Final Wildlife Research Report, ADF&G/DWC/WRR-2012-7

Response of moose and their predators to wolf reduction and short-term bear removal in a portion of Unit 19D

Federal Aid in Wildlife Restoration, Grants W-33-4 through W-33-10, Project 1.62

Mark A. Keech

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Alaska Department of Fish and Game   Division of Wildlife Conservation

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Cover Photo: Moose calf with expandable, VHF radio collar in Unit 19D East. These radio collars expand with neck growth and detach in approximately 2 years.

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Summary

The demand for increased sustained yield of moose (*Alces alces*) has been the impetus for predator reduction efforts within selected areas of Alaska in recent years. The north and eastern portion of Unit 19D, in western Interior Alaska, was one area selected by the Alaska Board of Game to provide higher harvests of moose. As a result, a portion of Unit 19D East, primarily around the community of McGrath, has been the focus of active predator reduction efforts that began in spring 2003 and have continued to present. The goal of this research project was to document the effect of predator reductions, as well as other environmental and individual factors, on moose survival and population dynamics.

Predator reduction efforts to increase moose harvests in Unit 19D East differed from predator reduction efforts elsewhere in Alaska in 2 principal ways. First, the Alaska Board of Game and the Alaska Department of Fish and Game (ADF&G) focused private aircraft-assisted take of wolves (*Canis lupus*) in the most heavily utilized portion of Unit 19D East, as opposed to authorizing aircraft-assisted take throughout the entire unit. Secondly, ADF&G conducted thorough experimental translocations of black bears (*Ursus americanus*) and brown bears (*U. arctos*) from a small portion of Unit 19D East surrounding McGrath to increase survival of newborn moose.

Concurrent with predator reduction efforts, this research project (federal aid project 1.62) in conjunction with its predecessor (federal aid project 1.58) documented abundance of wolves, bears, and moose within a study area that encompassed the core area of predator reductions, the experimental micromanagement area (EMMA) and the moose management area (MMA). We also estimated changes in survival and causes of mortality for all age classes of moose within the study area.

In May 2003 and 2004, ADF&G reduced black bear and brown bear numbers by translocating bears ≥240 km from the study area. We estimated black bears were reduced by approximately 96% by June 2004 and recovered to within 27% of preremoval numbers by May 2007 and were fully recovered by May 2010. Brown bears were reduced approximately 50% by June 2004. Aircraft-assisted take reduced wolf numbers markedly in the study area during 2004–2007. Late-winter wolf numbers were reduced by 75% by 2005 and likely remained at reduced levels through 2010. In addition to predator reductions, moose hunting closures during 2004–2007 reduced harvests of male moose by 60% in the study area.

Predator removals resulted in increased calf survival rates during summer (primarily from reduced black bear predation) and autumn (primarily from reduced wolf predation). Predator removals had little influence on survival of moose calves during winter; instead, calf survival was influenced by snow depth and possibly temperature. Increased survival of moose calves during summer and autumn combined with relatively constant winter survival in most years led to a corresponding increase in annual survival of calves following predator removals. Nonpredation mortalities of calves increased following predator removals; however, this increase provided little compensation to the decrease in predation mortalities resulting from removals. Thus, predator-induced calf mortality was primarily additive. Following predator removals, survival of yearling moose increased during summer and autumn. Annual survival of adult female moose also increased in years with predator reductions and was also negatively related to age. Moose density increased 45% (from 0.38 moose/km^2 in 2001 to 0.55 moose/km^2) in 2007, which resulted from annual increases in overall survival of moose, not increases in reproductive rates. Indices of nutritional status in moose remained constant throughout our study despite increased moose density.

Key words: adult, aircraft-assisted take, Alaska Board of Game, calf, mortality, nutritional status, reproductive rate, survival, translocation, yearling, yield.

Background

Historically, moose (*Alces alces*) numbers were at relatively high levels in the upper Kuskokwim/Unit 19D during the late 1960s (Shepherd 1975). This period of high moose abundance was followed by an Interior-wide decline in moose numbers, which was particularly pronounced during the severe winter of 1971–1972 (Shepherd 1975, Gasaway et al. 1983). Subsequently, moose populations in Unit 19 recovered (Shepherd 1975), and moose in most of Unit 19 occurred at moderate densities again by the mid-1980s (Pegau 1985). However, Pegau (1985) believed that moose numbers continued to remain low in the north and eastern Unit 19D (hereafter Unit 19D East) and that moose were unable to sustain the combined mortality from hunting and predation. The relatively low moose population in Unit 19D East apparently declined further during a period of generally severe winters and increased wolf numbers in the early 1990s (Whitman 1994, 1998; Boudreau 2000*a,b*). Consequently, the subsistence needs of local Unit 19D moose hunters were not met (Boudreau 2000*a*), thus leading to management actions that included predator reductions.

In response to low moose harvests in Unit 19D East, the Commissioner of the Alaska Department of Fish and Game (ADF&G) appointed a team of Alaskans from diverse interest groups to recommend a management program that would increase moose harvest. In February 2001 the team recommended eliminating predation by wolves (*Canis lupus*), and reducing predation by black bears (*Ursus americanus*) in a relatively small area along the Kuskokwim River in the vicinity of Takotna, McGrath, and Nikolai in Unit 19D East. The Commissioner's appointed team also recommended a short-term closure on the hunting of moose and recommended research studies to gain additional information on moose, predators, and habitat. By 2002 the Commissioner's appointed team had become defunct and recommendations for management actions in Unit 19D East were resumed through the established process between the public, Fish and Game advisory committees, ADF&G, and the Alaska Board of Game. However, several of the initial recommendations of the Commissioner's appointed team remained; primarily the recommendation for predator reductions on a small geographic scale, a temporary hunting closure, and concurrent research, and have distinguished the predator control efforts in Unit 19D East from other Interior units. Ultimately, the need for information on which to base management actions and evaluate their effects was the impetus for project.

Objectives

The major objective of project 1.62 was to document and evaluate the effects of predator reductions in Unit 19D East relative to moose survival and abundance. Predator reductions were implemented prior to this project and included 2 years (2003 and 2004) of department led bear translocations as well as private aircraft-assisted wolf reductions than began in 2004 and have continued through 2010. Other important objectives included data collection relative to predator abundance and moose hunting harvest, and providing information to assist in making management decisions. Keech et al. (2011) provides a thorough description of predator removals and hunting closures relative to this project. Because of the importance of having a continuous data set for comparative purposes, we present data starting with the initiation of intensive research in 2001 (collected during project 1.58) when that data exists relative to objectives for project 1.62.

Specific objectives for project 1.62 included:

Objective 1a: Estimate moose numbers and population composition in Unit 19D East.

Objective 1b: Determine primary causes of mortality of moose calves.

Objective 1c: Determine condition, movements, and mortality rates of yearling moose.

Objective 1d: Determine twinning rates and reproductive indices of moose in Unit 19D East.

Objective 1e: Monitor collared adult and yearling moose for survival and movement information.

Objective 2: Characterize winter moose browse in Unit 19D East, with emphasis on the intensive study area.

Objective 3: Estimate wolf numbers in Unit 19D East with emphasis on the intensive study area.

Objective 4: Estimate black bear numbers in the intensive study area.

Objective 5: Analyze hair and tissue samples for species, sex, and age information.

Objective 6: Review literature, write annual progress reports, write final project report, and publish results in peer-reviewed journals.

Study Area

Unit 19D East is a large (22,049 km^2) portion of Subunit 19D (31,194 km^2) with a complex recent history (2001–present) of moose management that includes varying temporal, spatial, and species-specific predator control efforts coupled with intensive research-oriented studies. Because of this, there are multiple areas of interest within Unit 19D East for the purposes of this research project (Fig. 1). These areas include 1) the 1,368 km^2 intensive study area or experimental micromanagement area (EMMA), 2) the 2,896 km^2 moose management area (MMA), 3) the 8,314 km^2 wolf control zone, and 4) the 13,761 km^2 Unit 19D East moose survey area (Unit 19D East MSA). We estimated moose abundance within EMMA, MMA, and the Unit 19D East MSA, while moose survival and productivity is estimated only for those moose primarily captured within EMMA. Bear removals occurred primarily within EMMA and bear abundance is estimated only within EMMA. Wolf abundance is estimated only within the wolf control zone.

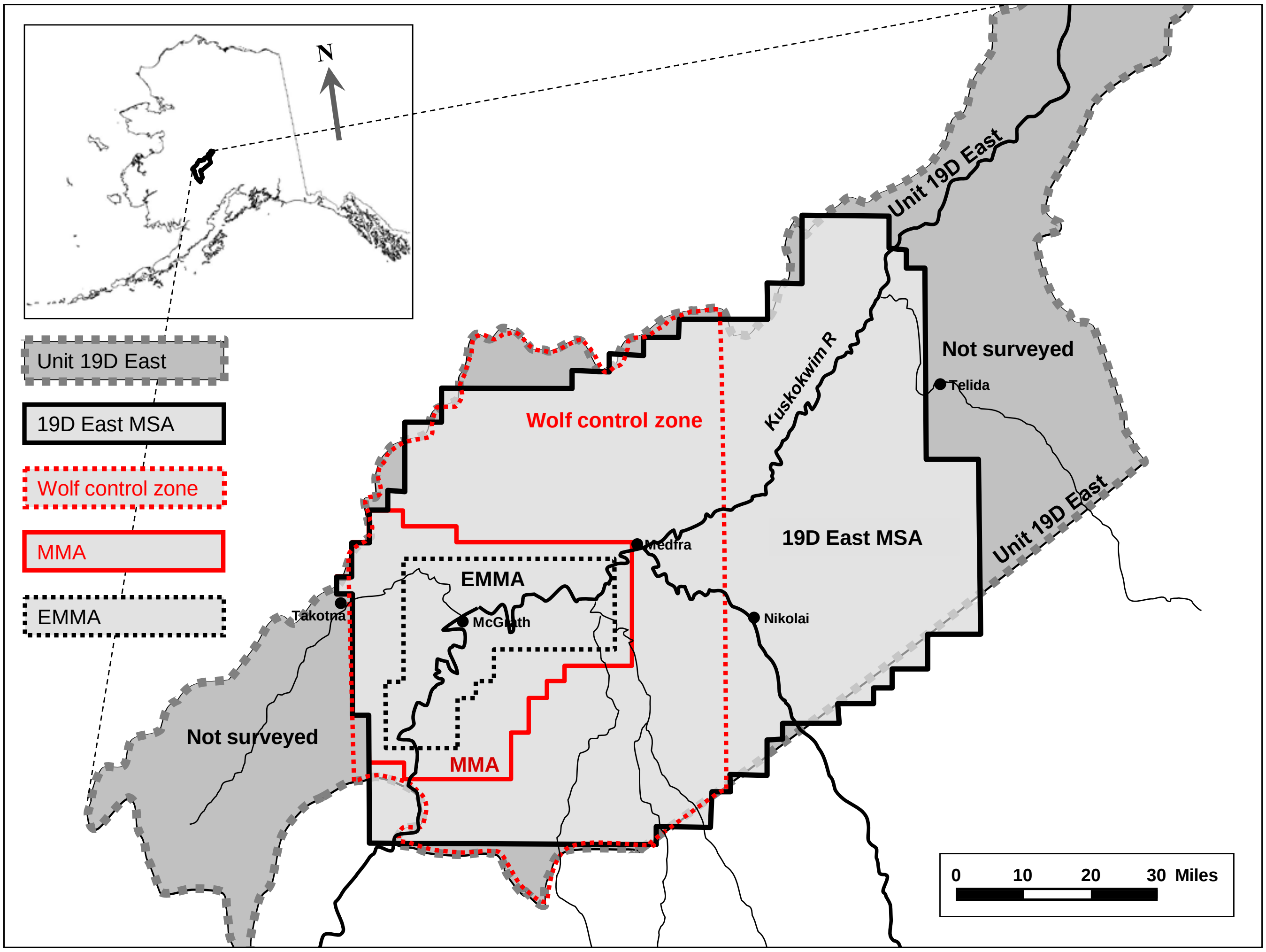

FIGURE 1. Unit 19D East, depicting the locations of the Unit 19D East MSA, wolf control zone, MMA, and EMMA, western Interior Alaska, 2001–2010.

Habitat within the Unit 19D East study areas was characterized riparian lowlands surrounded by rolling hills. Elevations varied between 100 and 1,374 m. Large rivers played a major role in the creation of shallow oxbow lakes and mixed-age successional plant communities. In these areas, early successional willow (*Salix* sp.) and alder (*Alnus* sp.) graded into stands of mature cottonwood (*Populus balsamifera*), white spruce (*Picea glauca*), and paper birch (*Betula papyrifera*) and were ultimately replaced by climax bogs and older forests of black spruce (*Picea mariana*) and tamarack (*Larix laricina*). In the hills, lower elevations were characterized by stands of white and black spruce, paper birch, and quaking aspen (*Populus tremuloides*), whereas shrub communities of willow, dwarf birch (*B. glandulosa* and *B. nana*), and alder predominated at higher elevations and eventually grade to alpine habitat on a few of the highest hills. A natural fire regime contributed to a mosaic of shrub, young spruce forest, and older mixed taiga.

Temperatures ranged from 31 C in summer to −47 C in winter, and early March snow depth in McGrath ranged between 41 and 104 cm. In general, this region experienced more frequent snowfall and snow accumulation than elsewhere in Interior Alaska. The period of snow cover usually extended from late October to the beginning of May. Large mammals inhabiting Unit 19D East included moose, wolves, black bears, brown bears (*U. arctos*), and low numbers of caribou (*Rangifer tarandus*).

Methods

Moose Numbers and Population Composition in Unit 19D East

We present estimates of moose numbers and composition for EMMA, MMA, and the Unit 19D East MSA. For comparisons as well as trend analysis prior to and following predator reductions, we present estimates from surveys conducted between 2001 and 2010. All surveys were conducted using geospatial survey techniques (Kellie and DeLong 2006); however, the frequency of surveys and sampling intensity varied between areas and years.

We estimated moose numbers and composition within EMMA during 2001 and 2003–2010. For surveys conducted during 2001 and 2004–2007, every sample unit (SU; 87 SUs in EMMA) within EMMA was sampled. In 2003, we defined high- and low-density strata (using results from previous surveys; Gasaway et al. 1986) and surveyed 45 of the 87 SUs, of which 60% were in the high-density stratum. Keech et al. (2011) provides detailed methodology for EMMA moose surveys 2001–2007. During 2008–2010, we used a single stratum and systematically sampled every other SU within EMMA (50% sampling coverage).

We estimated moose numbers and composition within MMA during 2001, 2004, and 2006–2010. Surveys within MMA (184 SUs) use the geospatial survey techniques (Kellie and DeLong 2006) to combine data from surveys conducted within EMMA (MMA entirely encompasses EMMA) and that portion of MMA outside of EMMA. Sample units were selected randomly for the portion of the survey area within MMA that was outside EMMA during 2001–2007 (SUs selected = 8% 2001, 11% 2004, 35% 2006, 32% 2007). During 2008–2010, we systematically selected every other SU within MMA (50% coverage). The 2007–2010 estimates are based upon a single stratum while estimates prior to 2007 are based upon 2 strata.

We estimated moose numbers and composition within the Unit 19D East MSA during 2001, 2004, and 2008. Surveys within the Unit 19D East MSA (879 SUs) are calculated by adding geospatial estimates from MMA (the Unit 19D East MSA entirely encompasses MMA) and separate geospatial estimates from that portion of the Unit 19D East MSA outside of MMA. For estimates with the portion of Unit 19D East outside of MMA we used 2 strata and randomly sampled SUs (18% 2001, 13% 2004, and 14% 2008). We selected 60% of SUs from high density strata and 40% from low density strata.

To obtain estimates of total moose abundance, composition ratios, and their variances during 2001, 2003, and 2005–2008, sightability correction factors (SCF) were calculated and applied to estimates of observable moose. For sightability calculations, we located radiocollared moose in SUs prior to survey pilots entering them. After completion of survey flying in each SU, survey pilots checked with the telemetry plane to determine if any radiocollared moose were present in the SU. If radiocollared moose were in completed SUs, the survey crew would then use telemetry equipment to relocate radiocollared moose and determine whether or not they had been sighted during the survey (Boertje et al. 2009, Keech et al. 2011). We calculated SCF and its variance using the Delta method (Rice 1995) to account for nonlinearity in its expected value. Thus, SCF differs slightly from simply dividing available collared moose by observed collared moose. Because of the distribution of radioed moose in Unit 19D East, sightability was recorded only within MMA. However, snow conditions and habitat types were similar enough in MMA and the portion of the Unit 19D East MSA outside of MMA that we assumed that there were no differences in sightability between the areas. Therefore, we also applied SCF calculated for MMA to the Unit 19D East MSA. We calculated variances for SCF corrected population estimates using Goodman's formula for a product of random variables (Goodman 1960) and present these population estimates and their 90% confidence intervals. The ratio estimates as well as their variances and 90% confidence intervals (CI) also incorporate variation in SCF. We used both the Delta method and Goodman's formula in these calculations. We did not determine year-specific SCFs during 2004, 2009, and 2010; therefore, SCF for those years was an average of the 2001 and 2003–2008 SCFs. Variability of SCFs for 2004, 2009, and 2010 is based upon the largest observed variation of the 4 complete surveys (2001, 2005, 2006, and 2007) with SCF calculations.

DETERMINE PRIMARY CAUSES OF MORTALITY OF MOOSE CALVES

To determine primary causes of mortality of moose calves and ascertain survival rates, we captured newborn moose, affixed radio collars, monitored radioed individuals, and investigated mortality sites. To locate newborn moose calves for capture from mid-May through early June 2001–2007 and 2010 (newborns not captured 2008 or 2009), we radiotracked adult females (see below for adult females captures) and opportunistically searched for calves of uncollared females. We captured calves as soon as practical, typically within 1 day of observation. We captured a total of 499 calves during 2001–2010. We considered 37 (7.4%) calves to be study-induced mortalities or abandonments. We excluded 17 calves from data analysis because they were captured well outside of the study area, primarily during 2001 when study area borders had not fully been established. Of the 482 calves used for analysis, we captured 244 from radiocollared females and 238 from uncollared females.

We captured calves using helicopter (Hughes 500 during 2001 and Robinson R-44s during all other years) techniques described by Ballard et al. (1979), Keech et al. (2000), and Bertram and Vivion (2002). We released calves <5 minutes after capture (even if data collection was incomplete) to minimize their separation from the dam. When twins were present, the 2-person crew captured, processed, and released both calves together. During processing, we determined sex of calves and weighed calves by placing them in a bag and suspending them with a calibrated 25- or 50-kg Chatillon™ spring scale (AMETEK, Inc., Kew Gardens, NY). To estimate age, we recorded posture, umbilicus condition, and hoof hardness (Haugen and Speake 1958, Adams et al. 1995). We deployed VHF radio collars weighing approximately 180 g and constructed from 4 layers of 10-cm wide elastic bandage with a diameter of 14 cm when sewn (model 335, Telonics, Inc., Mesa, AZ; PEG™ elastic bandage, Franklin Lakes, NJ). Collars expanded with neck growth and detached after approximately 2 years (Osborne et al. 1991, Keech et al. 2000). Pulse rate of collars doubled after remaining motionless for 1 hour.

We visually located calves within 24 hours postcapture to determine if they rejoined the dam, were separated from the dam, or had died. Thereafter, we monitored radio signals of calves approximately daily until mid-June and every other day until early July, after which tracking interval increased to every 5 days until mid-August, every other week until November, and once per month thereafter (Keech et al. 2000).We accessed mortality sites within 24 hours of mortality detection in most instances. We examined carcasses and mortality sites using criteria and techniques described by Ballard et al. (1979) and Adams et al. (1995).

For calves captured during 2001–2007, we used chi-square tests and Fisher's exact tests (FET) on 2×2 contingency tables (Agresti 2007) to identify differences in cause-specific rates of calf mortality. To test for differences in mortality rates relative to predator reductions, we followed the method specified by Scott and Seber (1983), which accounts for the covariance associated with sampling a multinomial distribution. We used the Kaplan-Meier estimator (Pollock et al. 1989) to describe patterns of calf moose survival at 15 intervals during 2001–2007 and 2010. Because no calves were radiocollared during 2008 and 2009, we estimated crude summer and annual survival rates for those years by monitoring parturient radiocollared adult females on an approximately monthly basis. We also used known-fate models for 2001–2007 data to investigate seasonal (summer, fall, and winter) changes in calf survival relative to predator reductions while evaluating potential covariates such as weather and individual moose traits (Keech et al. 2011).

DETERMINE CONDITION, MOVEMENTS, AND MORTALITY RATES OF YEARLING MOOSE

To determine condition, movements, and mortality rates of yearling moose, we captured 10-month-old moose, affixed radio collars, monitored radioed individuals, and investigated mortality sites. We also monitored radioed yearlings that had been captured as calves and had survived to the yearling age class. We captured 15–16 short-yearling (10 months old) female moose annually during late March or early April 2001–2007 and 2009–2010. In addition, we captured 8 female and 7 male yearlings during mid-May 2008. During 2001–2007, we immobilized all short yearlings with approximately 1.2 mg (0.4 cc) carfentanil citrate (Zoopharm, Windsor, CO) and 60 mg (0.6 cc) xylazine hydrochloride (Butler Schein Animal Health, Dublin, OH) delivered via a 1 cc projectile syringe fired from a CO^2 powered short range pistol projector. Reversal dosing was 125–150 mg (2.5–3 cc) naltrexone hydrochloride (Zoopharm) and 200–250 mg (2.0–2.5 cc) tolazoline hydrochloride (Zoopharm), with two-thirds given intramuscularly and one-third typically given intravenously. During 2008–2010, we captured short-yearlings using net-gunning techniques, no drugs were administered. Five of 105 (4.8) short-yearlings captured using drug immobilization and 1 of 46 (2.2%) short-yearlings captured using net-gunning techniques died soon after capture and were considered study-induced mortalities. We used a Hughes 500 helicopter for the 2001 capture, a Robinson R-22 helicopter in 2004, and Robinson R-44 helicopter during all other years

When short-yearling moose were immobilized (or restrained during net gun captures), we 1) measured neck girth, metatarsus length, and total length along the dorsal body contour from the hairless patch on the nose to the tip of the tail bone; 2) weighed the moose with a dynamometer using a portable tripod and winch or the helicopter to lift the animal; and 4) collected 30–50 cc of blood from the jugular vein. Measurements, body weight, and blood samples were not obtained from short-yearlings captured in 2008. We also deployed radio collars on all short-yearling moose captured each year during 2001–2004 and 2008–2010, 9 captured in 2005, and 11 captured in 2006. Collars were not deployed in 2007. Collars were expandable and equipped with motion-sensitive mortality sensors.

We monitored radiocollared short-yearling and yearling moose monthly to detect mortalities and movements. We used criteria and techniques described by Boertje and Gardner (2000) to evaluate causes of death. We used the Kaplan-Meier estimator (Pollock et al. 1989) to describe patterns of yearling moose survival at 30 intervals during 2001–2010. We also used known-fate models for 2001–2007 data to investigate seasonal (summer, fall, and winter) changes in yearling survival relative to predator reductions while evaluating potential covariates such as weather and individual moose traits (Keech et al. 2011). We analyzed average yearly weights from short-yearling female moose for trend using a linear mixed effects model (Zhang et al. 1998, McCulloch and Searle 2001, DeLong and Taras 2009, Keech et al. 2011).

DETERMINE TWINNING RATES AND REPRODUCTIVE INDICES OF MOOSE IN UNIT 19D EAST

To determine twinning rates and reproductive indices of moose we monitored radiocollared adult (>2 yr-of-age) moose daily in May and early June in order to detect newborn calves. We also recorded observations of twin and single calves of uncollared females (Boertje et al. 2007) during May and June flights to determine twinning rates for uncollared females. Radiocollared adult females were either captured as adults, or were adults that had been captured as yearlings and had survived to the adult age class. We captured 25 adult female moose (>33 months old) during March 2001, 10 during June 2001, and 15 during March 2002. We immobilized all adult moose with 3.0–4.5 mg (1.0–1.5 cc) carfentanil citrate and 150–167 mg xylazine hydrochloride, administered intramuscularly via a 3 cc projectile syringe (2.9 cm needle) fired from either an extra long range Palmer Cap-Chur rifle (Palmer Chemical and Equipment Company, Douglasville, GA) or CO^2 powered short range pistol projector. Reversal dosing was 300–450 mg (6–9 cc) of naltrexone hydrochloride and 350–400 mg (3.5–4.0 cc) tolazaline hydrochloride intramuscularly. We considered 1 (2.0%) adult moose a study-induced mortality because it died shortly after capture. We excluded 10 adults from data analysis because they were captured well outside of the study area (June 2001 captures), before study area borders had fully been established. We used a Hughes 500 helicopter for the March 2001 capture, a Robinson R-22 helicopter for the June 2001 capture, and a Robinson R-44 helicopter for the March 2002 capture.

For adults captured during March 2001 and 2002 we 1) measured neck girth, metatarsus length, and total length along the dorsal body contour from the hairless patch on the nose to the tip of the tail bone; 2) measured depth of rump fat on the rump via ultrasound (Stephenson et al. 1998); 3) extracted a canine tooth as needed to determine age from cementum annuli; and 4) collected 30–50 cc of blood from the jugular vein. We deployed radio collars with motion-sensitive mortality sensors on all adult moose captured.

We used generalized linear models to assess the effect of year and collar status (i.e., radiocollared or uncollared) on twinning rates of adult moose and compared these models using quasi-AICc (QAICc; Lebreton et al. 1992) for 2001–2007 data.

MONITOR COLLARED ADULT AND YEARLING MOOSE FOR SURVIVAL AND MOVEMENT INFORMATION

We monitored radiocollared adult and yearling moose on a monthly basis to determine survival and movements. We accessed mortality sites as soon as practical after detection, generally within

1 week. We evaluated causes of death using criteria and techniques described by Boertje and Gardner (2000) and Ballard et al. (1979). We also used known-fate models to assess annual survival of radiocollared adult females relative to predator reductions during 2001–2007, while evaluating the effect of covariates such as weather and individual moose traits (Keech et al. 2011).

Characterize Winter Moose Browse in Unit 19D East, with Emphasis on the Intensive Study Area

Browse surveys were conducted throughout EMMA in March 2003 and throughout MMA in March 2009 using browse biomass removal techniques described in detail by Seaton et al. (2011). The March 2009 surveys were conducted under federal aid project 5.20. During 2003, a total of 39 plots (298 plants) were sampled using snowmobiles to access 23 systematically selected floodplain/willow plots adjacent to the Kuskokwim River and a helicopter to access 16 randomly chosen plots off the river. During 2009, a total of 42 plots (278 plants) were sampled using a helicopter to access 15 systematically selected floodplain/willow bar plots adjacent to the Kuskokwim River and 27 randomly chosen plots off the river. During both years randomly selected plots were based on selection of geospatial survey units.

Estimate Wolf Numbers in Unit 19D East with Emphasis on the Intensive Study Area

We conducted surveys to estimate wolf density (Stephenson 1978, Gasaway et al. 1983, Hayes and Harestad 2000) during 21–24 February 2001, 17–19 March 2005, 14–17 March 2006, and 19–20 March 2009. Wolves have large territories (500–2,500 km^2; Mech et al. 1998) in Interior Alaska, and our intensive study area (EMMA) was comparatively small (1,368 km^2) and contained only portions of pack territories. Therefore, we used estimates of wolf density for the 8,314 km^2 wolf control zone (Fig. 1).

We conducted surveys several days following a fresh snowfall (<8 days). We used 3–4 small aircraft flown by pilots experienced at snow-tracking wolves. We searched the entire area, generally using parallel transects, with increased effort along likely wolf travel routes, following tracks until we sighted the wolves or until the tracks were lost. If we did not observe wolves or if they were obscured by cover, we estimated wolf numbers from tracks where individuals traveled separate paths. Survey teams met daily to summarize observations and to resolve potential discrepancies. To estimate population size, we totaled the number of wolves believed to occupy territories primarily within the survey area plus 50% of wolves believed to occupy territories substantially overlapping survey area boundaries.

Estimate Black Bear Numbers in the Intensive Study Area

We estimated black bear numbers in EMMA during 4 distinct times relative to black bear reduction efforts: 1) immediately prior to bear removal (spring 2003); 2) immediately postremoval (spring 2004); 3) 3 years postremoval (spring 2007); and 4) 6 years postremoval (2010). We estimated the abundance of independent black bears because cubs were unlikely to kill moose calves.

We used removal estimators (Gould and Pollock 1997) to estimate abundance of black bears prior to removal efforts in 2003, while accounting for female bears with dependent cubs intentionally left in EMMA. We based our postremoval estimate of black bear numbers in 2004 solely upon the removal estimator because we removed all bears encountered during 2004. To determine removal estimates, we ran the closed capture models in Program MARK (version 5.1, updated 15 November 2008; White and Burnham 1999) constraining recapture probabilities to zero. See Keech et al. 2011 for a more detailed methodology for 2003 and 2004 abundance estimates.

During May 2007 and 2010, we used mark–resight techniques to estimate abundance of independent black bears using EMMA (Miller et al. 1987, Miller et al. 1997). To premark individuals in our population, we captured and radiocollared 53 bears (20, 17, 7, and 9, respectively during May 2006, 2007, 2009, and 2010). We also recaptured 23 of these premarked individuals to refit radio collars (21 in May 2008 and 2 in May 2009). We used radio collars (model 500, Telonics, Inc.) modified to drop-off in approximately 2–3 years (Hellgren et al. 1988). We extracted a vestigial premolar (PM1) for cementum annuli age analysis (Willey 1974; Matson's Lab, Milltown, MT). Keech et al. (2011) provided a detailed description of protocols for black bear capture and immobilization.

For the 2007 survey, we partitioned EMMA into 5 sections, each approximately 275 km^2, and searched all sections daily 1–8 May, totaling 8 sampling occasions. For the 2010 survey, EMMA was partitioned into 4 sections (each approximately 342 km^2) and we searched all sections daily 5–12 May, for a total of 8 sampling occasions. During both surveys we searched areas using small aircraft (Piper PA-18, Piper Aircraft Corporation, Lock Haven, PA, or Bellanca 8GCBC, American Champion Aircraft Corporation, Rochester, WI) at a search intensity of approximately 1.2 min/km^2. Additionally, we located all radiocollared bears on each sampling occasion to identify marked bears present within the study area. For all bears located during the survey, we recorded the location, the general habitat type, and the number of dependent young present.

We determined estimates of the 2007 and 2010 black bear abundance using an extension of the nonlinear logit-normal mixed effects estimator (LNE; McClintock et al. 2009). This approach modified the LNE to account for immigration and emigration (IELNE) by adding a binomial term to the likelihood, modeling the probability that an animal was in the search area (McClintock and White 2012). The IELNE allowed for the introduction of marks between sampling occasions, produced estimates of the number of animals using the study area during the survey (i.e., the super population) and the average of the number of animals in the study area on each occasion, and enabled us to assess whether density within the study area was constant throughout the survey. The IELNE did not require all animals to have the same sighting probability within occasions, and variability in resighting probabilities was accounted for by including a random effect for individual heterogeneity and temporal and individual covariates. See Keech et al. 2011 for a detailed methodology for the 2007 abundance estimate.

Analyze Hair and Tissue Samples for Species, Sex, and Age Information

We collected samples of suspected predator hairs at mortality sites of radiocollared moose calves while investigating causes of death. Hairs were typically collected from branches, rough bark, or understory vegetation at the mortality site or on immediately adjacent (<25 m) travel paths. We also collected hair samples from the forest floor at bedding areas at or adjacent (<25 m) to mortality sites. We placed hair samples in paper envelopes and stored samples in cool dry conditions. We sent samples to the University of Idaho for species, sex (bears only), and individual-specific DNA analysis (University of Idaho laboratory, Moscow, ID; Farrell et al. 2000, Murphy et al. 2000, Onorato et al. 2006).

Review Literature, Write Annual Progress Reports, Write Final Project Report, and Publish Results in Peer Reviewed Journals

During times when little fieldwork occurred; literature was reviewed, data was analyzed, and reports, presentations, and papers for publication in peer reviewed journals were prepared.

Results and Discussion

Moose Numbers and Population Composition in Unit 19D East

Surveys of both EMMA and MMA indicated an increasing trend in moose abundance in these areas between 2001 and 2010, which was largely the result of predator removal reduction efforts that began in spring 2003 (Keech et al. 2011). Early winter moose abundance estimates for EMMA ranged from 520 (90% CI = ±61) in November 2001 to 868 (90% CI = ±129) in November 2007 (Table 1). Early winter moose abundance estimates for MMA ranged from 859 (90% CI = ±146) in November 2001 to 1,791 (90% CI = ±322) in November 2009 (Table 2). Early winter calf:cow ratios increased dramatically in both EMMA and MMA during 2003–2007 (Tables 1 and 2), primarily the result of black bear removals (Keech et al. 2011). Data from early winter surveys during 2008–2010 indicate calf:cow ratios were still elevated but had declined below the high levels documented immediately following bear removals (Tables 1 and 2). Bull:cow ratios also increased between 2001 and 2010 in both EMMA and MMA (Tables 1 and 2), and were likely the result of the combined effects of predator reductions and a partial hunting closure in EMMA during 2004–2007 (Keech et al. 2011).

TABLE 1. Results of the 2001–2010 moose surveys in EMMA (1,368 km^2) western Interior Alaska.

Year	% SUs sampled[a]	Number of moose observed	Counts or estimates of observable moose (90% CI)[a]	SCF ($n_{observed}$, $n_{available}$)	Estimate with SCF applied (90% CI)	Calves:100 cows (90% CI)	Bulls:100 cows (90% CI)	Yearling bulls:100 cows (90% CI)	Total moose/km^2
2001	100	440	440 (±0)	1.18 (32,38)	520 (±61)	34 (±6)	18 (±3)	8 (±1)	0.38
2003	52	237	424 (±79)	1.32 (21,28)	559 (±136)	56 (±20)	18 (±8)	5 (±3)	0.41
2004	100	531	531 (±0)	1.25	663 (±104)	63 (±14)	13 (±3)	6 (±1)	0.48
2005	100	479	479 (±0)	1.28 (38,49)	614 (±79)	51 (±9)	18 (±3)	9 (±2)	0.45
2006	100	591	591 (±0)	1.16 (42,49)	687 (±67)	58 (±8)	25 (±3)	14 (±2)	0.50
2007	100	662	662 (±0)	1.31 (31,41)	868 (±129)	56 (±12)	39 (±8)	16 (±3)	0.63
2008	49	296	599 (±103)	1.23 (16,20)	739 (±189)	43 (±16)	33 (±13)	14 (±7)	0.54
2009	51	331	654 (±93)	1.25	816 (±172)	44 (±14)	31 (±11)	7 (±3)	0.60
2010	49	311	625 (±74)	1.25	780 (±153)	43 (±13)	38 (±13)	15 (±5)	0.57

[a] All SUs were sampled during 2001 and 2004–2007, thus counts of observable moose have no variance or CI.

TABLE 2. Results of the 2001, 2004, and 2006–2010 moose surveys in the expanded MMA (2,896 km^2) western Interior Alaska.

Year	% SUs sampled within EMMA/EMMA buffer[a]	Estimate of observable moose (90% CI)	SCF ($n_{observed}$, $n_{available}$)	Estimate with SCF applied (90% CI)	Calves:100 cows (90% CI)	Bulls:100 cows (90% CI)	Yearling bulls:100 cows (90% CI)	Total moose/km^2
2001	100/8	727 (±89)	1.18 (32, 38)	859 (±146)	36 (±10)	21 (±6)	8 (±3)	0.30
2004	100/11	940 (±107)	1.25	1173 (±227)	66 (±18)	18 (±6)	8 (±4)	0.41
2006	100/35	1117 (±102)	1.16 (42, 49)	1299 (±173)	55 (±11)	30 (±8)	12 (±3)	0.45
2007	100/32	1290 (±131)	1.31 (31, 41)	1692 (±305)	53 (±14)	36 (±10)	15 (±4)	0.58
2008	49/51	1356 (±116)	1.23 (16, 20)	1673 (±350)	44 (±14)	40 (±13)	14 (±5)	0.58
2009	51/49	1435 (±127)	1.25	1791 (±322)	38 (±10)	40 (±11)	11 (±4)	0.62
2010	49/51	1416 (±114)	1.25	1767 (±311)	43 (±11)	49 (±13)	16 (±5)	0.61

[a] Percentage of SUs sampled within EMMA and the EMMA buffer are separated with a slash.

In the entire Unit 19D East MSA, we observed an increase in point estimates from 2,538 in 2001 to 2,700 moose in 2004 to 3,788 moose in 2008 (Table 3). Although the slope of the trend line is substantial (183 moose/year; Fig. 2), we cannot conclude that there has been a statistically significant population change in the entire Unit 19D East MSA at the 90% confidence level. The *P*-value of 0.25 indicates the slope is significantly different than zero at only the 75% confidence level (Fig. 2). Low statistical power resulting from less frequent surveys and lower sampling intensity for that portion of the Unit 19D East MSA outside of MMA (which comprises 79% of the entire Unit 19D East MSA), likely prevented us from detecting an increasing trend in the Unit 19D MSA at the 90% confidence level, if such a trend existed. Therefore, we conclude that the moose population in the entire Unit 19D East MSA may have increased, although our data are statistically inadequate.

TABLE 3. Estimated population and ratios of moose within the entire Unit 19D East MSA (13,761 km^2), based upon data combined from MMA and the remainder of the Unit 19D East MSA, western Interior Alaska.

Year	Estimate of observable moose (90% CI)	Estimate with SCF applied (90% CI)	Calves: 100 Cows (90% CI)	Bulls: 100 Cows (90% CI)	Yearling bulls:100 cows (90% CI)
2001	2148 (±556)	2538 (±720)	25 (±10)	34 (±17)	7 (±4)
2004	2163 (±403)	2700 (±655)	54 (±20)	31 (±13)	12 (±6)
2008	3071 (±499)	3788 (±948)	41 (±15)	55 (±22)	17 (±6)

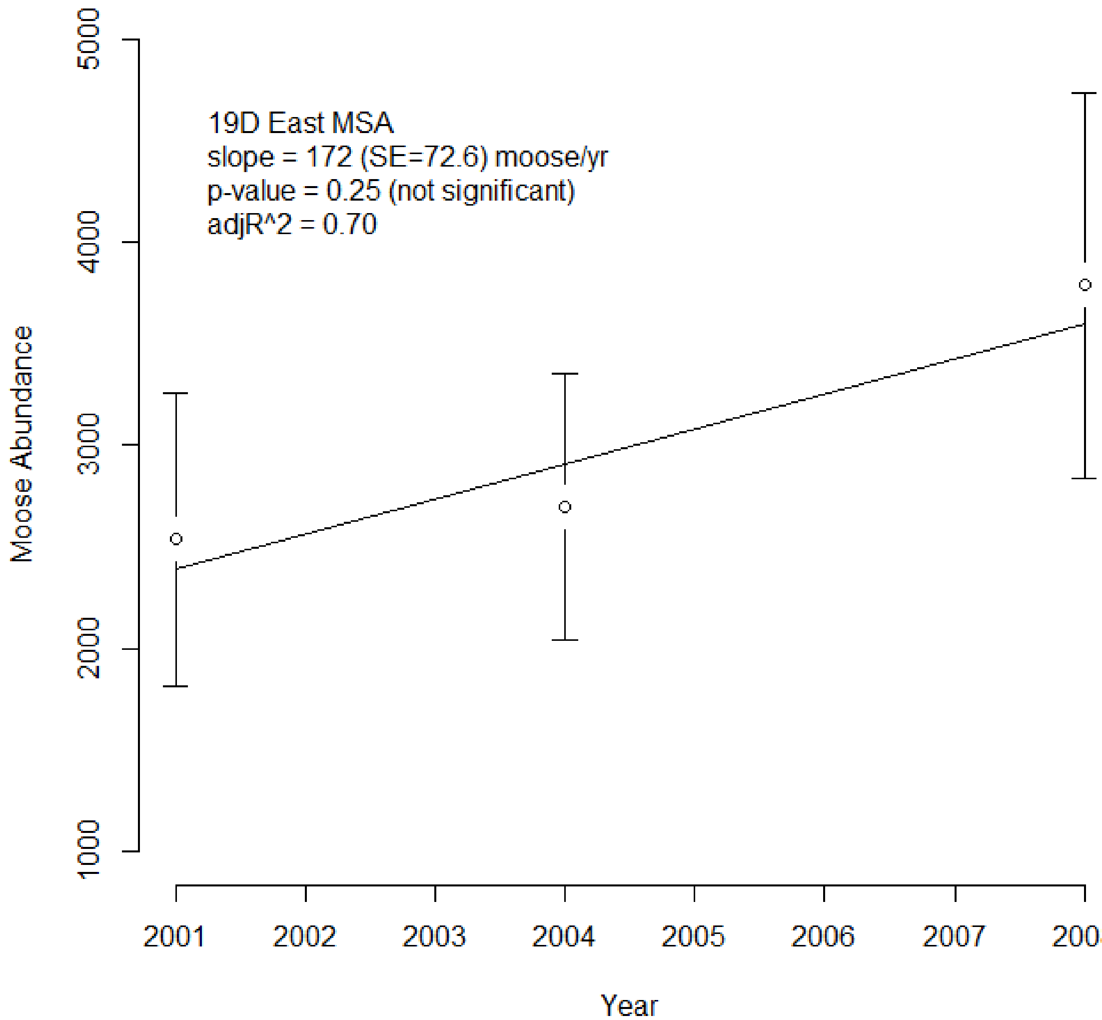

FIGURE 2. Survey estimates and their 90% confidence limits for the Unit 19D East MSA along with the trend line (weighted regression), western Interior Alaska, 2001, 2004, and 2008.

DETERMINE PRIMARY CAUSES OF MORTALITY OF MOOSE CALVES

Annual survival rates for radiocollared moose calves ranged from 27% for the 2002 cohort to 63% for the 2005 cohort (Fig. 3). Estimated survival rates for calves of radiocollared females during 2008 and 2009 were 23% and 50% respectively (Fig. 4). Most calf mortality occurred within 60 days of birth (Fig. 3), and summer survival was generally much lower than winter survival (Figs. 3 and 4). Combined predation by black bears, brown bears, and wolves accounted for most mortality of moose calves during the summer and fall of all years (Fig. 5 and Table 4). During winter, wolf predation accounted for most calf mortality prior to predator removals while nonpredation deaths accounted for most calf mortality following predator removals (Fig. 6 and Table 4). Winter survival of moose calves was particularly low during deep snow winters, with

50% of radiocollared calves surviving winter 2004 and an estimated 42% of calves of radiocollared females surviving winter 2008 (Fig. 4). Snow depth exceeded 80 cm during the winters of both 2004 and 2008 (Fig. 4).

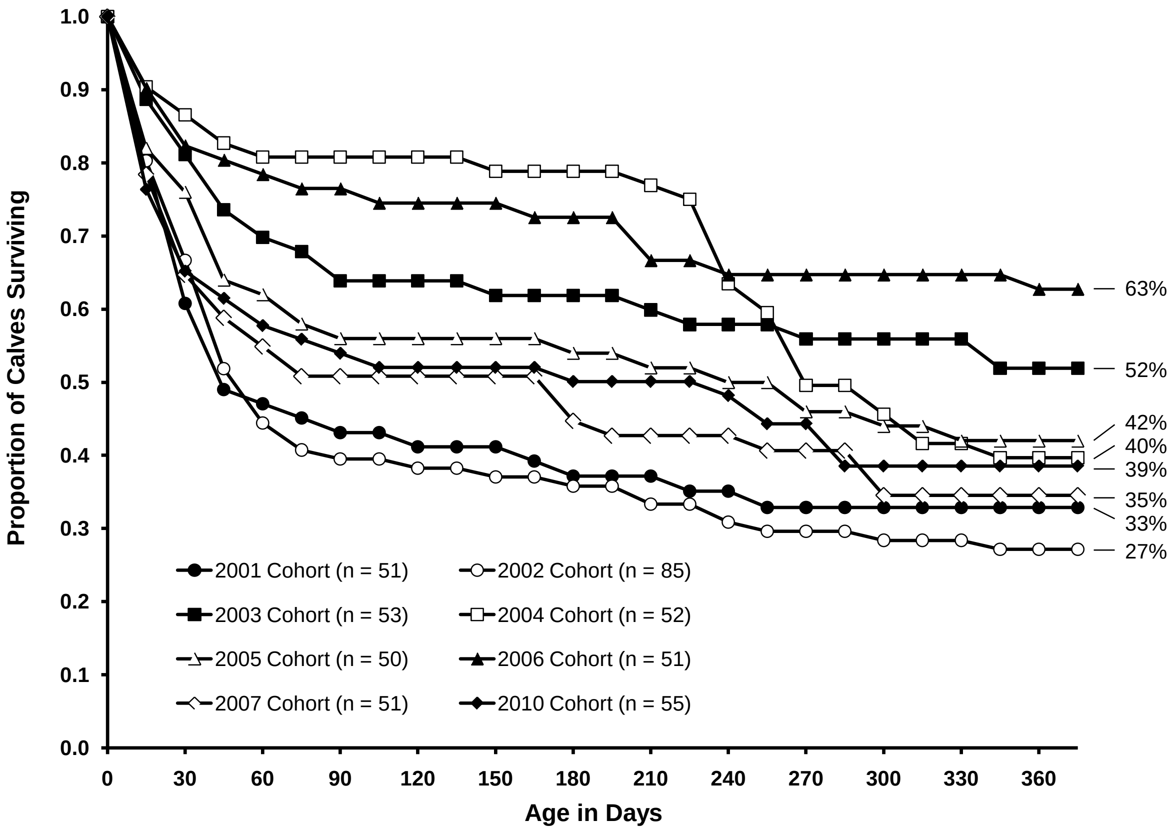

FIGURE 3. Average survival functions for radiocollared calf moose, birth to 1 year-of age, using Kaplan-Meier analysis, western Interior Alaska.

	2001	2002	2003	2004	2005	2006	2007	2008*	2009*	2010
Birth - Nov 15	37%	36%	62%	79%	54%	73%	45%	54%	63%	50%
Nov 16 - May 15	89%	76%	84%	50%	78%	86%	77%	42%	81%	77%
Annual	33%	27%	52%	40%	42%	63%	35%	23%	50%	39%

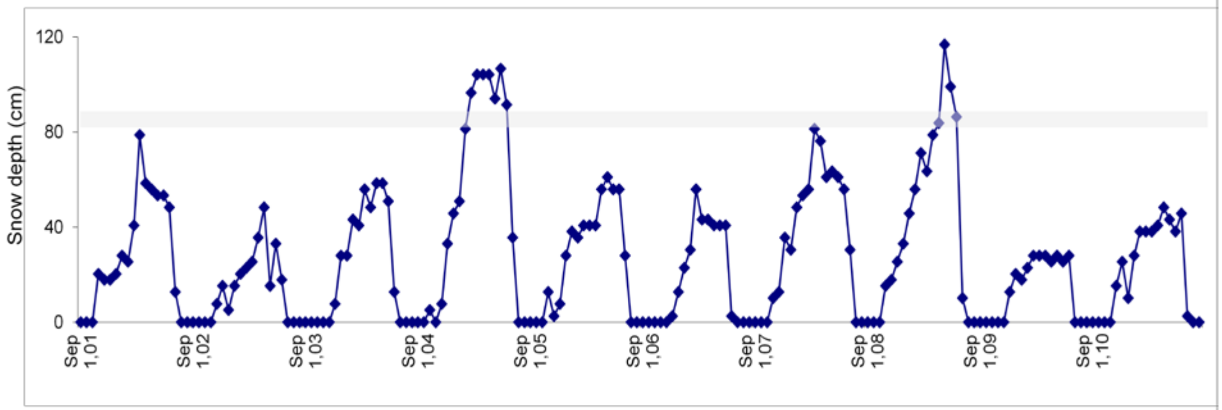

FIGURE 4. Survival estimates for moose calves and cumulative snow depths, 2001–2010, western Interior Alaska. Survival estimates for 2001–2007 and 2010 based on Kaplan-Meier analysis of radiocollared calf survival data. *Survival estimates for 2008 and 2009 based on observations of parturient, radiocollared, adult female moose.

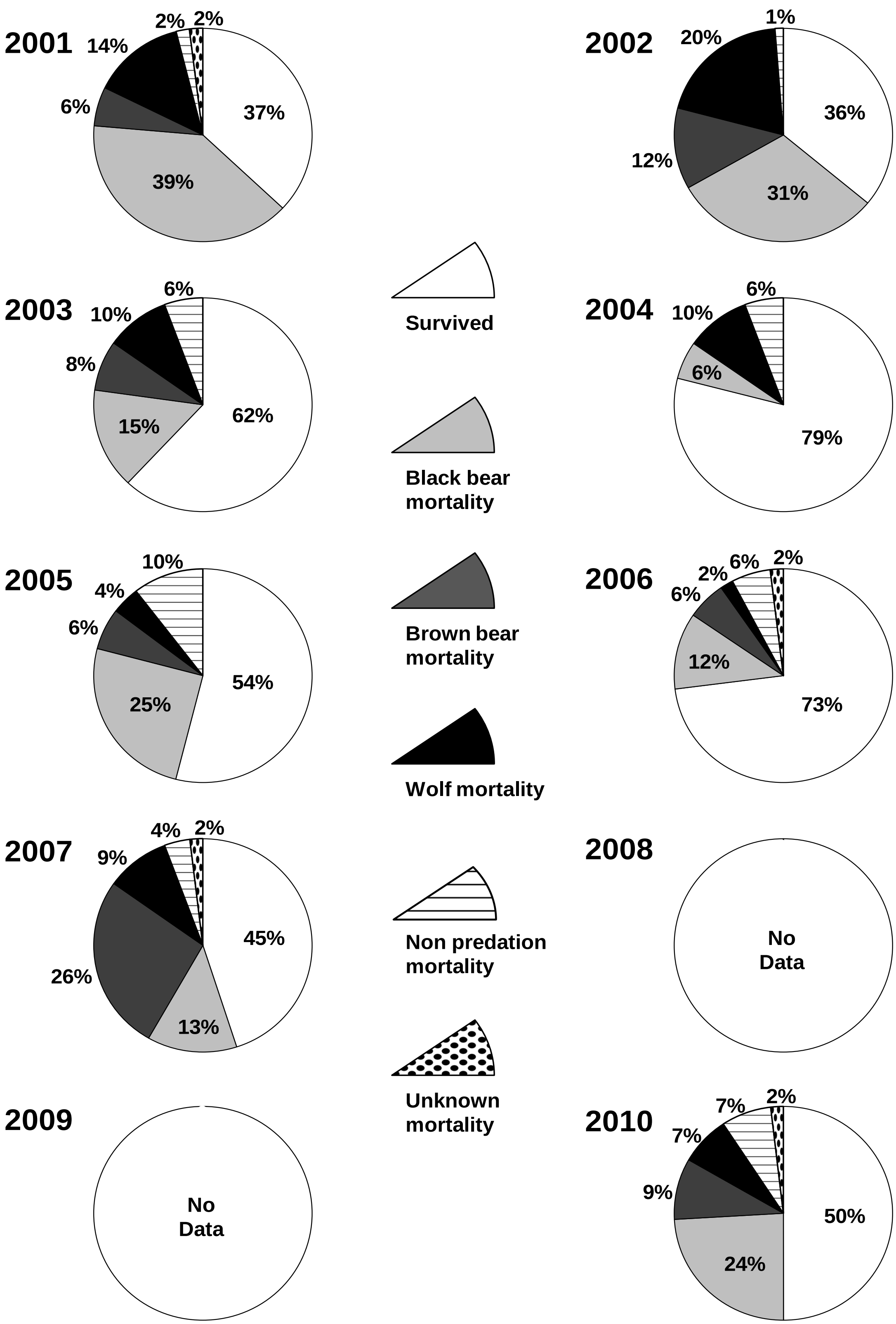

FIGURE 5. Fates of radiocollared moose calves during summer and fall (birth to 15 November), western Interior Alaska.

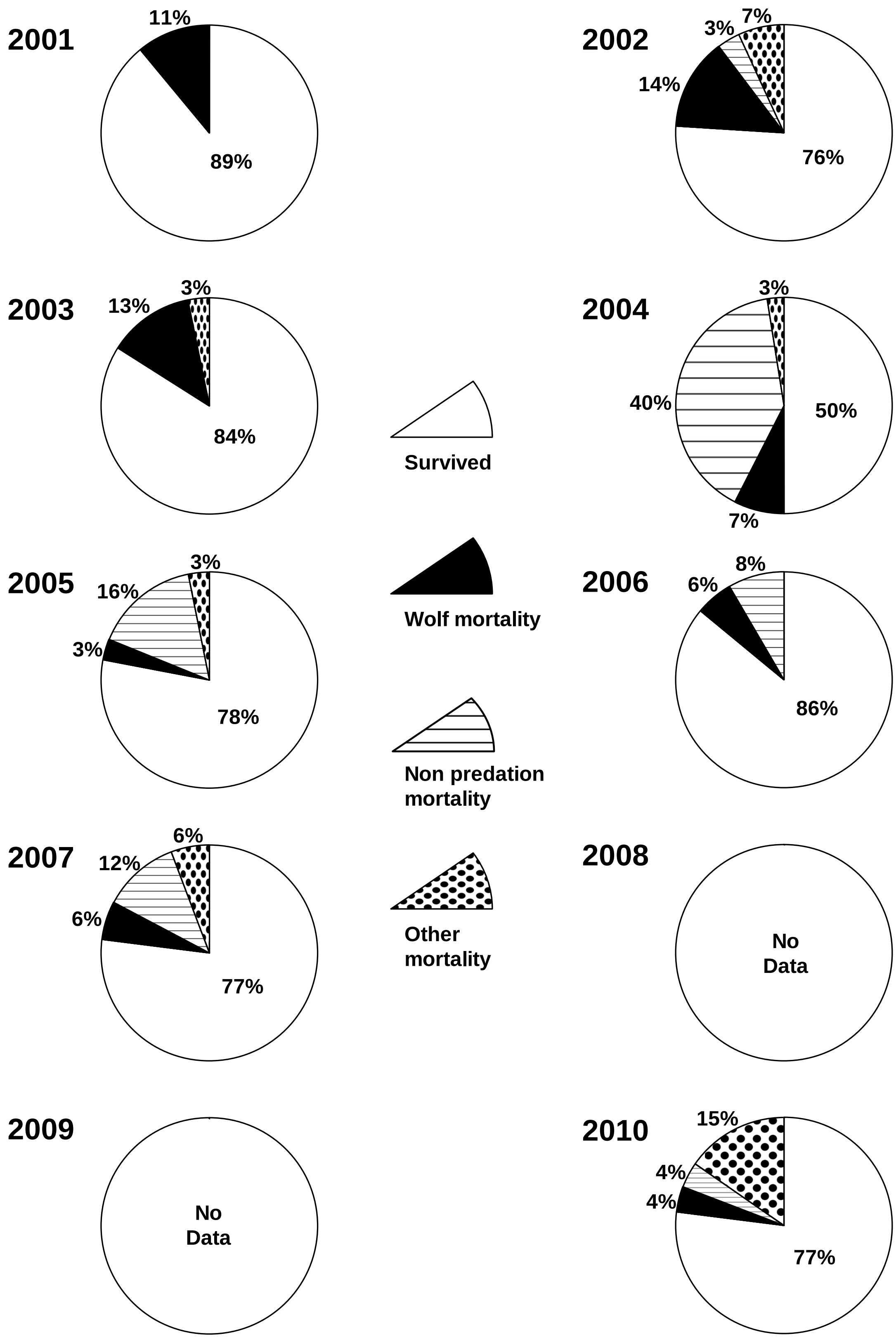

FIGURE 6. Fates of radiocollared moose calves during winter (16 November–15 May), western Interior Alaska. “Other mortality” is unknown cause and a single illegal take in 2004.

TABLE 4. Sources of mortality for radiocollared moose calves, western Interior Alaska, 2001–2010[a].

Sources of mortality	Year 2001	2002	2003	2004	2005	2006	2007	2010
Black bear	20	25	8	3	12	6	7	13
Brown bear	3	10	4	0	3	3	14	5
Wolf	9	20	9	8	3	3	6	5
Nonpredation	1	2	3	19	10	6	4	5
Illegal take[b]	0	0	0	1	0	0	0	0
Unknown	1	2	1	0	1	1	2	5
No. monitored	51	81	51	52	50	51	50	55

[a] Calves not radiocollared in 2008 or 2009.
[b] Taken in a snare set for furbearers.

Survival of radiocollared calves was significantly lower in years prior to predator removals (2001 and 2002) than years following predator removals (Keech et al. 2011), including the 2010 cohort (Fig. 3). Despite increases in nonpredation mortalities following predator removals, predators were still the primary sources of mortality for radiocollared calves following predator removals, with the exception of 2004, when nonpredation winter kill was the leading cause of mortality (Figs. 5 and 6, Keech et al. 2011). Although, nonpredation sources of mortality increased following predator removals, these increases did little to offset increases in survival attributable to predator removals, which indicated predation mortality was largely additive (Keech et al. 2011).

During 2001–2007, cause-specific mortality rates varied between years prior to predator removals and years following predator removals, yet black bears were the dominant source of predation mortality during all years except 2007 (Figs. 5 and 6). During years prior to predator removals, we attributed the deaths of 34% (n = 45) of radiocollared calves to black bear predation versus 14% (n = 36) during years following predator removals, a significant (χ_1^2 = 20.78, P < 0.001) decrease. Wolves and brown bears were largely secondary predators compared to black bears. However, comparing years prior to wolf control (2001–2003) to years with wolf control (2004–2007), we also observed a significant reduction in wolf-induced calf mortality during summer (12% vs. 4%, χ_1^2 = 6.66, P = 0.010). Mortality attributable to brown bear predation varied, accounting for few deaths except in 2007 (Fig. 5). Data collected from radiocollared calves during 2010 indicated that mortalities caused by black bears may still have been reduced 6 years following removals when compared to preremoval rates (Fig. 5).

Similar to information gained from Kaplan-Meier analysis and changes in cause specific mortality rates, results of known-fate models applied to the 2001–2007 calf survival data indicated survival of radiocollared moose calves increased following predator removals during the summer and fall. Modeling analysis indicated predator removals did not significantly change winter survival of moose calves, while snow depth was an important determinate of winter calf survival. In addition to predator removals and snow depth, variables of individual condition including number of siblings and birth weight also significantly influenced calf survival. Keech et al. (2011) provided a thorough description of results of modeling analysis relative to calf survival in the study area.

DETERMINE CONDITION, MOVEMENTS, AND MORTALITY RATES OF YEARLING MOOSE

Weights of short-yearling, female moose ranged from 191.4 kg in 2002 to 160.7 kg in 2009, with an average for all years of 176.9 kg (Table 5). These weights fall between the values for moose populations with poor nutritional status (e.g., 155 kg, northcentral Unit 20A) and those with high nutritional status (e.g., 204 kg, Denali National Park, Unit 20C), as reported by Boertje et al. (2007). Although short-yearling weights were above those of populations in poor nutritional condition throughout the study, results of the linear mixed effects model trend analysis indicated a declining trend in average weight of 2 kg/yr (SE = 0.9, $P = 0.073$) during the study. This trend suggests nutritional status may have declined commensurate with increasing population density.

TABLE 5. Average weights (kg) of newborn moose calves and short-yearlings captured, western Interior Alaska, 2001–2010. We included only newborn calves known or estimated to be ≤3 days old.

	Newborn calf mass (kg)									Short-yearling mass (kg)		
	Singletons			Twins			All calves					
Year	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
2001	19	19.6	0.68	13	17.4	0.48	32	18.8	0.48	14	178.1	4.67
2002	16	18.9	0.47	38	17.4	0.26	54	17.8	0.25	15	191.4	5.47
2003	23	19.4	0.44	18	16.4	0.70	41	18.1	0.46	15	179.5	4.62
2004	23	20.2	0.51	26	16.2	0.43	49	18.1	0.44	15	184.9	3.75
2005	20	18.3	0.59	32	15.4	0.57	52	16.5	0.46	15	174.8	3.95
2006	15	17.5	0.76	30	15.2	0.48	45	16.0	0.44	15	167.5	3.79
2007	14	18.8	0.71	23	16.4	0.37	37	17.3	0.40	15	185.3	5.39
2009	--	--	--	--	--	--	--	--	--	16	160.7	5.20
2010	20	18.9	0.60	16	16.0	0.51	36	17.6	0.47	15	171.4	5.55
All yr	150	19.0	0.21	196	16.2	0.18	346	17.5	0.16	135	176.9	1.73

Annual survival rates for radiocollared yearling moose (hunting mortality removed) ranged from 74% for the 2002 cohort to 96% for the 2005 cohort (Fig. 7). Yearling mortalities occurred throughout the year; however, more mortalities occurred during summer and fall than winter (Fig. 7). Unlike moose calves, the 2 deep snow (>80 cm) winters that occurred during this study (2004 and 2008, Fig. 4) apparently had little effect on survival of radiocollared yearling moose. We observed yearling mortalities from nonpredation, unknown, and hunter causes as well as a black bear and an illegal take (caught in a snare set for furbearers); however, predation by wolves accounted for most mortality of radiocollared yearling moose throughout the study (Fig. 8 and Table 6).

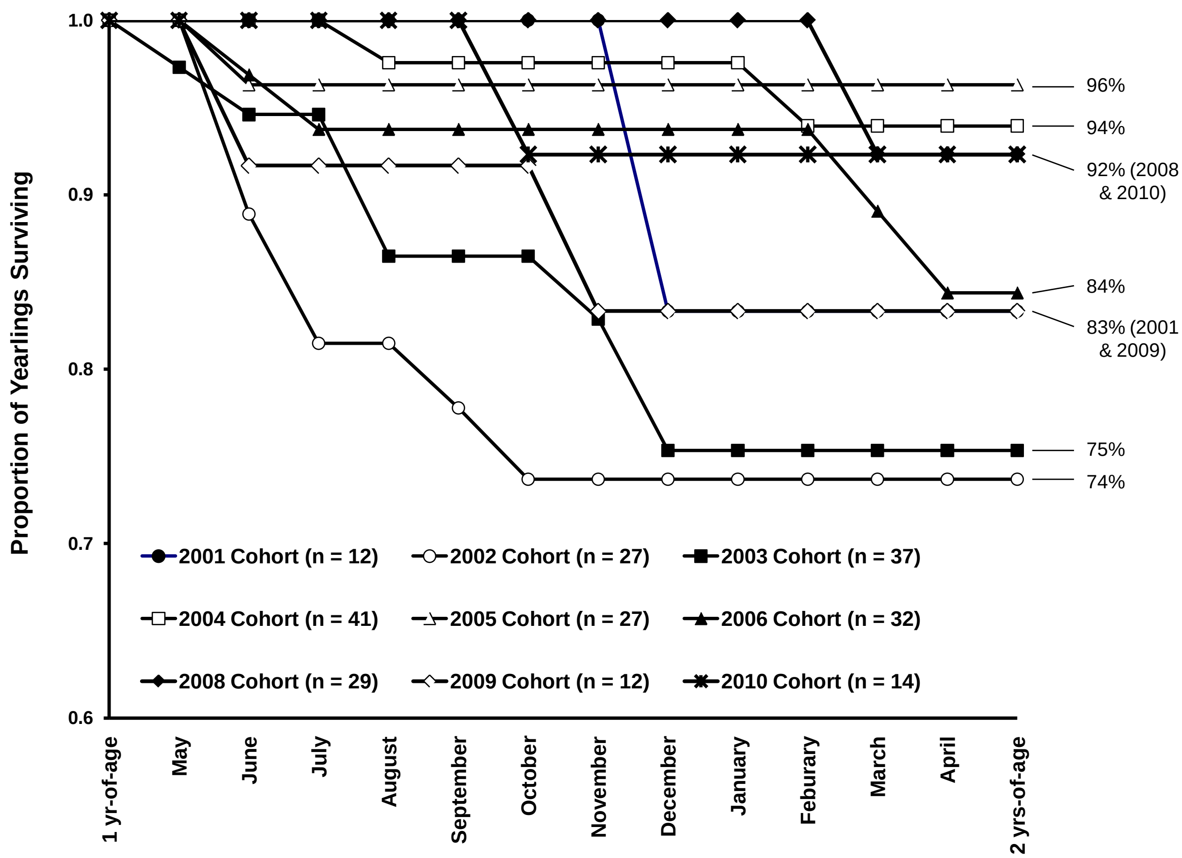

FIGURE 7. Average survival functions for radiocollared yearling moose, 1 year of age to 2 years of age, using Kaplan-Meier analysis, western Interior Alaska. Survival function for 2007 not included because survival due to inadequate sample size. Hunting mortality removed.

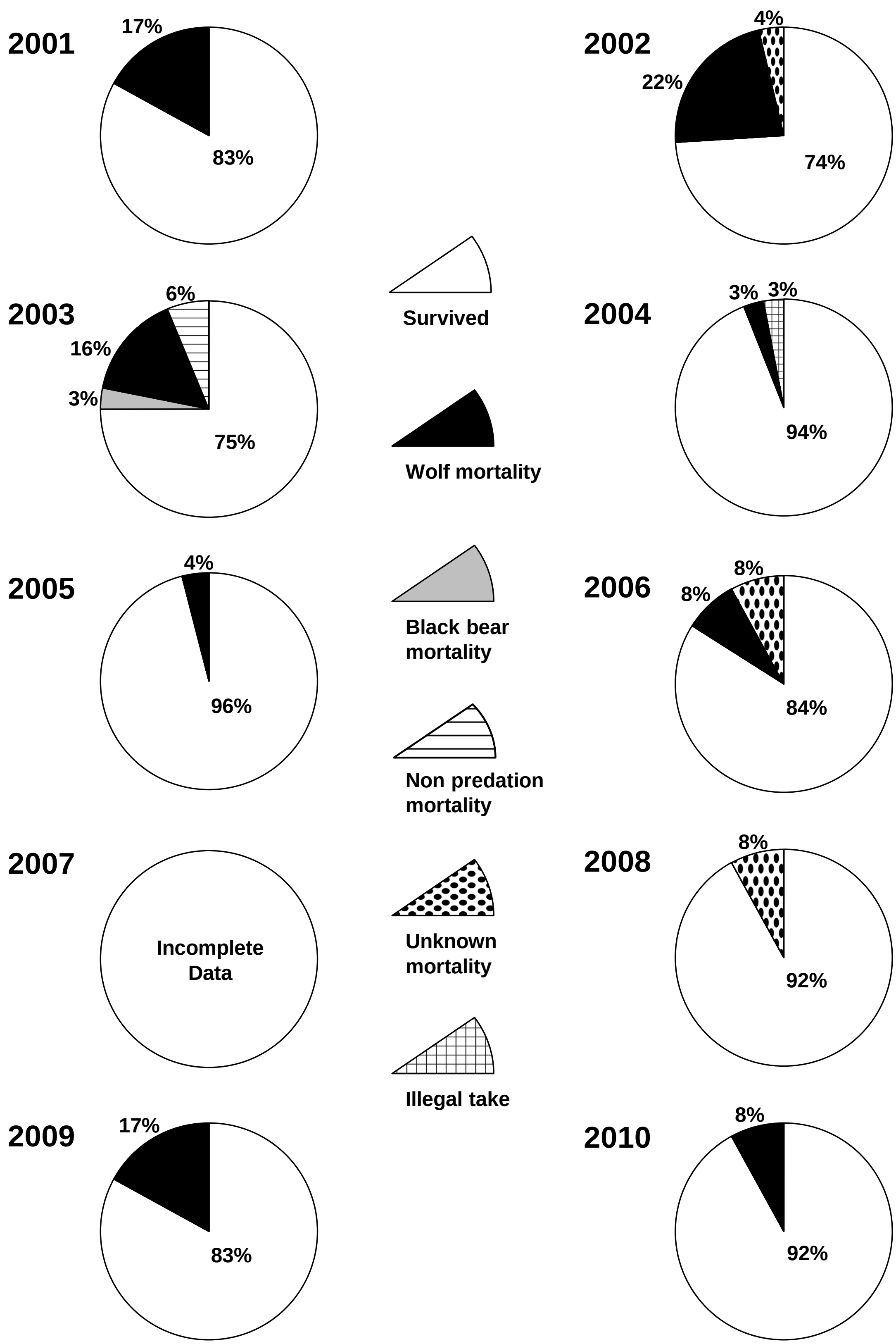

FIGURE 8. Fates of radiocollared yearling moose, 16 May–15 May (1 year of age to 2 years of age), western Interior Alaska. Hunting mortality removed.

TABLE 6. Annual (16 May–15 May) sources of mortality for radiocollared yearling moose 2001–2010, western Interior Alaska. Number censored each year is large because many yearlings monitored were collared as calves with collars designed to be shed after the first year.

Sources of mortality	Year									
	2001	2002	2003	2004	2005	2006	2007[a]	2008	2009	2010
Black bear	0	0	1	0	0	0	0	0	0	0
Wolf	2	6	5	1	1	2	0	0	2	1
Nonpredation	0	0	2	0	0	0	0	0	0	0
Illegal take[b]	0	0	0	1	0	0	0	0	0	0
Unknown	0	1	0	0	0	2	0	1	0	0
Hunter	0	2	2	0	0	1	0	0	0	0
No. monitored	12	27	37	41	27	32	32	29	12	14
No. censored during year	0	4	11	19	14	10	32	17	1	5

[a] Data for 2007 collected May thru October only.
[b] Taken in a snare set for furbearers.

Survival of radiocollared yearlings was higher in years following wolf removals than years prior to wolf removals (Keech et al. 2011). Known-fate models applied to the 2001–2007 yearling survival data indicated this increase can be attributed to an increase in summer and fall survival of yearlings following wolf removals; wolf removals had no effect on winter survival of yearlings (Keech et al. 2011). Modeling analysis also indicated survival of male yearlings was lower than that of females during the summer and autumn, even after accounting for hunter take.

Radiocollared yearling moose within and around EMMA (intensive study area) were essentially resident moose. We did not observe any discernible large-scale, migratory pattern from the monthly location flights.

DETERMINE TWINNING RATES AND REPRODUCTIVE INDICES OF MOOSE IN UNIT 19D EAST

Annual twinning rates for radiocollared female moose ≥3 years old ranged 24–59% (average 42% for all years, 2001–2010) and were similar to those for uncollared females (Table 7). Results of generalized linear models and quasi-AICc comparisons on the 2001–2007 data indicated an overall twinning rate of 42% (95% CI = 38–47%) with no year or collaring effects (Keech et al. 2011). These twinning rates fall between the values reported for moose populations with poor nutritional status (e.g., 7%, northcentral Unit 20A) and those with high nutritional status (e.g., 64%, Yukon Flats, Unit 25D). During 2001–2010, the rate of parturition for radiocollared 3 year-old female moose averaged 79% and the rate of parturition for radiocollared female moose ≥3 years of age averaged 89% (Table 7). These parturition rates are similar to populations with high nutritional status (e.g., 87% for females ≥3, Denali National Park, Unit 20C) as reported by Boertje et al. (2007).

TABLE 7. Observed parturition and twinning rates for female moose, western Interior Alaska, 2001–2010.

	Observed parturition (collared)						Observed twinning					
	3 yr of age			≥3 yr of age			≥3 yr of age (collared)			Uncollared		
Year	*n*	Rate	SE	*n*	Rate	SE	*n*	Rate	SE	*n*	Rate	SE
2001	3	1.00		22	0.73	0.097	16	0.25	0.112			
2002	1	0.00		25	0.88	0.066	22	0.59	0.107	46	0.39	0.073
2003	9	0.56	0.175	31	0.84	0.067	25	0.24	0.087	39	0.36	0.078
2004	10	0.70	0.153	40	0.80	0.064	31	0.32	0.085	31	0.39	0.089
2005	11	1.00		51	0.92	0.038	45	0.44	0.075	40	0.50	0.080
2006	13	1.00		62	0.97	0.022	60	0.40	0.064	29	0.35	0.090
2007	7	0.71	0.185	59	0.95	0.029	56	0.52	0.067	30	0.50	0.093
2008	8	0.63	0.182	58	0.88	0.043	51	0.55	0.070			
2009	--	--	--	52	0.87	0.047	43	0.33	0.073	87	0.26	0.047
2010	--	--	--	44	0.93	0.039	41	0.34	0.075	45	0.29	0.068
All yr	62	0.79	0.052	444	0.89	0.015	390	0.42	0.025	347	0.36	0.026

During 2001–2007, calves of radiocollared moose were born between 11 May and 7 July, with a median parturition date for all years of 22 May. Weights of sampled calves estimated to be ≤3-days old at capture (*n* = 346) ranged 7.7–25.9 kg with an average of 17.5 kg (Table 5). Average maximum rumpfat depth for adult females captured during 2001 and 2002 was 0.71 cm (SE = 0.11, *n* = 25, median = 0.55) and 1.51 cm (SE = 0.18, *n* = 15, median = 1.58), respectively.

MONITOR COLLARED ADULT AND YEARLING MOOSE FOR SURVIVAL AND MOVEMENT INFORMATION

Annual survival rates observed for radiocollared adult (≥2 years of age) moose ranged from 83% for the 2001 cohort to 100% for the 2004 cohort (Fig. 9). We observed adult mortalities from wolves, illegal take, and nonpredation causes, as well as single mortality attributed to a brown bear. We observed only one wolf-induced mortality after wolf removals began. Illegal take was a significant source of mortality during the study, 3 of 4 illegal takes resulted from capture in snares set for furbearers; the other was mistakenly shot during the fall hunting season (Fig. 9 and Table 8).

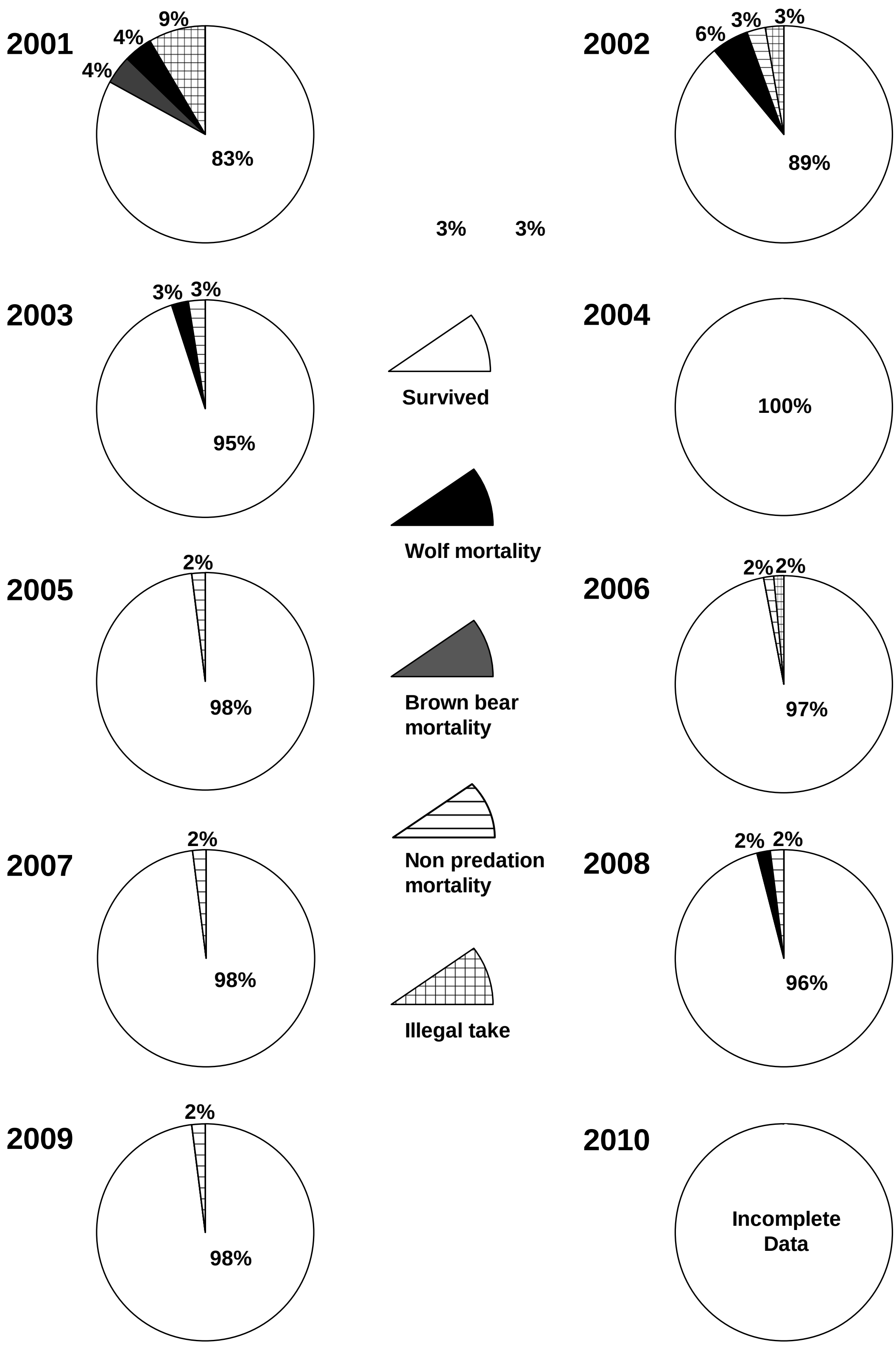

FIGURE 9. Fates of radiocollared adult (≥2 years of age) female moose, 16 May–15 May, western Interior Alaska. Proportion surviving during 2003–2009 is likely biased high because the proportion of prime age females monitored was high during those years.

TABLE 8. Annual (16 May–15 May) sources of mortality for radiocollared adult (≥2 years of age) female moose, western Interior Alaska, 2001–2010.

Sources of mortality	Year									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010[a]
Brown bear	1	0	0	0	0	0	0	0	0	0
Wolf	1	2	1	0	0	0	0	1	0	0
Nonpredation	0	1	1	0	1	1	1	1	1	0
Illegal take[b]	2	1	0	0	0	1	0	0	0	0
No. monitored	23	35	42	51	64	64	60	53	49	46

[a] Data for 2010 collected May thru November only.
[b] Includes 2 taken in a snares set for furbearers, 1 accidentally shot, and 1 of unknown human cause.

The age structure of our radiocollared sample of adult females changed during the study and contained a larger proportion of prime age (2–7 years old) females during latter years of the study. Females in this age group have higher survival than other adults (Boertje et al. 2009), Therefore comparisons of adult survival between years should only be done when age is controlled. Results of known-fate models indicated adult female survival probability decreased with age during all years, and all ages of adult females had higher survival probability during years with wolf removals (Fig. 10; Keech et al. 2011). Survival of adult females was not influenced by any other covariates investigated, including snow depth and moose density (Keech et al. 2011).

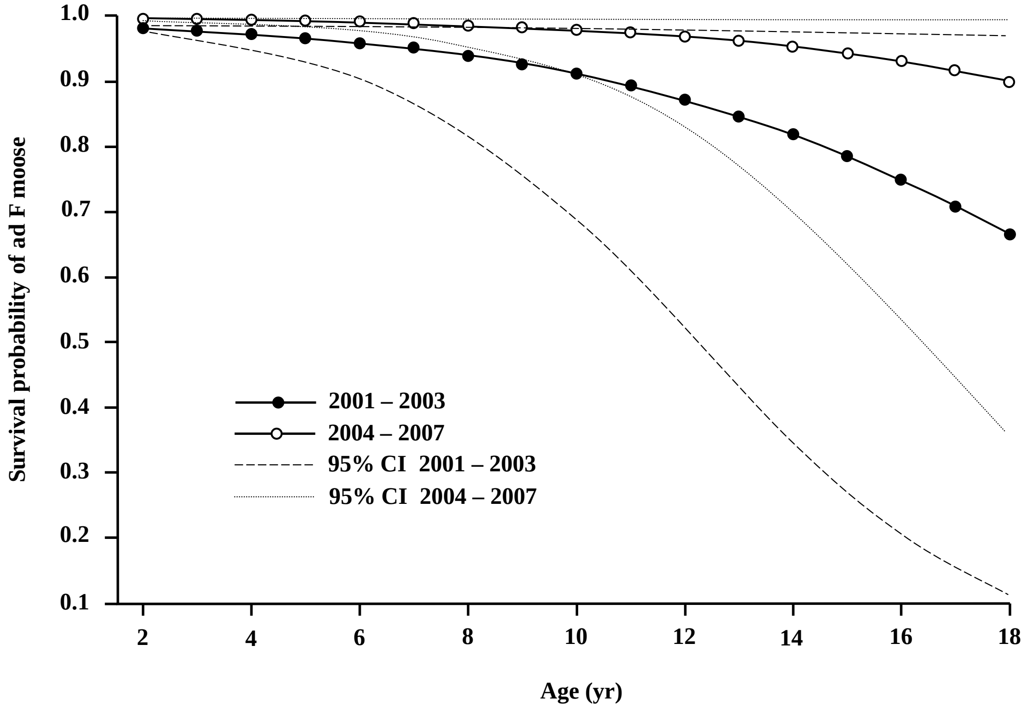

FIGURE 10. Effects of predator removals and age on annual survival of adult (≥2 years old; human-caused mortality censored) female moose for years with no wolf removal (2001–2003) and wolf removals (2004–2007), western Interior Alaska, 2001–2007.

Radiocollared adult female moose within and around EMMA (intensive study area) were essentially resident moose. We did not observe any discernible large-scale, migratory pattern from the monthly location flights.

CHARACTERIZE WINTER MOOSE BROWSE IN UNIT 19D EAST, WITH EMPHASIS ON THE INTENSIVE STUDY AREA

Overall mean biomass removal for 2003 was 17.0% (95% CI: 14.4–22.2%). Browse biomass removal was 12% in randomly selected sites and 24% in high-use wintering sites in 2003. Overall mean biomass removal for 2009 was 40.5% (95% CI: 33.2–47.1%). Browse biomass removal was 37.8% in randomly selected sites and 41.9% in high-use wintering sites in 2009. The substantial increase in browse removed between 2003 and 2009 is consistent with the population increase in EMMA and MMA between 2003 and 2009. The relatively high 2009 browse removal rate (40.5%) is similar to moose populations believed to have low nutritional condition (Seaton et al. 2011). Although, other measures of moose nutritional status (twinning, parturition, and 10-month calf weights; Boertje et al. 2007) indicate adequate nutrition in our population, results of the 2009 browse survey suggest close nutritional monitoring will be an important future consideration.

ESTIMATE WOLF NUMBERS IN UNIT 19D EAST WITH EMPHASIS ON THE INTENSIVE STUDY AREA

During February 2001, we estimated a density of 5.1 wolves/1,000 km^2 (n = 42 wolves) in the 8,314 km^2 wolf control zone. We estimated 1.3 wolves/1,000 km^2 (n = 11 wolves) in the 8,314 km^2 wolf control zone during both the March 2005 and March 2006. During March 2009, we estimated 1.9 wolves/1,000 km^2 (n = 16 wolves) in the 8,314 km^2 wolf control zone. These surveys indicate the wolf population within the wolf control zone declined as much as 75% following wolf removals.

ESTIMATE BLACK BEAR NUMBERS IN THE INTENSIVE STUDY AREA

We estimated approximately 96 (SE = 6.4) independent black bears used EMMA in early May 2003 prior to bear removals and we estimated 4 (SE = 4.5) bears used EMMA immediately following the 2004 removals (Table 9; Keech et al. 2011). These estimates indicate removal efforts reduced the black bear population in EMMA by as much as 96%.

TABLE 9. Estimated independent black bear abundance prior to and following bear removal efforts in EMMA, western Interior Alaska, 2003–2007. Abundance estimates for 2003 and 2004 based on removal estimators, and 2007 and 2010 abundance based on mark-resight estimators.

Year	Abundance of independent bears	SE	95% CI
2003 preremoval	96	6.4	83–109
2004 postremoval	4	4.5	0–13
2007	70	6.9	56–84
2010	123	16.6	96–162

We estimated 70 (SE = 6.9) independent black bears used EMMA during our 2007 survey (27% fewer than the 2003 estimate prior to treatment; Keech et al. 2011). By 2010, the black bear population had completely recovered from removal efforts; we estimated 123 (SE = 16.6) independent black bears used EMMA during our 2010 survey (Table 9). These postremoval population estimates for EMMA indicate a relatively rapid (6 year) population recovery of black bears in EMMA following a 96% reduction in population.

Our estimates of the proportions of independent females in the population were similar before (53%) and after (50% in 2007 and 59% in 2010) bear removals. These results indicate both sexes of black bears rapidly reoccupied the study area.

ANALYZE HAIR AND TISSUE SAMPLES FOR SPECIES, SEX, AND AGE INFORMATION

We submitted 151 samples of suspected predator hair for DNA identification of species and sex. Most samples (124) provided adequate DNA for identification of species (wolves, black and brown bears, and a moose were identified; Table 10) and 65% (69 of 106) of samples identified as bears provided sex identification. Roughly similar numbers of male (31 black and 9 brown) and female (24 black and 7 brown) bears were identified (Table 10), indicating both sexes of both species of bears are likely effective predators of moose calves.

TABLE 10. Results of DNA species and sex identification of suspected predator hair samples collected at mortality sites of radiocollared moose calves, western Interior Alaska, 2001–2007 and 2010.

Year	Total samples[a]	Wolf[b]	Black bear			Brown bear[c]			Moose
			Male	Female	Total[c]	Male	Female	Total[c]	
2001	28	3	7	3	15	2	0	3	1
2002	41	8	8	8	18	1	4	9	0
2003	17	2	4	4	10	1	0	1	0
2004	6	3	0	1	2	0	0	0	0
2005	16	0	4	2	11	1	1	2	0
2006	10	1	2	1	5	1	0	2	0
2007	17	0	1	3	6	3	1	8	0
2010	16	0	5	2	9	0	1	5	0
Total	151	17	31	24	76	9	7	30	1

[a] Total samples submitted for analysis, not all of these were successfully identified to species
[b] Wolf samples not identified to sex
[c] Total black bear and brown bear differs from sum of male and female because sex could not be determined for all samples identified to species.

REVIEW LITERATURE, WRITE ANNUAL PROGRESS REPORTS, WRITE FINAL PROJECT REPORT, AND PUBLISH RESULTS IN PEER REVIEWED JOURNALS

In addition to annual progress reports; staff time, resources, and data from this project contributed to the following peer-reviewed, published articles:

BOERTJE, R. D., M. A. KEECH, AND T. F. PARAGI. 2010. Science and values influencing predator control for Alaska moose management. Journal of Wildlife Management 74:917–928.

BOERTJE, R. D., M. A. KEECH, D. D. YOUNG, K. A. KELLIE, AND C. T. SEATON. 2009. Managing for elevated yield of moose in Interior Alaska. Journal of Wildlife Management 73:314–327.

BOERTJE, R. D., K. A. KELLIE, C. T. SEATON, M. A. KEECH, D. D. YOUNG, B. W. DALE, L. G. ADAMS, AND A. R. ADERMAN. 2007. Ranking Alaska moose nutrition: signals to begin liberal antlerless harvest. Journal of Wildlife Management 71:1494–1506.

KEECH, M. A., M. S. LINDBERG, R. D. BOERTJE, P. VALKENBURG, B. D. TARAS, T. A. BOUDREAU, AND K. B. BECKMEN. 2011. Effects of predator treatments, individual traits, and environment on moose survival in Alaska. Journal of Wildlife Management 75:1361–1380.

Conclusions

PRINCIPAL BIOLOGICAL CONCLUSIONS

Removing moose predators in the McGrath area resulted in significant growth of the moose population (Keech et al. 2011). This growth resulted from increases in survival of all age classes of moose following removal of predators. Removal of primarily black bears, and to a lesser degree, wolves, resulted in increased summer and fall survival of moose calves. Removal of wolves resulted in increased summer and fall survival of yearling moose. Removal of wolves resulted in increased annual survival of adult female moose. We did not observe a benefit of predator removals to calves or yearlings during winter. However, winter calf survival was strongly and negatively influenced by deep snows. We observed no effect of snow depth on survival of yearling or adult moose. We did observe a significant increase in nonpredation mortalities following removals of predators, indicating some component of observed predation mortality on calves is compensatory. However, increases in nonpredation calf deaths did little to offset increases in survival following removals, indicating most calf mortality was additive. We observed the complete numerical recovery of the black bear population in EMMA within 6 years after a 96% population reduction. This illustrates the resilience of black bear populations to exploitation when harvests/removals occur in localized areas surrounded by unexploited habitat. We also concluded that male and female bears preyed on calves at similar rates; thus, both sexes of bears were effective calf predators.

MANAGEMENT APPLICATION

This is a thorough study where 3 predators were treated to successfully increase moose survival and numbers. Given results of this and previous studies, wildlife managers and policymakers may expect similar results from predator treatment programs elsewhere, but use less costly and less thorough study designs. Managers, especially in multi-predator systems, should recognize that a substantial suite of covariates and confounding effects may complicate program results. Consequently, managers should be prepared to adapt study designs as well as treatment methods to increase the likelihood of program success and understanding. To accomplish this, we recommend managers implement programs that include collecting comparative data on 1) the relative abundance and harvest of moose and predators, 2) basic information on moose nutritional status and population composition, 3) the frequency of deep snowfall winters, and 4) the relative effects of different predators on moose survival, because the effects vary considerably among study areas.

RECOMMENDATIONS FOR THE FUTURE

Reducing predation sufficient to allow moose population growth is a key step toward increasing sustainable harvest densities in much of Interior Alaska where moose occur at low densities and are predator-limited (Gasaway et al. 1992, Boertje et al. 2009). The ultimate goal when reducing predation is to elevate the sustained yield of moose. The results of this study reflect a short-term response (7 year) to reducing predators and the duration of elevated moose numbers and future yield of moose remains to be determined. Whether predator reductions will prove to be a successful management action in the long term will require time and additional effort from ADF&G. To assess long-term success of the predator removals in the McGrath area, the following activities are recommended as a minimum:

1. Annually collect accurate harvest data from MMA and Unit 19D East to determine if elevated harvest (or some other measure of increased success) will occur and for how long.

2. Conduct intensive moose surveys in MMA at a minimum of every third year to determine if the population increases we observed during the previous 7 years continue, or if population stabilization or decline occurs.

3. Collect indices of moose nutritional status in MMA, including twinning surveys on an annual basis and 10-month-old calf weights on an every third year (or more frequent) basis.

4. Use measures of nutritional condition as a guide for implementing moose harvest strategies that maintain the overall nutritional health and reproductive productivity of the population (Boertje et al. 2007, 2009).

5. Conduct an estimate of black bear abundance in EMMA in spring 2013 (and 2016 pending the results from 2013). This estimate will be used to determine if the black bear population stabilizes at the preremoval 2003 abundance or continues to increase.

6. Conduct late winter surveys of wolf abundance in the 8,314 km^2 wolf control zone a minimum of every third year.

7. Work to publish a peer-reviewed article in roughly 5 years that discusses the longer term outcome of the McGrath area predator reductions relative to moose harvests and the expectations of predator removals.

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