundance estimates corrected for moose not seen during aerial surveys). Recent irregularity in snow cover during traditional survey periods has further hindered observation of moose from aircraft, but the understanding of seasonal dispersion and movement patterns may aid design of other monitoring strategies.

Seasonal dispersion of age and sex classes is an important consideration when designing aerial surveys to infer composition for managing moose populations (Hundertmark 1997:333). Ratio estimates from composition surveys can be biased through non-random selection of survey units and differences in sightability, although their utility for signaling gross changes in population dynamics may be sufficient if these biases are relatively constant (Gasaway et al. 1986:72). The November composition area in the joint floodplain of the Innoko and Yukon rivers was positioned and scaled for 2 fixed-wing planes to survey in 1 day including ferry time from McGrath. Dispersion of GPS locations and individual occupancy of survey areas by the collared sample of adult moose suggested the fall survey area in Unit 21E was biased toward females when compared with the larger survey area for late winter abundance. Including information about calves at heel of collared females further suggested a bias toward calves in the fall survey area. Our collar deployment was intended for geographic distribution to be roughly even for both sexes across the study area (Fig. 5) but not representative of sex-specific density within the study area. The November survey boundary seems reasonable for inference on age-sex composition, recognizing it may be conservative for the male segment of the population. Bias toward females and calves could be beneficial given the limited resources for fall surveys and the importance of calf-to-female ratio in monitoring effects of predation or predator control (e.g., Gasaway et al. 1983). The fall composition area is in the northern half of the GASH moose management area[8] near the villages of Grayling, Anvik, Shageluk, and Holy Cross (Fig. 1) within which wolf control is authorized to occur if density declines below 1 moose/mi^2 in the GSPE survey area.

We pooled migratory and resident moose for this analysis, so removal of -resident males from the floodplain ≤1.6 km from navigable rivers during the September hunting season might be expected to reduce male occupancy in subsequent months. However, the degree of riparian occupancy by female and male moose did not exhibit substantive trends from September to March. The higher degree of female occupancy suggests the long-standing regulation prohibiting winter moose harvest at distances ≤0.8 km on the Innoko and Yukon rivers probably protects female moose to a greater degree than male moose. We observed adult females increasingly using the riparian corridor (shallower snow and greater browse biomass) instead of uplands during winter in an adjacent growing population in Unit 19D (K. Kellie Seaton and T. Paragi, ADF&G, federal aid project 5.20, unpublished data, Fairbanks) and assume this spatial pattern would generally hold if moose density increased in Unit 21E. Based on monthly dispersion of moose in primary hunting corridors along navigable rivers, winter harvest of antlerless moose (particularly females) should allow adequate harvest opportunity to manage population growth if wolf control is conducted. Elevated harvest at higher moose densities can prevent a decline in moose nutritional condition or degradation of forage plants (Boertje et al. 2007; Young and Boertje 2011; Paragi et al. 2015b).

Migratory moose in this area formerly (Appendix A) and presently foraged in recent and older burns during summer and fall before returning to winter range in the floodplains. This pattern is similar to that of moose near Three Day Slough in the lower Koyukuk drainage in Unit 21D (Osborne and Spindler 1993). Adult males in our study utilized upland burns in winter to a

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[8] Alaska Administrative Code, Title 5, Chapter 92, Section 124

greater degree than adult females, which may select for riparian areas in winter because of greater forage availability and shallower snow compared with uplands (K. Kellie Seaton and T. Paragi, Unit 19D, unpublished data). Present seasonal patterns of burn occupancy could be affected by future climatic trends leading to greater potential for fire (Young et al. 2017) and increased forage in the uplands (Oldemeyer and Regelin 1987; MacCracken and Viereck 1990; Weixelman et al. 1998). A future analysis could look at degree of burn selection by browse production and fire severity (Lord and Kielland 2015), moose sex, time since fire, snow depth, and season of use to understand potential drivers of seasonal moose distribution and how migratory patterns might change in response to changes in snow depth and forage abundance and quality. Although spatial estimates of burn severity are now available for selective fires back to 1984[9], lack of validation on preexisting vegetation type and on burn severity soon after the fire (Kasischke et al. 2008; Murphy et al. 2008) may hinder or confound interpretation on the importance of older fires to fitness for this moose population. The ultimate question is how environmental changes might affect harvestable surplus or season of harvest. The abovementioned factors have implications for fire management options by land managers, possible adjustment of population and harvest objectives for intensive management of moose, and regulatory strategies for adapting harvest periods to animal behavior and safe access by hunters as climate changes (Adaptation Advisory Group 2010:5–8 to 5–9; McNeeley and Shulski 2011). However, based on multi-year moose concentration in the floodplain by March (Fig. 7), the frequency of flooding rejuvenation of riparian willows and of deep snow events than concentrate spatial use may be more important as factors limiting winter forage access for moose in Unit 21E than age and extent of upland fires.

We described moose movements primarily for evaluating coverage of current survey boundaries but gained understanding of migratory distances and behavioral patterns. Joly et al. (2015b) noted that NSD calculations are more objective than describing migration by allopatry in summer and winter ranges, but NSD tends to reveal greater movement distances. Migration in our study occurred within distances that described separation of summer and winter ranges for moose in North America (Hundertmark 1997) but lacked the extreme movements observed in 2 moose during the 1980s study in Unit 21E (Appendix A). Based on gross movements, Unit 21E March-caught moose in the 1980s had 50% migratory females and 60% migratory males, proportions of partial migration in the population that were similar to our recent observations (56% female and 60%, male). For comparison in Interior boreal forest, migration occurred in about 39% of the moose within Unit 20A, with additional animals migrating into an adjacent game management unit (Boertje et al. 2009:318–319). Most (91%) of females in the Alaska Range foothills in Unit 20A migrated to the Tanana Flats for calving, which was believed to confer higher calf survival than for females remaining in the foothills because the flats contained fewer black bears (*Ursus americanus*) and brown bears (*U. arctos*) (Boertje et al. 2009). In the lower Koyukuk drainage, Osborne and Spindler (1993:10) classified 91% of females and 73% of males as migratory. They hypothesized that movement out of winter range to reduce foraging pressure on plants is a more plausible cause of migration than predation relief because migratory males and calf-female pairs had greater mortality than residents. In the upper Koyukuk drainage

[9] http://www.mtbs.gov/

within Unit 24, Joly et al. (2015b) found that 25–34% of females and 36–57% of males were migratory but noted that movement behaviors exhibited multi-annual complexity.

We did not have the covariates to evaluate how temporal or spatial distribution of environmental conditions (e.g., snow depth or habitat quality) or predation risk (e.g., White et al. 2014) might favor a migratory strategy for moose in Unit 21E. Van Ballenberghe (1977) reported that moose migration may occur at smaller scales in winters of below-average snow depths that allow access to forage covered by snow (or require less locomotive effort) compared with average or deep-snow winters where movements to areas of shallow snow confers a fitness advantage. During our study the maximum snow depth each winter in the northern part of the study area was comparable to U.S. Department of Agriculture-National Resource Conservation Service's records for winters back to 1997–1998 with the exception that snow in 2008–2009 (the winter prior to captures) was substantially deeper and more prolonged (Appendix E). Thus our study period represents "average" conditions where late winter snow depth incurs physiological costs in moose that favor migration (Coady 1974).

The pattern of average weekly change in displacement of male and female moose provides managers with an indication of how frequently VHF telemetry frequency might be needed to answer questions on moose dispersion or movements at specified times of the year in Unit 21E. Our findings were similar to periods of high weekly movement rates shown by Joly et al. (2015a) for Unit 24. Peak movements in spring and fall corresponded to periods of migration, the former associated with calving and the latter associated partly with the rut (LeResche 1974; Ballard et al. 1991:26). NSD or movement rates could be calculated for other wide-ranging terrestrial wildlife populations with short-interval GPS data to inform VHF telemetry schedules for monitoring seasonal range uses and detecting movement corridors. Achieving the greatest utility of VHF telemetry on a fixed budget (limited number of flights) to discern location status of marked animals requires knowledge of seasonal movements to avoid oversampling during periods of relatively stationary behavior (e.g., winter range) and avoid under-sampling during periods of relatively long movements. Adequate sampling may be important to describe the spatial location of calving or rutting areas or travel corridors when evaluating potential effects of proposed or existing resource development (e.g., logging or mining) on moose habitat or populations.

Short-term Female Movements Indicative of Parturition

Our validation of BCPA using females with known reproductive history (within the constraints of our few telemetry flights) suggests it may have utility for estimating parturition in moose outside our study area and for other species where GPS telemetry is feasible and VHF telemetry for observations is difficult. It is unlikely that if we judged a female moose as barren during spring twinning surveys that we would have also fail to detect a calf at heel during subsequent telemetry in November and March, provided the calf had survived the intervening periods. However, twinning surveys a week after median parturition date may fail to detect earlier birth events that were subjected to neonatal mortality, such as bear predation (Osborne et al. 1991; Keech et al. 2011). Although parturition estimates require multiple flights during the entire calving period to reduce potential of neonatal predation bias and include litter size (Boertje et al. 2007), for comparative purposes with BCPA, a single telemetry flight in spring would underestimate the proportion of parturient females by 16% (7/43; Table 3). We were unable to determine whether females that lost 1 of 2 calves would have a different movement pattern than females that lost a single calf to mortality because we did not do multiple observations in the calving period. BCPA will not replace estimates of parturition or twinning rate that require direct observation, but similar to vaginal implant transmitters (Patterson et al. 2013), it may augment understanding of moose reproduction, particularly in dense foliage that hinders visual detection or in remote areas where repeated visual monitoring is expensive.

A rolling MCP is conceptually intuitive, objectively identifies movement localization as a complement to BCPA, and seems less subjective than interpreting output from other tools (e.g., the Tracking Analyst method in ArcGIS). However, a rolling MCP requires a sampling frequency sufficient to capture changes in movement behavior. Thus it is not accurate in all instances and should be viewed as a starting point in identifying parturition, rather than a certainty. Both methods are based on the same GPS locations: MCP is a measure of area used, whereas BCPA is a measure of movement, albeit with the requirement of fitting 3 empirical parameters of positional change.

Male Movements Related to Fall Temperature

We expected temperature on moose collars to better represent ambient conditions than the temperature at the Anvik airport with respect to influence on male movement rate in fall because the airport was up to 75 km away from the closest edge of some male home ranges and 60 m higher elevation (more subjected to winds along the Yukon River) than much of the floodplain. Pearson's correlation was of roughly equal magnitude (positive and negative) for both temperature methods, but even the rare maxima (0.45 squared) would explain only 20% of variation. Our study was not designed to address this question, and lack of finding a strong association[10] between movement rate of male moose in fall and ambient temperature does not mean moose are not responding behaviorally to temperature or that hunting success is unrelated to temperature. Our 4-hour movement rates are conservative because the travel path of a moose could be highly sinuous compared to the straight line we had to assume between successive locations. A shorter relocation interval or use of activity sensors could better describe movement rate or behavioral activities. Further, habitat selection by the animal may be equally or more important to thermoregulation than activity levels. Moose seek shade during periods of higher temperature (McCann et al. 2013; Wattles 2015) whether beneath deciduous trees or shrubs prior to leaf fall or beneath conifers year round. Moose may cool themselves by submersion in water, lying on snow, or occupying a landscape position conducive to evaporative winds (Renecker and Schwartz 1997:435; Lenarz et al. 2011). Behavioral choices to reduce heat stress may limit forage intake and result in weight loss for moose, which is a greater factor for adults than subadults because of large mass of adults (Renecker and Schwartz 1997:436). If leaf fall from shrubs and trees is delayed during warmer weather, the foliage may reduce visibility of moose and could explain lower harvest rate during periods of unseasonably warm weather. Independent

[10] Pearson's *r* of 0.5–1.0 (Laerd Statistics: https://statistics.laerd.com/statistical-guides/pearson-correlation-coefficient-statistical-guide.php)

of harvest opportunity, some hunters may avoid hunting when warmer conditions complicate meat care (McNeeley and Shulski 2011; McNeeley 2012).

Conclusions and Recommendations

1. The 2012 late-winter survey boundary included 99% of March and 95% of September moose locations of both sexes during 2010–2014, regardless of individual migratory behavior. The 1980s telemetry study in the same general area (Appendix A) showed similar concentration of moose onto winter range in the Innoko and Yukon rivers floodplain. The late-winter survey area in Unit 21E allows abundance estimation for a population that corresponds to the area of fall harvest for which the harvestable surplus of males is determined.

2. The fall composition area likely includes a substantial proportion of moose that occupy the Unit 21E winter range in November but a possible bias toward females and calves. If wolf control occurs in the GASH moose management area, distribution of wolf removal should guide consideration of whether the composition area should be increased for corresponding spatial assessment of calf- and yearling-to-female ratios (at the same search effort) if they remain the primary metrics for monitoring moose response to wolf control. Selection of other composition areas nearby but outside the wolf control area would provide nonconfounded context for age-sex ratios observed within the wolf control area.

3. If human actions or natural events caused the Unit 21E moose population to increase to the point of density-dependent negative feedback on animal health or forage plant, providing additional harvest opportunity during winter to reduce density appears to be feasible based on moose occupancy of riparian areas used for hunting access (particularly females). In urgent situations, the moose harvest prohibition during winter for distances ≤0.8 km of the Innoko and Yukon rivers could be modified to further increase harvest opportunity.

4. Practices for data acquisition, storage, and analysis evolved (for the better) during this project. Better documentation of data management steps early in a study, including queries used in creating database tables, will facilitate the archive process. Future GPS projects should define best practices for data management before beginning collection of the high volume of GPS locations and associated data (e.g., 474,129 records in this study). Advice from a GIS analyst or analyst-programmer on the design of practices and systems is warranted, including documentation of metadata and database queries. Contracting of services with an established provider for data download and processing may be more cost effective than having agency staff do it. Although GPS telemetry can benefit wildlife managers working in remote situations, technical support from research or analytical staff is warranted because of the effort and specialized tools helpful for managing and analyzing high volumes of data.

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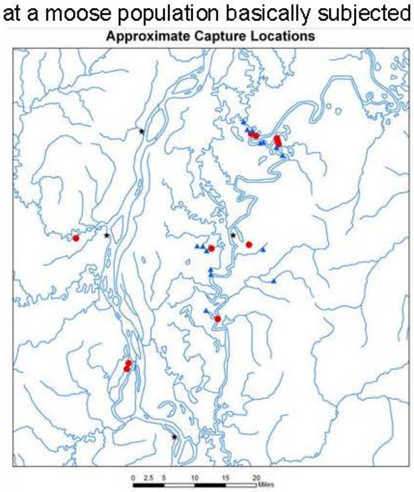
Appendix A. Summary of earlier telemetry study on moose movements in Unit 21E, western Interior Alaska (Alaska Department of Fish and Game and U.S. Fish and Wildlife Service-Innoko National Wildlife Refuge, unpublished study).

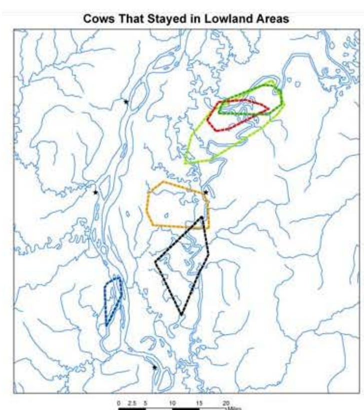
PARADISE CUA MOOSE RADIO TELEMETRY STUDY – 1986-1989

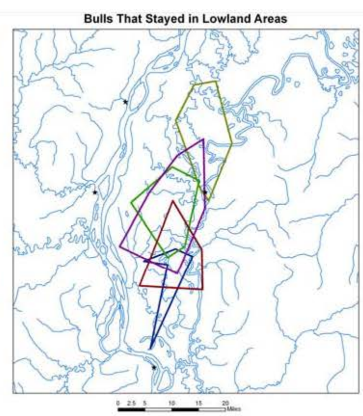
Steven Kovach
Innoko National Wildlife Refuge

This study consisted of 2 parts – one to look at a moose population basically subjected only to subsistence hunting, and second, to look at a moose population basically subjected only to sport hunting. This project was a cooperative effort between Innoko Refuge, BLM, and ADFG. The first part of the study concentrated on the Paradise CUA, the second part of the study was to concentrate on the upper Innoko River area in the vicinity of the Mud and Dishna Rivers. The second part of the study, though started, was never completed.

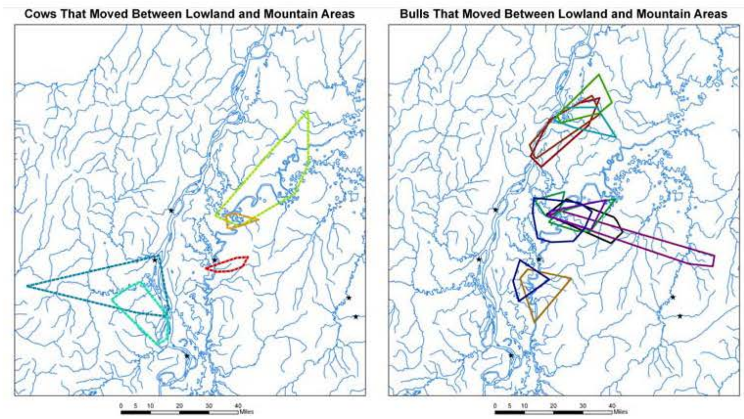


The Paradise CUA part of the study began in March 1986 when 15 cows and 20 bulls were captured. As you can see, many of the captures were clumped in their distribution. Moose generally moved less than 10 miles between collaring and late May. Between late May and mid June, bulls began moving away from their capture areas; cows, limited their movements during the calving periods. After mid June, movements by both bulls and cows increased.

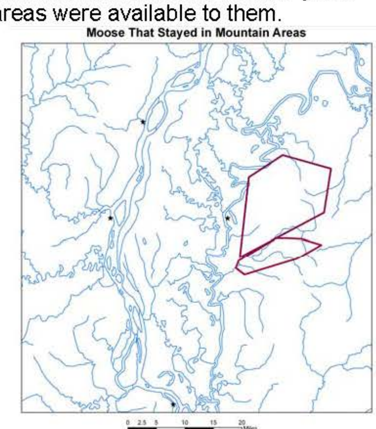




Over the course of the study moose tended to belong to 1 of 2 groups when it came to habitat selection. The first group consisted of 6 cows and 5 bulls. This group predominately spent their entire year in lowland areas.



The second group consisted of 5 cows and 12 bulls. This second group generally displayed greater movements, spending winters in the lowland areas and summers in the mountains. Many of these moose tended to select areas that had burned more than 30 years prior to the study, even though more recent burned over areas were available to them.



Lastly, 2 bulls showed a unique pattern in that they spent the entire year in the mountains.

Only two moose, 1 bull and 1 cow, showed extreme movements. The bull was caught near Holikachuk and spent his summers in the upper Iditarod River area. The cow was caught north of Holy Cross and spent her summers down river of Mountain Village. Apparently, both animals were relocated only a few times, so we really only know the extremes of their movements but not much else.

It would appear that this study showed us that about half of the cows that winter in the low areas, spend their summers there as well, while half move into the mountains and spend time in old burned areas. It also appears that most bulls leave the low wintering areas for the mountains, selecting for old burned areas as well. Moose do move very long distances between winter and summer areas, but that appears to be the rare exception and not the rule.

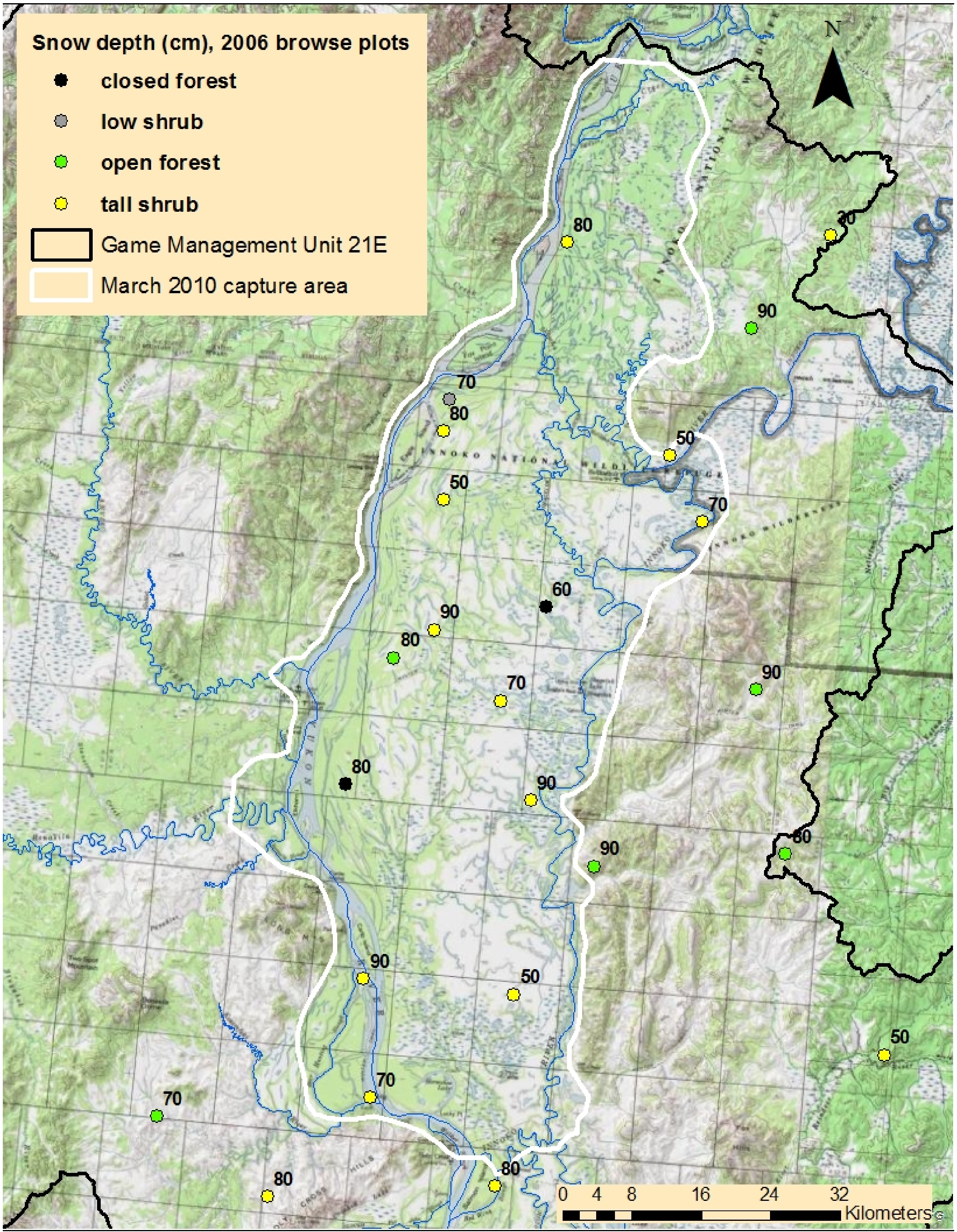
During one summer a large fire burned through an area occupied by some radio collared moose. Relocations of those moose both during and after the fire showed that the fire did not displace the moose; they avoided the main fire, but then returned to familiar sites once the fire had cooled down.

Appendix B. Observations of moose calves associate with radio-marked adult females (dams) and number of calves observed to fall and late winter for 4 cohorts in Unit 21E, western Interior Alaska, 2010–2014. For behavioral change point analysis to evaluate movements of females with GPS collars (sampling requirements in text), bold numbers indicate evidence of parturition within a cohort, whereas underlined numbers indicate evidence of no parturition within a cohort.

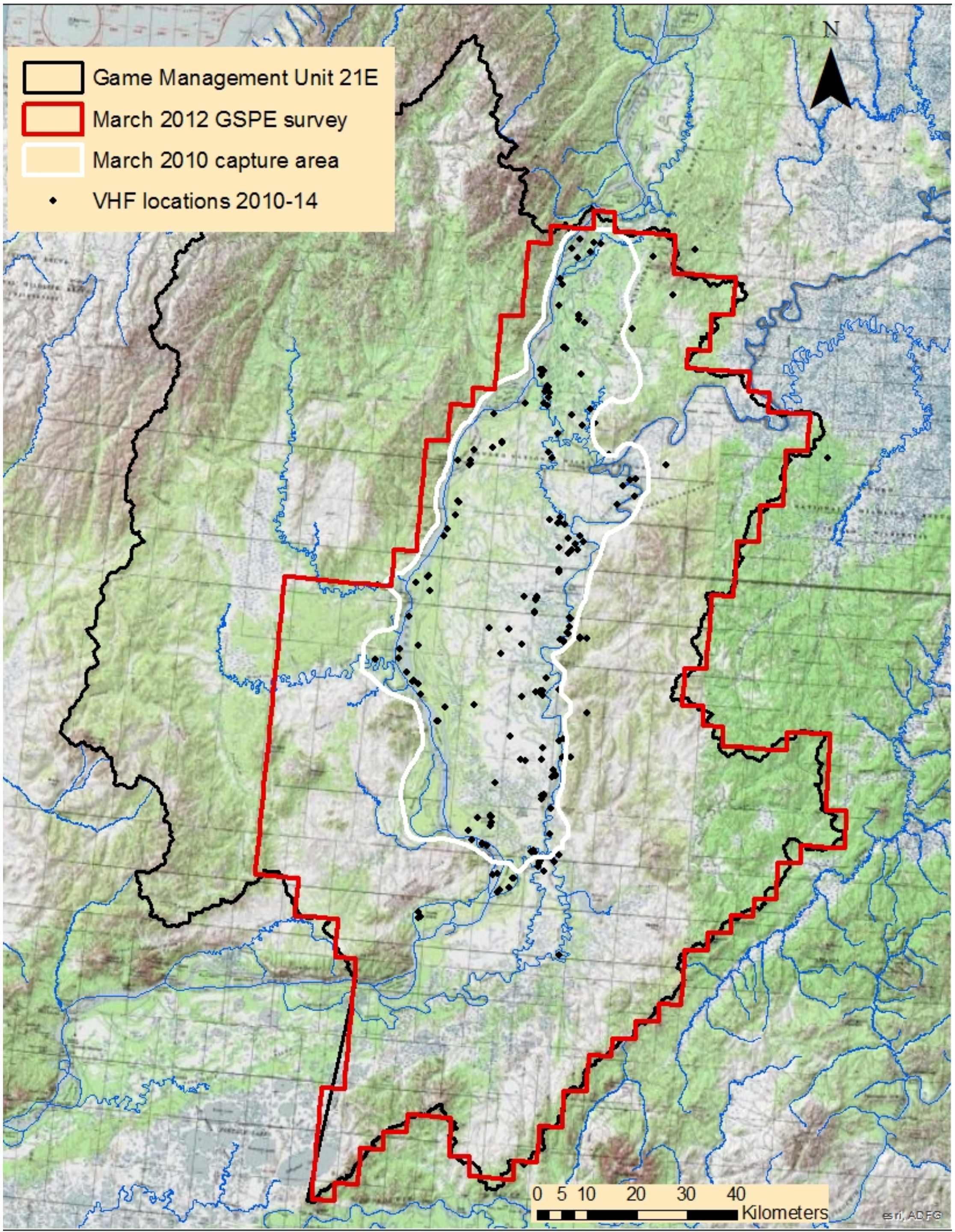
				2010–2011 cohort			2011–2012 cohort			2012–2013 cohort			2013–2014 cohort		
Dam VHF freq.	ID	Dam age (yr) Mar 2010[a]	10-mo calf Mar 2010	26–28 May 2010	Nov 2010[b]	28 and 31 Mar 2011	2 and 6 Jun 2011	2–3 Nov 2011	12–16 Mar[c] 2012	Early Jun[b] 2012	28–29 Nov 2012	Mar[b] 2013	Late May[b] 2013	Nov[b] 2013	29–30 Mar 2014[d]
168.156	1	#	0			**2**	–[e]								
168.130	2		1			**1**	0[f]		<u>0</u>		0				0
169.906	3		0	**2**		1	**1**	1	1		**2**				0
169.768	6		1			**1**	**2**	2	2		<u>0</u>				0
169.931	9	#	0	**2**		–[e]									
169.756	10		0	**1**		0	**2**	1	?[g]		0				0
169.355	11		0	**2**		2	2	–[e]							
169.631	12		0	**2**		2	0		<u>0</u>		0				1
169.618	15	9	0	**1**		1			**1**	–[e]					
168.143	16		0			**1**	0	**1**[h]	1		**1**				<u>0</u>
169.644	20		0			<u>0</u>		**2**	1		**1**				0
168.118	21	#	0	0		<u>0</u>	**1**	0	0		**1**				
169.331	24	#	1	0		<u>0</u>	0	0	<u>0</u>		0		–[e]		
169.156	25[i]		0			1	2	1	1		0				0
169.318	27		0	0[j]		<u>0</u>		0	<u>0</u>		0				0
169.780	28		0	**2**		0	0	0	<u>0</u>			–[k]			**1**
169.106	29[i]	#	0			1	1	1	1						–[l]
169.144	32[i]		0			1			1						1
169.981	33		0	**1**		0	**1**	1	1		0				0
169.343	36		0	**1**		1		**1**	–[e]						
169.231	38[i]		0	2		1	2	1	1		2				0
169.831	39		0	**2**		1	**1**	1	1		0				**1**
169.919	43		0	**2**		–[m]	**1**	0	0		0				
169.119	44[i]		0			1	1	2	2		2				0
169.944	46	8	1			**1**	**2**	0	0						
169.169	47[i]		1	2		1			0		0				0
169.219	50[i]		0	–[j]		0		1	1		0				–[n]
169.081	52[i]		0			2	1	1	0		1				0
169.131	54[i]		0			1	2	2	2		1				–[e]
169.931	56					1[o]	**1**	1	1		**1**				<u>0</u>

[a] No tooth removed during female captures; age estimated (as of March 2010) from cementum if tooth was subsequently recovered from mortality. Number symbol indicates tooth obtained from mortality but results not yet received.
[b] No flight this period: not scheduled (November 2010), poor weather (May–June 2012), aircraft mechanical and electrical problems developed in flight that precluded telemetry (May 2013), competing work and poor weather (November 2013).
[c] Multiple observations on some dams during telemetry trials associated with a moose survey.
[d] Last flight for this project to estimate twinning rate after GPS collars were removed and replaced with VHF collars.
[e] Dam mortality since last observation.
[f] Still had 1calf (10 month old) from last year.
[g] Observed once with several adults on riparian bar, could not confirm whether calf was associated with marked dam.
[h] Calf missed in spring or birth possibly occurred after twinning flight.
[i] VHF transmitter only; collars on other dams also have capability of storing GPS locations every 4 hours.
[j] Dam not pregnant in March 2010 based on bovine pregnancy-specific protein B concentration in blood (ID 27 was a small female presumed to be young, and ID 50 appeared to be young). These were not included in calculations of parturition for the entire data set (which include VHF females in footnote i) because they may have been immature, but F27 was used in behavioral change point analysis (BCPA) for confirmation of negative movement pattern associated with parturition.
[k] Dam was included in BCPA analysis because of adequate requirements for movement sampling. Even though not observed during flights, her behavior pattern indicated parturition in spring 2012.
[l] Inadvertently not listed for telemetry flight.
[m] Two females, 1 calf.
[n] Heard but could not obtain visual on weak signal.
[o] Collar redeployed from mortality on F9 in November 2010 to F56 in April 2011, which had a 10-month-old calf. Thus this female was not eligible for BCPA analysis in the 2010–2011 cohort.

Appendix C. Location of browse plots with associated snow depth and vegetation cover type in Unit 21E, western Interior Alaska, during 10–13 April 2006.

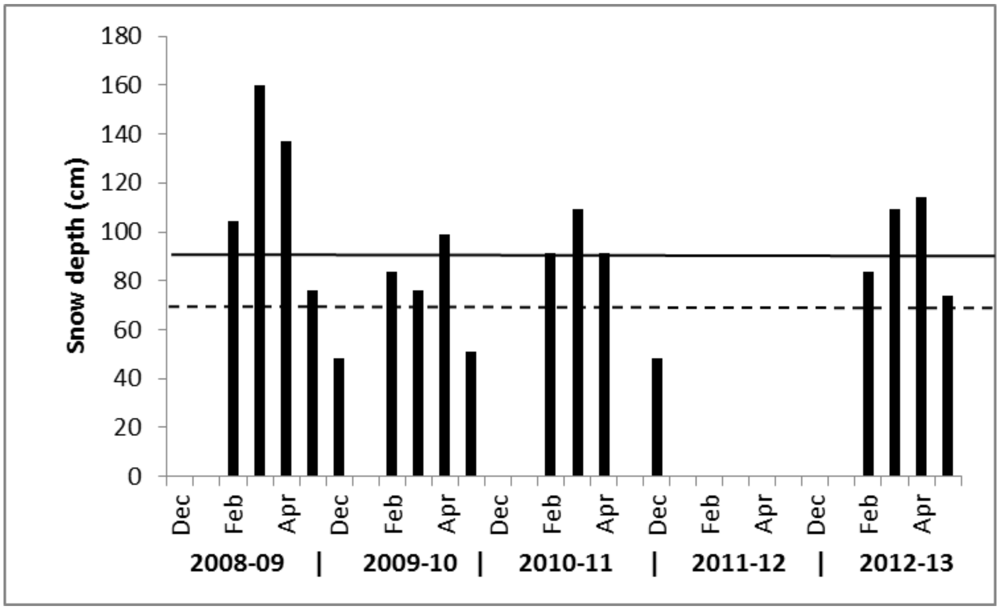


Appendix D. Supplemental VHF locations of 21 female and 25 male moose (0–8 per individual) acquired during 2010–2014, Unit 21E, western Interior Alaska.

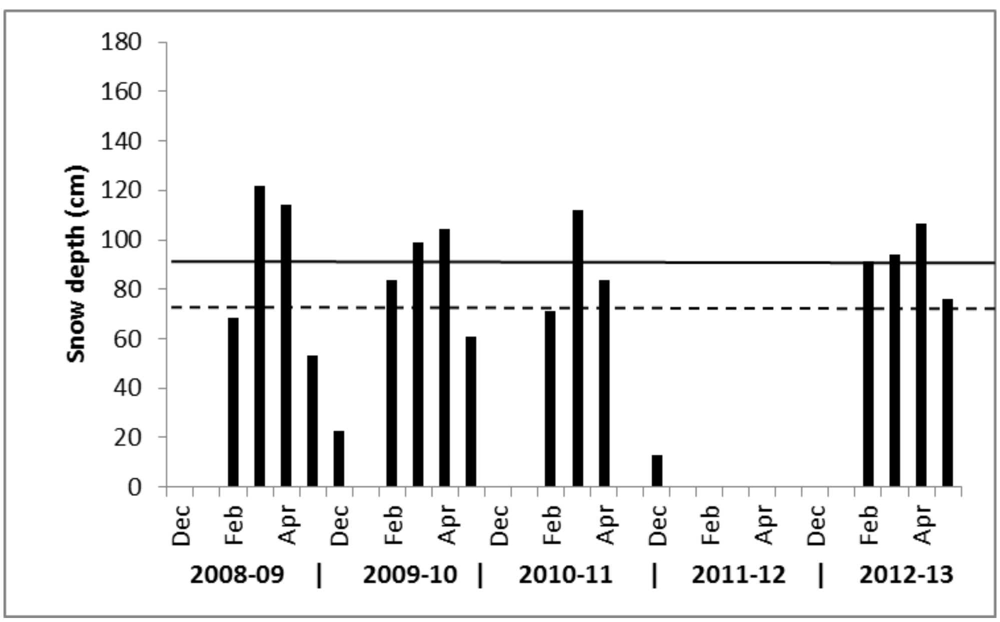


Appendix E. Snow depth observed on vertical gauges from fixed-wing aircraft around the first day of December through May, winters 2008–2009 through 2012–2013, Unit 21E, western Interior Alaska: (a) Holikachuk (62.92°N, 159.22°W) and (b) Yankee Slough (63.26°N, 159.27°W). Thresholds indicate snow depths that begin to influence adult female moose habitat selection (dashed line) and high energy expenditure (solid line). Data were missing for January–May 2012 and December 2013–May 2014; other periods courtesy of Innoko National Wildlife Refuge.

a



b



Appendix F. Snow depth (cm) on vertical gauges estimated from fixed wing aircraft at the beginning of the month and year indicated in Unit 21E.

Gauge	MonthYr	Depth
Reindeer R	Feb12	53
Reindeer R	Apr12	69
Reindeer R	May12	0
Reindeer R	Dec12	38
Lower Innoko R	Dec12	33
Carlo Island	Dec12	28
Anvik River	Dec12	38
Fox Point Island	Dec12	23
Bonasilla R	Feb13	64
Anvik River	Feb13	84
Reindeer R	Feb13	43
Anvik River	Feb14	61

Appendix G. Age (increasing order), change in neck circumference (March–October 2010), antler width, and neck condition beneath expandable radio collars of male moose in Unit 21E.

ID	Age (yr)	Neck circumference (cm)		Circumference increase (Mar–Oct %)	Max. antler spread (cm)	Neck condition[a]
		Mar	Oct			
40	1	63	71	13	85	1
13	3	83	87	5	101	2
48	3	100	118	18	117	6[b]
4	4	79	96	21	117	2
14	4	73	–[c]		127	2
37	9	91	–[d]		163	4[e]

[a] 1 = no rub, 2 = hair broken, 3 = hair removed, 4 = skin broken, 5 = wound, 6 = infected wound, 7 = deep tissue infection.

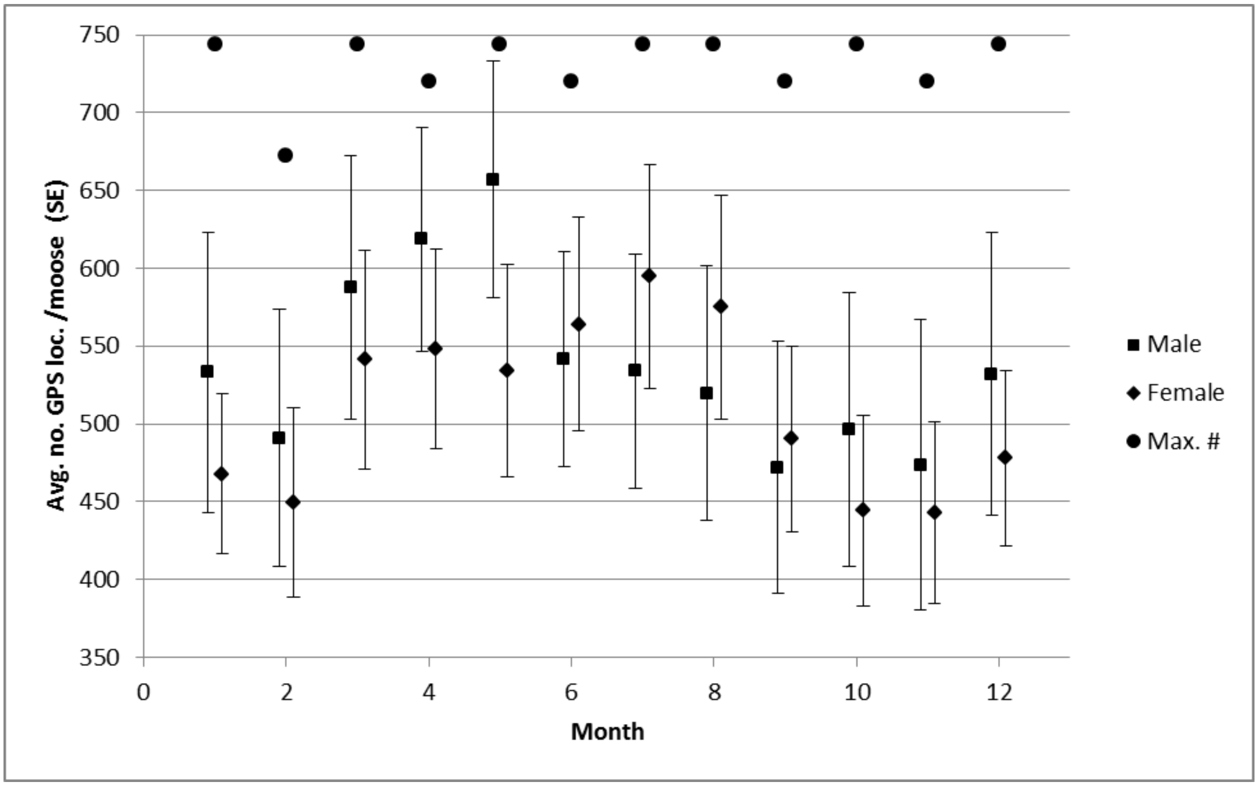
[b] Collar expanded only half of full distance and sat behind ears (wound treated with antiseptic)

[c] Found recently dead.

[d] No measurement taken because of a need for quick reversal of immobilization drug due to animal position.

[e] Collar expanded only half of full distance.

Appendix H. Average number of 3-D GPS locations of moose from 25 male collars (side-mounted antenna) and 21 female collars (top-mounted antenna) by month during March 2010 to March 2014, Unit 21E, western Interior Alaska. The maximum number of locations possible each month based on 6 fixes per day over 4 years is indicated.



Appendix I. Duration of GPS data and number of locations for male and female moose in Unit 21E, western Interior Alaska.

Moose sex_ID	Deploy date	Last GPS loc in field alive	Mort	End cont. GPS[a]	Months cont. GPS	GPS loc. type	GPS locations	VHF locations	Total locations	Notes
F01	03/14/10	04/07/11	Y	Aug-11	17	datalog	2,485	2	2,487	
F02	03/14/10	09/04/11		Aug-11	17	datalog	3,426	7	3,433	
F03	03/14/10	03/15/14		Dec-13	45	datalog	6,408	5	6,413	
M04	03/14/10	10/01/11	Y	Aug-12	29	datalog	3,497	1	3,498	
M05	03/14/10	08/12/12		Aug-12	29	CD	4,969	2	4,971	VHF failed, not recovered
F06	03/14/10	11/10/13		Nov-13	40	datalog	6,882	6	6,888	
M07	03/14/10	09/13/12	Y	Apr-12	25	datalog	5,540	3	5,543	
M08	03/14/10	05/24/12		May-12	26	CD	4,161	4	4,165	VHF failed, not recovered
F09	03/14/10	11/27/10	Y	Apr-11	13	CD	951	1	952	no datalog; refurbed, redeployed F56
F10	03/14/10	05/01/13		Apr-13	37	datalog	4,777	5	4,782	
F11	03/14/10	07/29/11	Y	Jul-11	16	datalog	2,546	5	2,551	ARGOS mort began 10/08/2011
F12	03/15/10	10/28/12		Feb-12	23	datalog	4,237	6	4,243	
M13	03/15/10	10/18/11	Y	Oct-11	19	CD	3,051	0	3,051	VHF failed, not recovered
M14	03/15/10	10/12/10	Y	Oct-10	7	datalog	2,514	0	2,514	raw datalog w M48 collar (redeploy)
F15	03/15/10	06/07/12	Y	Aug-12	29	datalog	5,123	7	5,130	
F16	03/15/10	03/20/14		Mar-14	48	datalog	16,702	7	16,709	
M17	03/15/10	03/20/14		Mar-14	48	datalog	8,405	1	8,406	
M18	03/15/10	06/11/11	Y	Jun-14	20	datalog	2,756	2	2,758	GPS gap June 2011-Oct 2013
M19	03/15/10	07/08/11		Jul-11	15	CD	2,251	0	2,251	VHF failed, not recovered
F20	03/15/10	03/23/14		Mar-14	48	datalog	8,531	3	8,534	
F21	03/15/10	01/17/14		Dec-13	45	datalog	7,231	7	7,238	
M22	03/15/10	03/20/14		Mar-14	18	datalog	17,558	1	17,559	
M23	03/16/10	09/22/11	Y	Dec-11	21	datalog	3,218	0	3,218	
Moose sex_ID	Deploy date	Last GPS loc in field alive	Mort	End cont. GPS[a]	Months GPS	GPS loc type[b]	GPS locations	VHF locations	Total locations	Notes
F24	03/16/10	04/27/13	Y	Mar-14	48	datalog	6,542	8	6,550	
F25	03/16/10	n/a		n/a	n/a	VHF	--	7	7	
M26	03/16/10	03/02/14	Y	Mar-14	48	datalog	8,469	4	8,473	
F27	03/16/10	12/22/13		May-13	38	datalog	4,371	7	4,378	

Moose sex_ID	Deploy date	Last GPS loc in field alive	Mort	End cont. GPS[a]	Months cont. GPS	GPS loc. type	GPS locations	VHF locations	Total locations	Notes
F28	03/16/10	03/22/14		Mar-14	48	datalog	9,537	4	9,541	
F29	03/16/10	n/a		n/a	n/a	VHF	--	5	5	
M30	03/16/10	11/03/11	Y	Jun-14	48	datalog	3,465	1	3,466	
M31	03/16/10	09/02/11	Y	Sep-11	18	CD	2,593	0	2,593	VHF failed, not recovered
F32	03/16/10	n/a		n/a	n/a	VHF	--	2	2	
F33	03/16/10	03/22/14		Mar-14	48	datalog	7,529	6	7,535	
M34	03/17/10	11/12/11	Y	Aug-12	22	datalog	3,772	2	3,774	GPS gap Nov 2011-May2012
M35	03/17/10	09/17/13	Y	Dec-13	45	datalog	7,651	2	7,653	
F36	03/17/10	01/24/12	Y	May-12	26	datalog	4,431	5	4,436	
M37	03/17/10	10/12/10		Oct-10	7	datalog	1,238	0	1,238	GPS removed, deployed VHF
M37	04/21/11	03/23/14		Mar-14	35	datalog	4,928	1	4,929	2nd GPS collar this animal (from M48)
F38	03/17/10	n/a		n/a	n/a	VHF	--	7	7	
F39	03/17/10	03/20/14		Mar-14	48	datalog	5,820	6	5,826	
M40	03/17/10	03/20/14		Mar-14	48	datalog	18,034	1	18,035	
F41	03/17/10	n/a		n/a	n/a	VHF	--	0	0	never heard after deployment
M42	03/17/10	09/25/11	Y	Jul-12	28	CD	1,906	0	1,906	collar not recovered (submerged)
F43	03/17/10	07/19/13	Y	Jun-12	27	datalog	4,627	6	4,633	ARGOS mort 08/10/13
F44	03/17/10	n/a		n/a	n/a	VHF	--	5	5	
M45	03/17/10	08/12/13	Y	Sep-13	42	CD	4,554	2	4,556	VHF failed, not recovered; mort signal start 8/27/13
Moose sex_ID	Deploy date	Last GPS loc in field alive	Mort	End cont. GPS[a]	Months cont. GPS	GPS loc. type	GPS locations	VHF locations	Total locations	Notes
F46	03/17/10	03/27/12	Y	Apr-12	25	datalog	4,128	8	4,136	
F47	03/18/10	n/a		n/a	n/a	VHF	--	7	7	
M48	03/18/10	10/12/10		Oct-10	7	datalog	1,256	2	1,258	GPS collar removed
M48	10/12/10	03/20/14		Mar-14	41	datalog	7,768	0	7,768	2nd GPS collar directly from M14
M49	03/18/10	03/20/14		Mar-14	48	datalog	18,080	4	18,084	
F50	03/18/10	n/a		n/a	n/a	VHF	--	5	5	
M51	03/18/10	9/13/2011	Y	Feb-12	23	datalog	3,266	0	3,266	

Moose sex_ID	Deploy date	Last GPS loc in field alive	Mort	End cont. GPS[a]	Months cont. GPS	GPS loc. type	GPS locations	VHF locations	Total locations	Notes
F52	03/18/10	n/a		n/a	n/a	VHF	--	4	4	
M53	03/18/10	03/20/14		Mar-14	48	datalog	9,034	3	9,037	
F54	03/18/10	n/a		n/a	n/a	VHF	--	8	8	
M55	04/21/11	05/31/14		Mar-14	35	CD	5,445	1	5,446	not captured March 2014
F56	04/21/11	09/10/13		Aug-13	28	datalog	11,070	5	11,075	refurbed GPS collar from F9

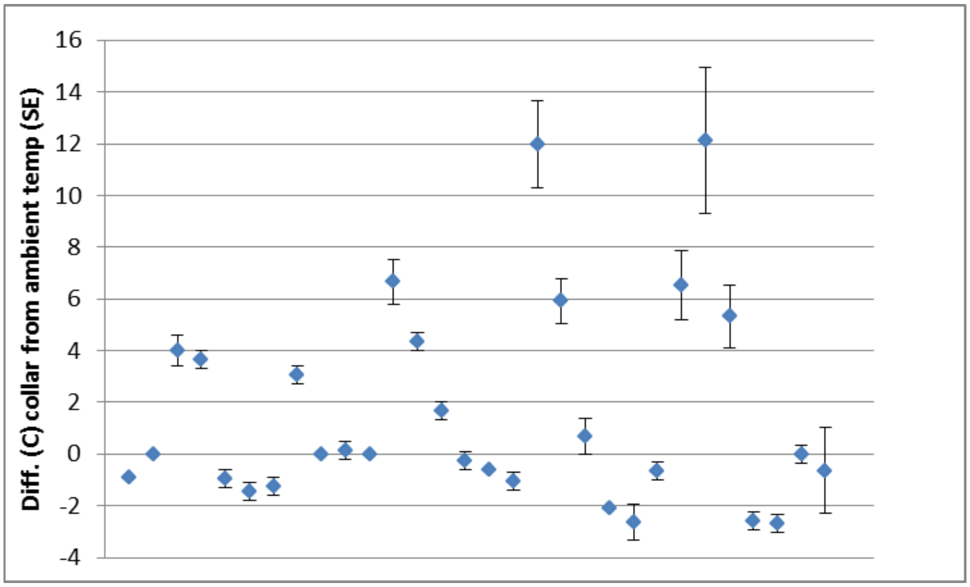
[a] Beginning of intermittent GPS fixes with gaps of various duration.
[b] Data logs obtained from collars retrieved at the end of study were called “final” in databases.

Appendix J. Distance and bearing indicating difference in position of collar in 68 trials (F = female design, M = male design) based on downloaded GPS location compared with location of the stationary collar (true location) as determined by a Trimble GeoXT GPS with an external antenna. Bearing from the true location has no relationship with the magnitude of the distance away from the true location.

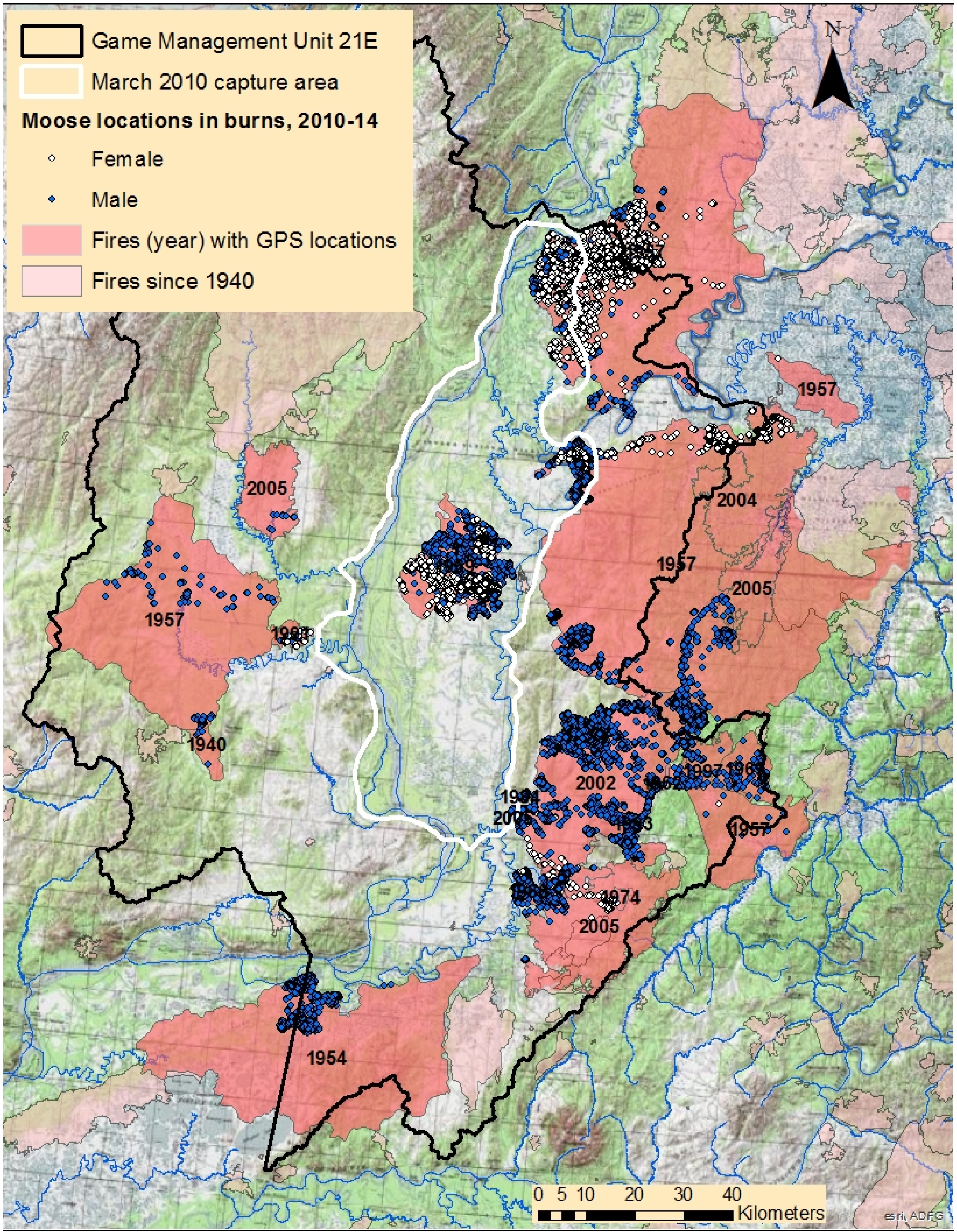
	Collar	Mean	SD[a]	Min.	25% percentile	50% percentile	75% percentile	Max.
Bearing (deg.)	F_28B	196	94	0	157	198	260	357
	M_28C	215	106	7	146	231	310	349
	M_34C	189	109	1	114	188	291	358
Distance (m)	F_28B	7	4	1	4	7	10	21
	M_28C	9	7	1	5	7	12	40
	M_34C	12	9	1	7	10	15	44

[a] SD = standard deviation.

Appendix K. Difference in temperature between GPS collars (1 female design, 2 male design) and ambient (National Weather Service) during 30 trials in early April 2011, McGrath, Alaska. Male and female collar results were pooled for each trial over a range of ambient temperatures.



Appendix L. Dispersion of GPS locations within burns for 11 female and 20 male moose monitored during 2010–2014 that used burns at least seasonally in Unit 21E, western Interior Alaska. (All September moose locations are shown relative to fire history in Fig. 8.)



Appendix M. Percentage of 286,733 moose GPS locations by sex and month (January = 1, February= 2, etc.) that were in 22 burns (fire years: 1940–2005) for 11 female and 20 male moose during 2010–2014.