

FINAL RESEARCH REPORT

DISTRIBUTION AND ABUNDANCE OF BIGHORN SHEEP IN ROCKY
MOUNTAIN NATIONAL PARK, COLORADO

SUBMITTED TO:

ROCKY MOUNTAIN NATIONAL PARK

BY

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ABSTRACT

Anecdotal evidence of a pneumonia epizootic among bighorn sheep in Rocky Mountain National Park (RMNP), Colorado, during the mid-1990s prompted Park officials to examine the current condition of the herds. With an emphasis on the adult ewe population, we designed a mark-resight study to estimate abundance, recruitment, survival, minimum fecundity, rate of population change, distributions, and movements based on observations from December 2002 to May 2005. Fifty-nine adult ewes were captured, sampled, and radio-collared via helicopter net-gunning during winter 2002 – 2003. Mark-resight data for Bowden's Estimator of abundance were collected in 2003 and 2004 from ground surveys conducted May – September.

The 2003 adult ewe population was estimated at 175.7 (SE = 11.1) sheep. Overall observed ratios of yearlings:ewes, lambs:ewes, and rams:ewes produced abundance estimates of 42.1 (SE = 5.2) yearlings, 78.7 (SE = 9.4) lambs, and 93.3 (SE = 9.2) rams for a total 2003 bighorn population estimate of 389.9 (SE = 34.9, 95% CI = 327.2 – 464.6). In 2004, adult ewe abundance was estimated at 168.9 (SE = 11.9). Overall yearling, lamb, and ram ratios produced abundance estimates of 33.7 (SE = 4.8), 92.1 (SE = 10.0), and 71.7 (SE = 8.1), respectively, providing a total 2004 population estimate of 366.4 (SE = 34.7, 95% CI = 304.4 – 441.0). The majority of sheep continue to be found in the West-side herd. Marked ewes were observed to have 100% fidelity to 4 sub-ranges. No evidence of movements between the East-side and West-side ranges was recorded.

Minimum fecundity for 2003 and 2004 averaged 0.74 (SE = 0.05) lambs per ewe, but annual lamb recruitment per ewe and lamb survival from July 2003 to July 2004 were 0.15 (SE = 0.07) and 0.24 (SE = 0.09), respectively. Mean adult ewe survival for 2003 – 2004 was 0.89 (SE = 0.09) for the East-side herd and 0.91 (SE = 0.04) for the West-side herd. Mean adult ewe survival for 2004 – 2005 was 0.44 (SE = 0.20) and 0.91 (SE = 0.04) for the East-side and West-side herds, respectively. We found some evidence of declining adult ewe survival as age increases.

Previous abundance estimates suggest a Park-wide decline has occurred between the late-1980s and the suspected pneumonia epidemic of the mid-1990s. Sample analyses indicate the presence of bovine viral diarrhea, bovine respiratory syncytial virus, parainfluenza 3, blue tongue, chlamydia, lungworm, and *Pasteurella* spp. in the population. Survival analyses in Program MARK suggest interactions of these pathogens may be related to mortality. Such interactions provide evidence of the “pneumonia-complex” associated with massive sheep die-offs, and the combined inferences from this study suggest the recent decline was likely pneumonia-related. If the population does recover to numbers observed prior to the suspected die-off, the population likely remains at risk of future outbreaks. Unless reproductive and survival rates increase, declines in both herds are expected to continue, particularly in the East-side. A better understanding of the factors driving low demographic rates and the pneumonia-complex in RMNP bighorn is critical for future monitoring and management of this fragile species.

INTRODUCTION

Prior to widespread settlement of western North America, naturalist Ernest Thompson Seton estimated bighorn sheep (*Ovis canadensis*) numbers at 1.5 to 2 million (Valdez and Krausman 1999). Severe declines followed, and the fragile species now exists in relative obscurity compared to other native ungulates. The relentless losses from 1800 to 1970 have been attributed to many factors including overharvesting, habitat loss, competition with domestic livestock, and disease (Buechner 1960). The majority of mortality today is believed a result of disease, particularly pneumonia. The so-called “pneumonia-complex” refers to multiple infectious elements including lungworms (*Protostrongylus* spp.), viruses, and bacteria (primarily *Pasteurella* spp.) combined with stressing factors such as disturbance, competition, weather, and malnutrition (Onderka and Wishart 1984, Schwantje 1988, Foreyt 1990). The complex is often associated with sudden (< 12 months) and catastrophic all-age die-offs exceeding 50% of a population (Shackleton et al. 1999). These have been well documented in Colorado (Bear and Jones 1973, Feuerstein et al. 1980, Bailey 1986), Nevada (Jessup 1981), Oregon (Coggins and Matthews 1992, Cassirer et al. 1996), Wyoming (Ryder et al. 1994), Montana (Enk et al. 1998), and Alberta (Onderka and Wishart 1984, Festa-Bianchet 1988a). Pneumonia epidemics now pose the greatest threat to the remaining bighorn herds in North America and have plagued wildlife managers for decades.

The history of the Rocky Mountain bighorn sheep (*O. c. canadensis*) herds in Rocky Mountain National Park (RMNP) is synonymous with that of the majority of North American populations, and represents a 150-year battle against extinction. A thorough review from pre-settlement to the mid-1970s was completed by Goodson (1978). Believed to once number 4,000, the herds were reduced to 1,000 by 1915 when RMNP was established (Packard 1946). The borders of the Park did not include sufficient historic low-elevation winter ranges used by the herds, and they were soon restricted to more severe, less productive alpine winter ranges (Contor 1958). After a brief recovery following the establishment of RMNP, another severe decline occurred from 1920 to 1958 when grazing of domestic sheep was allowed along its borders (Packard 1946, Contor 1958). Packard believed the introduction of domestic sheep caused a pneumonia-related die-off during this period. The population then stabilized around 200 (Harrington 1969) and increased steadily from 1970 to an estimate approaching 700 by 1989 (Goodson 1978, Goodson and Stevens 1991, Goodson et al. 1991). The increase was supplemented by a successful 1977 reintroduction of 20 sheep to abandoned native range in the northeast section of the Park along Cow Creek (Stevens and Hanson 1986) and another successful reintroduction in 1980 just outside the RMNP boundary in the North St. Vrain Canyon (Goodson et al. 1996). Between 1987 and 1991, a total of 87 sheep were transplanted from the Cow Creek and Mummy Range areas to other regions in Colorado (Sherri Huwer, CDOW, pers. comm.).

Post (1976) suspected sheep populations may be more vulnerable to pneumonia epidemics when inhabiting restricted ranges as in RMNP. While there was no formal study of the Park’s herds in the 1990s, visitors and staff reported a decline in sheep sightings and lamb recruitment during this period (Stephen King, USFS, pers. comm.). There is sufficient anecdotal evidence to suggest that an outbreak of pneumonia in the mid-1990s may have caused another die-off in the Park’s herds. Of prime concern are

the numbers remaining in the herds and their ability to recover to previous levels. If substantial mortalities have occurred due to a pneumonia epizootic, low lamb survival and recruitment levels are known to persist for years following such events (Foreyt 1990, Coggins and Matthews 1992, Ryder et al. 1994, Enk et al. 1998, Monello et al. 2001).

This study was initiated to provide a better understanding of the population's current status and to assess the impacts of the suspected die-off. Radio-collared ewes throughout the range of bighorn sheep in RMNP were investigated from 23 May 2003 to 16 May 2005. The primary objectives of the study were:

- 1) Estimate population size (N) for each of the Park's herds from counts of radio-collared ewes and unmarked animals using the methodology of program NOREMARK (White 1996).
- 2) Estimate movement rates between herds based on movement of radio-collared animals.
- 3) Estimate lamb recruitment (r) rates by determining lambs at heel for each radio-collared animal.
- 4) Estimate adult ewe and lamb survival (S) rates from radio-collared animals.
- 5) Estimate minimum fecundity (f) rates from counts of radio-collared ewes.
- 6) Estimate rate of population change (λ) for the female segment of the population.
- 7) Develop baseline data on *Pasteurella* spp. (agent causing pasteurellosis), *Protostrongylus* spp. (lungworms), and other pathogens from analyses of pharyngeal swabs, nasal swabs, fecal samples, and serological samples taken at time of capture.

DESCRIPTION OF STUDY SITES AND HERDS

The population of interest resides in the Park permanently and does not include the reintroduced North St. Vrain Canyon herd which occasionally migrates into RMNP during the summer months (Goodson et al. 1996). Past studies and RMNP personnel have traditionally divided the permanent population into 4 groups: 1) Mummy Range; 2) Cow Creek; 3) Never Summer; and 4) Continental Divide. Incorporating the historical ranges of the 4 groups (Packard 1946, Goodson 1978, Stevens and Hanson 1986, Goodson and Stevens 1991), portions of RMNP and adjacent National Forests were divided into the West-side and East-side study sites (Figure 1).

West-side Study Site and Herd

The Never Summer (NS) and Continental Divide (CD) groups maintain separate but overlapping seasonal ranges west of and along the Continental Divide in RMNP. Previous studies have subdivided the Never Summer group into the North Never Summer and South Never Summer groups (Goodson and Bailey 1989, Goodson and Stevens 1991). We collectively refer to the NS and CD groups as the West-side herd. The 480 km² study site includes portions of the Never Summer Range within RMNP and parts of the Arapaho and Routt National Forests, and extends across the Colorado River Valley following the Continental Divide south of Mount Alice (Figure 1). Elevations range from

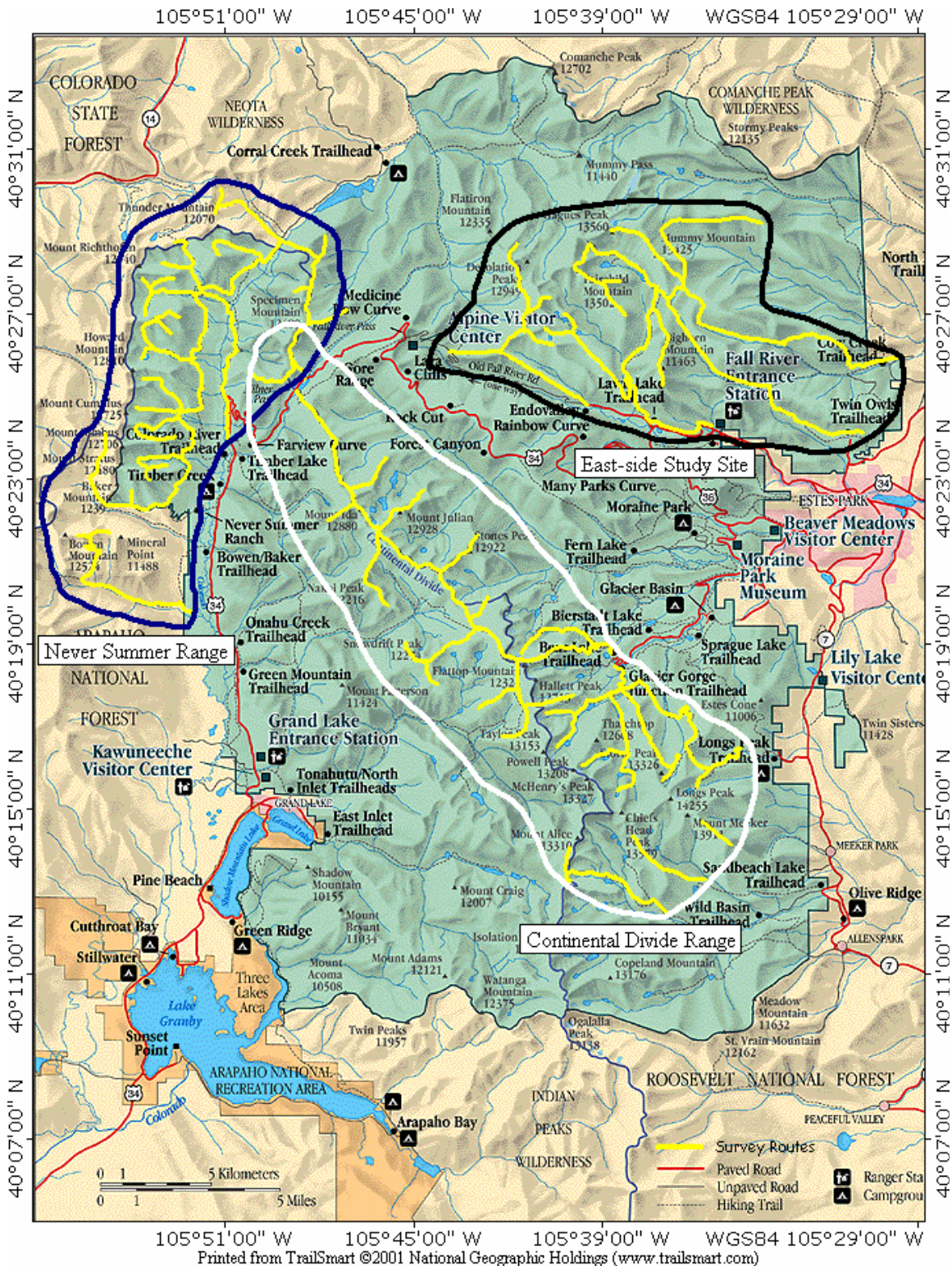


Figure 1. Resighting survey routes for bighorn sheep in the West-side and East-side study sites of Rocky Mountain National Park, Colo. The Never Summer and Continental Divide ranges comprise the West-side study site.

2750 m to 4345 m. The area is estimated at 54% subalpine forest, 42% alpine, and 4% upper montane forest (Goodson 1978).

East-side Study Site and Herd

Previous studies contend that the Mummy Range and Cow Creek groups maintain distinct but overlapping ranges in the northeast portion of RMNP (Stevens and Hanson 1986, Goodson et al. 1996). The Mummy Range group spends the entire year within RMNP borders in the Mummy Range. Both groups share high elevation summer ranges, but the Cow Creek group is believed to spend portions of the winter at lower elevations just outside the Park's eastern border (Stevens and Hanson 1986, Goodson et al. 1996). By documenting these winter movements, researchers were able to differentiate between the 2 groups. However, because the Cow Creek sheep were not observed in these lower elevation winter ranges during the capture period, no such distinction can be made for this study. We therefore refer to the Mummy Range and Cow Creek groups collectively as the East-side herd. The 170 km² East-side study site extends from the southern two-thirds of the Mummy Range eastward along Fall River and Cow Creek to the Park boundary (Figure 1). Elevations range from 2340 m to 4130 m. The site is characterized as roughly 50% alpine (3450 m to 4120 m), 37% subalpine forest (2750 m to 3350 m), and 13% upper montane forest (2340 m to 2870 m) (Baumann 1978).

METHODS

Fifty-nine adult (>2 years old) ewes were captured, sampled, and radio-collared via helicopter net-gunning during winter 2002 – 2003. Wildlife Capture Services, Inc. caught 4 sheep on 11 December 2002. All other captures were performed by Pathfinder Helicopter, Inc. between 13 March and 2 April 2003. Thirty-three ewes were caught in the Never Summer Range between Bowen Mountain and Static Peak, 11 were caught along the Continental Divide between Mount Meeker and Taylor Peak, and 15 were caught in the Mummy Range between Mount Chapin and Mummy Mountain (Appendix A). All collars were labeled with a unique letter and number combination allowing individual ewes to be easily identified by sight from a distance. Collars were also equipped with a mortality switch triggered after 8 hours of inactivity. Age was estimated as 2 – 3 years, 3 – 4 years, 4 – 5 years, 5 – 6 years, 6 – 8 years, or greater than 8 years of age based on tooth eruption and wear (Valdez and Krausman 1999).

Blood, fecal, hair, pharyngeal, and nasal samples were collected during processing. Nine milliliters of blood were drawn from the jugular vein and refrigerated in serum separator tubes. Sera were removed within 48 hours and refrigerated until tested for infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), bovine respiratory syncytial virus (BRSV), parainfluenza 3 (PI-3), blue tongue (BT), and chlamydia. At least 5 g of fecal pellets were extracted from the rectum and refrigerated in air-tight plastic bags before being counted for first-stage *Protostrongylus* spp. larvae/g using the Baermann technique (Sloss et al. 1994). Fecal samples less than 5 g were not included in the analysis. The Colorado State University Veterinary Diagnostic Laboratories analyzed all blood and fecal samples. Pharyngeal swabs were collected

from the tonsils of all ewes, and nasal swabs were collected from any ewes exhibiting a nasal discharge. To provide an indication of the bacteria's continued presence and potential nose-to-nose transmission from clinically healthy ewes to vulnerable lambs (Foreyt 1990), swabs were stored and refrigerated in BBL™ Port-A-Cul™ (Becton, Dickinson and Company, Sparks, Maryland, USA) transport tubes until cultured for beta-hemolytic and non-hemolytic biovariant isolates of *Pasteurella* spp. (Jaworski et al. 1998). Swabs were also cultured for *Mycoplasma* spp. (Corstvet 1987). Pharyngeal and nasal samples were analyzed by the University of Idaho Caine Veterinary Teaching Center. Hair samples remain to be analyzed.

Two fixed-wing overflights to radio-locate marked ewes were conducted each field season. Overflights occurred on 23 May and 17 July in 2003 and on 7 June and 26 July in 2004. An additional flight was conducted on 16 May 2005. These flights confirmed any marked mortalities and the presence of all marked ewes within the study area. From 31 May to 28 August 2003 and 3 June to 27 August 2004, 4 – 5 field technicians conducted 8 resighting surveys of the area on foot. A complete survey of the entire study area required 7 – 9 days and consisted of 35 routes (Figure 1). Survey routes were allocated proportional to the size of each study site and configured to minimize double counting within surveys. Without the use of radio-telemetry or information from the overflights, all visible terrain within 2 miles of each route was scanned for sheep using 8x42 binoculars and zoom (20x to 60x) spotting scopes. Three-month lamb survival and recruitment data were collected 2 – 15 September 2003 and 28 August to 11 September 2004 by radio-locating and observing marked ewes throughout the study area. The following data were recorded for all sheep observations: 1) identity of marked ewes and presence or absence of a suckling lamb at heel; 2) numbers of each sex-age class in band; 3) associations of any marked ewes with yearlings; 4) location; 5) habitat; 6) behavior and apparent health; 7) weather; and 8) movements. An individual was classified as either marked ewe, unmarked adult ewe, yearling (<2 years old), lamb of the year, class I ram, class II ram, class III ram, or class IV ram (Geist 1967). Unclassified sheep and unidentified marks were also recorded.

Adult ewe population sizes were estimated using Bowden's Estimator corrected for any unidentified marks in Program NOREMARK (Bowden and Kufeld 1995, White 1996). Of the 4 models included in NOREMARK, Bowden's Estimator is the most appropriate for this study because it successfully incorporates individual heterogeneity in sighting probabilities and sampling with replacement. Considerable heterogeneity occurs in bighorn sheep (Neal 1990, Neal et al. 1993, Bodie et al. 1995, George et al. 1996) and is a function of herding behavior and variable habitat types within its range. If not accounted for, heterogeneity may bias estimates low (Neal 1990, Neal et al. 1993, White 1993, White and Shenk 2001). For each field season, 3 estimates were produced with Bowden's Estimator: 1) total RMNP ewe population; 2) West-side ewe population; and 3) East-side ewe population.

Annual abundances for yearlings, lambs, and rams were estimated by multiplying Bowden's adult ewe estimates by the overall observed yearling:ewe ratios (31 May to 15 September 2003 and 14 June to 11 September 2004), lamb:ewe ratios (30 June to 15 September 2003 and 30 June to 11 September 2004), and ram:ewe ratios (31 May to 28 August 2003 and 14 June to 27 August 2004). Overall ram:ewe ratios did not include the radio-location periods late-August to mid-September because only ewe-juvenile bands

were observed. Standard errors for lamb and yearling ratios were calculated using the robust estimator for behaviorally dependent groups of Bowden et al. (1984). Ram bands were assumed to be sighted independently of ewe-juvenile bands, and the binomial distribution was used to estimate standard errors of these ratios. Variances for yearling, lamb, and ram abundance estimates were approximated using the delta method (Casella and Berger 2002). When a ratio produced an abundance or lower confidence interval estimate below the minimum number known alive, this value was used. Lamb per ewe recruitment to 3 months, minimum fecundity, and lamb survival to 3 months were estimated from the marked ewe population. Minimum fecundity was estimated because the nature of the resighting surveys prevented all marked ewes from being observed with optimal timing and duration during the lambing period to obtain unbiased fecundity estimates. Lamb recruitment and survival to 1 year (summer 2003 – 2004) were estimated from observations of the marked ewe population.

Two logistic regression analyses were performed in Program MARK (White and Burnham 1999) with the known fate data type to examine which pathogens may have played a role in marked ewe mortalities 11 December 2002 to 15 September 2003. The first analysis was comprised of ewes with serological and pharyngeal samples collected. Individual covariates included all the above pathogens (except lungworm), capture location (NS, CD, or East-side), age (2 – 3, 3 – 4, 4 – 5, 5 – 6, 6 – 8, and >8 years), and interactions of these. Pathogens were modeled as dummy variables (presence of pathogen = 1). Because the vast majority of sheep were captured in late-winter 2003, an additional dummy variable was included for the 4 ewes captured in December 2002 (December capture = 1). Many sheep were captured immediately prior to a blizzard 17 – 19 March 2003, so animals were grouped by proximity of their capture date to this blizzard. The second analysis included ewes from which fecal, serological, and pharyngeal samples were collected. Covariates and groupings were the same as the first analysis, but also included lungworm (larvae/g) and its interactions. For both analyses, model selection was based on minimum Akaike's Information Criterion adjusted for small-sample bias (AIC_c, Burnham and Anderson 2002). Model-averaged parameter estimates and estimated unconditional variances (Burnham and Anderson 2004) included only those models containing the parameter of interest.

Marked ewe survival from May 2003 to May 2005 was also estimated using the known fate data type in Program MARK. Ewes were grouped by capture location, and covariates included age and year (May 2003 – 2004 and May 2004 – 2005). Because 5 of 8 marked ewes in the East-side herd died May 2004 – 2005, an effect for this was also examined. Model selection was performed as above, and model-averaged estimates of survival and unconditional variances were computed with Program MARK. Because fewer covariates were included in this analysis, model-averaged parameter estimates and an unconditional variance-covariance matrix were computed across all candidate models (Burnham and Anderson 2002, 2004) using the SAS System for Windows (SAS Institute, Inc. 2002).

Based on our age-specific adult ewe survival estimates from May 2003 to May 2005, minimum fecundity estimates for 2003 and 2004, and 1-year lamb survival estimates from 2003 to 2004, we estimated the rate of population change for the female segment of the 3 sheep groups. We included 9 age classes for survival (lamb, yearling, 2 – 3 years, 3 – 4 years, 4 – 5 years, 5 – 6 years, 6 – 7 years, 7 – 8 years, and >8 years).

Because no data on yearling survival were collected, we estimated it proportional to the survival of ewes aged 2 – 3 years ($S_Y = 0.7 \cdot S_{2-3}$) based on the findings of Stewart (1980). Estimates of minimum fecundity from 2003 and 2004 were used for each group and assumed constant for all adults >2 years old. Although Festa-Bianchet (1988b) found evidence of lower fecundity and lamb survival rates for ewes aged 2 – 3 years, our sample sizes for this age class were not adequate for estimation of age-specific fecundity rates. Festa-Bianchet (1988b) found no statistically significant evidence of lower fecundity or lamb survival for ewes >8 years old, and we therefore modeled these parameters equal to those of the other adult ewe age classes. Minimum fecundity estimates for the West-side herd were used for both the NS and CD groups. Few studies have examined bighorn sex ratios at birth, but Woodgerd (1964) observed 1:1 ratios in Montana. With no data of our own on the proportion of lambs that are female (R), we assumed $R = 0.5$ with zero variance for our population model. Monte Carlo simulation was used to draw logit-scaled parameter values from a multivariate normal distribution with means equal to the model-averaged parameter estimates and variances and covariances from the unconditional variance-covariance matrix. Because estimates of adult age-specific survival were independent of fecundity and lamb survival, the covariances of any of the adult survival estimates and fecundity or lamb survival were zero. Estimates of lamb survival and fecundity were also estimated independently with zero covariance. The parameter estimates obtained for each draw from the multivariate normal distribution were transformed to probabilities using the logistic model and simulated for 30 years with the following post-birth Leslie matrix model:

$$\begin{bmatrix} 0 & S_Y fR & S_{2-3} fR & \dots & S_{7-8} fR & S_{>8} fR \\ S_L & 0 & 0 & 0 & \dots & 0 \\ 0 & S_Y & 0 & 0 & \dots & 0 \\ 0 & 0 & S_{2-3} & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & S_{7-8} & S_{>8} \end{bmatrix} \cdot \begin{bmatrix} N_{L,t} \\ N_{Y,t} \\ N_{2-3,t} \\ \vdots \\ N_{7-8,t} \\ N_{>8,t} \end{bmatrix} = \begin{bmatrix} N_{L,t+1} \\ N_{Y,t+1} \\ N_{2-3,t+1} \\ \vdots \\ N_{7-8,t+1} \\ N_{>8,t+1} \end{bmatrix}.$$

Each of the 9 age classes were given an initial population size of 100 individuals ($N_I = 900$). After allowing this initial age structure to be modified by the demographic rates, an estimate of λ was obtained as the ratio of the final 2 population sizes (N_{30}/N_{29}). This procedure was repeated 1,000,000 times to estimate a mean ($\bar{\lambda}$) and standard deviation (SD) for λ . The SD of $\bar{\lambda}$ may be interpreted as an SE that incorporates the sampling variation of the input parameters. Confidence intervals were computed as

$\bar{\lambda} \pm z_{1-\alpha/2} \text{SD}(\bar{\lambda})$ with $\alpha = 0.05$. The percentage of simulations where the population was stable or increasing ($\hat{\lambda} \geq 1$) was also calculated. To evaluate the sensitivity of λ to the 11 demographic rates included in the Leslie matrix model, the mean values for S , f , and R from the simulations were used. Sensitivity was computed as $[\lambda(\theta_i + \Delta) - \lambda(\theta_i)]/\Delta$, where $i = 1, \dots, 11$ and $\Delta = 0.001$.

RESULTS

Abundance Estimates

The overflights on 23 May and 17 July 2003 (Appendices B and C) and 7 June and 26 July 2004 (Appendices D and E) confirmed all collared sheep remained within the study area. Mortalities (4 in Never Summer and 6 in East-side) reduced the 2003 marked sample size to 49 ewes. Forty of these were in the West-side herd (29 in the Never Summers, 11 along the Continental Divide), and 9 were in the East-side herd. All 35 resighting survey routes were not completed in the first and sixth surveys of 2003 due to trail closings following the breach of the Grand Ditch in late-May and the death of a field technician in late-July, respectively. Six surveys of the entire RMNP study area, 6 surveys of the West-side study site, and 7 surveys of the East-side study site were therefore completed in 2003 for adult ewe abundance estimation. Additional mortalities and a censored ewe reduced the marked sample size for 2004 to 44 ewes. Thirty-six of these were in the West-side herd (27 in the Never Summers, 9 in Continental Divide), and 8 were in the East-side herd. An incomplete survey due to poor weather conditions in early June reduced the number of complete surveys to 7 for 2004. Seven additional mortalities were recorded by the 16 May 2005 overflight, bringing the total number of marked mortalities between 11 December 2002 and 16 May 2005 to 22 sheep (Appendix F).

Rocky Mountain National Park Population

The 6 resighting occasions completed in 2003 for RMNP recorded 999 visual locations of individual sheep between 11 June and 28 August (Figure 2). Of these, 117 were marked ewes, 325 were unmarked ewes, 108 were yearlings, 182 were lambs, and 229 were rams (80 class I, 83 class II, 46 class III, and 20 class IV). Thirty sheep were unclassified, and 8 marked ewes were not positively identified. The estimated mean sighting probability ($\hat{\mu}$) of the 49 marked ewes was 0.388 (SE = 0.028). In 2004, the 7 resighting occasions across RMNP recorded 964 visual locations of individual sheep between 14 June and 27 August (Figure 2). Of these, 105 were marked ewes, 323 were unmarked ewes, 85 were yearlings, 215 were lambs, and 185 were rams (43 class I, 81 class II, 47 class III, and 14 class IV). Forty-three sheep were unclassified, and 8 marked ewes were not positively identified. For the 44 marked ewes, $\hat{\mu} = 0.334$ (SE = 0.027).

After correcting for the 8 unidentified marked ewes, Bowden's Estimate for the 2003 RMNP adult ewe population was 175.7 (SE = 11.1) with a confidence interval (CI) length of 25.5% (Table 1). Abundance estimates for yearlings, lambs, and rams (Table 1) were derived from overall observed ratios to adult ewes between 31 May and 15 September (Figures 3, 4, and 5). Overall ratios to adult ewes were 0.240 (SE = 0.025) for yearlings, 0.448 (SE = 0.042) for lambs, and 0.531 (SE = 0.041) for rams (Table 2). From these ratios, the estimated yearling population was 42.1 (SE = 5.2), the estimated lamb population was 78.7 (SE = 9.4), and the estimated ram population was 93.3 (SE = 9.2). The total 2003 RMNP bighorn population was therefore estimated at 389.9 (SE = 34.9, CI = 327.2 – 464.6) sheep (Table 1).

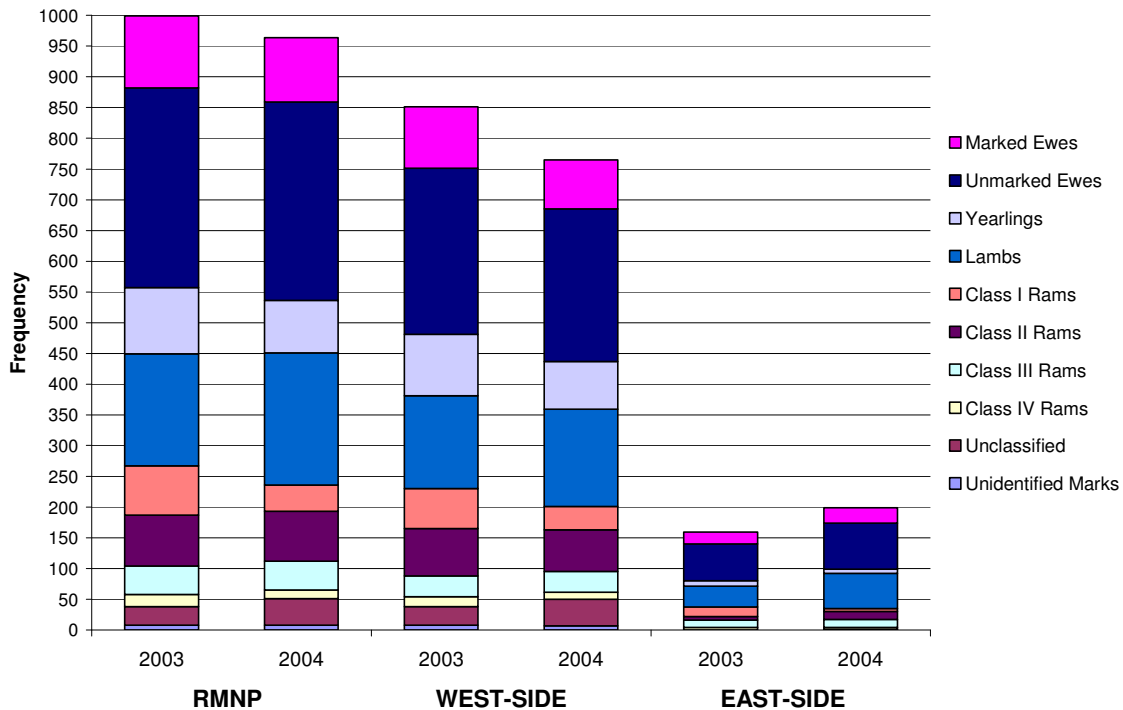


Figure 2. Summer 2003 and 2004 resighting frequencies of each bighorn sheep classification type for all of Rocky Mountain National Park, Colo. (RMNP), the West-side herd, and the East-side herd.

Bowden's Estimate for the 2004 RMNP adult ewe population was 168.9 (SE = 11.9, CI = 146.6 – 194.6, Table 1). Abundance estimates for yearlings, lambs, and rams (Table 1) were derived from overall observed ratios to adult ewes between 14 June and 11 September (Figures 3, 4, and 5). Overall ratios to adult ewes were 0.200 (SE = 0.025) for yearlings, 0.545 (SE = 0.045) for lambs, and 0.424 (SE = 0.037) for rams (Table 2). The estimated yearling population was 33.7 (SE = 4.8), the estimated lamb population was 92.1 (SE = 10.0), and the estimated ram population was 71.7 (SE = 8.1). The total 2004 bighorn population in RMNP was therefore estimated at 366.4 (SE = 34.7, CI = 304.4 – 441.0) sheep (Table 1).

West-side Herd

In 2003, 851 individual sheep locations were recorded during 6 resighting occasions in the West-side study area (Figure 2). Of these, 100 were marked ewes ($\hat{\mu}$ = 0.417, SE = 0.032), 270 were unmarked ewes, 100 were yearlings, 151 were lambs, and 192 were rams (65 class I, 77 class II, 34 class III, and 16 class IV). Thirty were unclassified, and 8 were unidentified marks. The 2003 West-side ewe population was estimated at 139.3 (SE = 9.7, CI = 121.1 – 160.3, Table 3). The overall ratio to ewes was 0.266 (SE = 0.030) for yearlings, 0.432 (SE = 0.050) for lambs, and 0.543 (SE = 0.045)

Table 1. Population abundance estimates ($\hat{N}$), standard errors (SE), 95% log normal confidence intervals (CI), and percent confidence interval lengths [%CIL = 100*(UCI – LCI)/ $\hat{N}$] for big-horn sheep in Rocky Mountain National Park, Colo., from resighting surveys conducted in 2003 and 2004. Total ram estimate combines abundances for class I, II, III, and IV rams.

		$\hat{N}$	SE	Lower CI	Upper CI	% CIL
RMNP Total						
	2003	389.9	34.9	327.2	464.6	35.2
	2004	366.4	34.7	304.4	441.0	37.3
Adult Ewes						
	2003	175.7	11.1	154.7	199.5	25.5
	2004	168.9	11.9	146.6	194.6	28.4
Yearlings						
	2003	42.1	5.2	33.1	53.6	48.5
	2004	33.7	4.8	25.5	44.6	56.7
Lambs						
	2003	78.7	9.4	62.3	99.4	47.2
	2004	92.1	10.0	74.6	113.8	42.6
Total Rams						
	2003	93.3	9.2	76.9	113.3	39.0
	2004	71.7	8.1	57.5	89.3	44.3
Class I						
	2003	33.7	4.3	26.2	43.3	50.7
	2004	16.7	2.9	12*	23.4	68.4
Class II						
	2003	34.1	4.4	26.5	43.8	50.6
	2004	31.4	4.4	23.9	41.2	55.3
Class III						
	2003	18.5	2.9	13.5	25.2	62.9
	2004	18.2	3.1	13.1	25.3	66.9
Class IV						
	2003	7.1	1.7	6*	11.2	73.5
	2004	5.4	1.5	4*	9.3	97.7

* Minimum number known alive.

Table 2. Overall ratios (standard errors) of yearlings, lambs, and rams to adult ewes for bighorn sheep observed in Rocky Mountain National Park (RMNP), Colo., June – September 2003 and 2004. Ratios are for all of RMNP, the West-side herd, and the East-side herd. Total ram ratios combine observations for Class I, II, III, and IV rams.

	Yearling	Lambs	Total Rams	Class I	Class II	Class III	Class IV
RMNP							
2003	0.240 (0.025)	0.448 (0.042)	0.531 (0.041)	0.192 (0.021)	0.194 (0.022)	0.105 (0.015)	0.040 (0.009)
2004	0.200 (0.025)	0.545 (0.045)	0.424 (0.037)	0.099 (0.016)	0.186 (0.022)	0.108 (0.017)	0.032 (0.009)
West-side							
2003	0.266 (0.030)	0.432 (0.050)	0.543 (0.045)	0.192 (0.023)	0.216 (0.025)	0.096 (0.016)	0.038 (0.010)
2004	0.233 (0.028)	0.536 (0.055)	0.451 (0.044)	0.113 (0.019)	0.203 (0.027)	0.101 (0.018)	0.033 (0.010)
East-side							
2003	0.100 (0.031)	0.547 (0.118)	0.468 (0.093)	0.190 (0.053)	0.076 (0.032)	0.152 (0.047)	0.051 (0.026)
2004	0.086 (0.036)	0.571 (0.073)	0.337 (0.067)	0.050 (0.023)	0.129 (0.038)	0.129 (0.038)	0.030 (0.017)

for rams (Table 2). These ratios produced estimates of 37.1 (SE = 4.9) yearlings, 60.1 (SE = 8.1) lambs, and 75.7 (SE = 8.2) rams for the West-side herd, a total of 312.3 (SE = 30.9, CI = 257.3 – 378.9) sheep (Table 3).

During the 7 resighting occasions of 2004, 765 individual locations were recorded in the West-side study area (Figure 2). Of these, 80 were marked ewes ($\hat{\mu}$ = 0.310, SE = 0.029), 248 were unmarked ewes, 78 were yearlings, 158 were lambs, and 151 were rams (38 class I, 68 class II, 34 class III, and 11 class IV). Forty-three were unclassified, and 7 were unidentified marks. The 2004 West-side ewe population was estimated at 137.6 (SE = 11.6, CI = 116.0 – 163.3, Table 3). The overall ratio to ewes was 0.233 (SE = 0.028) for yearlings, 0.536 (SE = 0.055) for lambs, and 0.451 (SE = 0.044) for rams (Table 2). These ratios produced estimates of 32.1 (SE = 4.8) yearlings, 73.8 (SE = 9.8) lambs, and 62.0 (SE = 8.0) rams for the West-side herd, a total of 305.5 (SE = 34.2, CI = 245.6 – 380.2) sheep (Table 3).

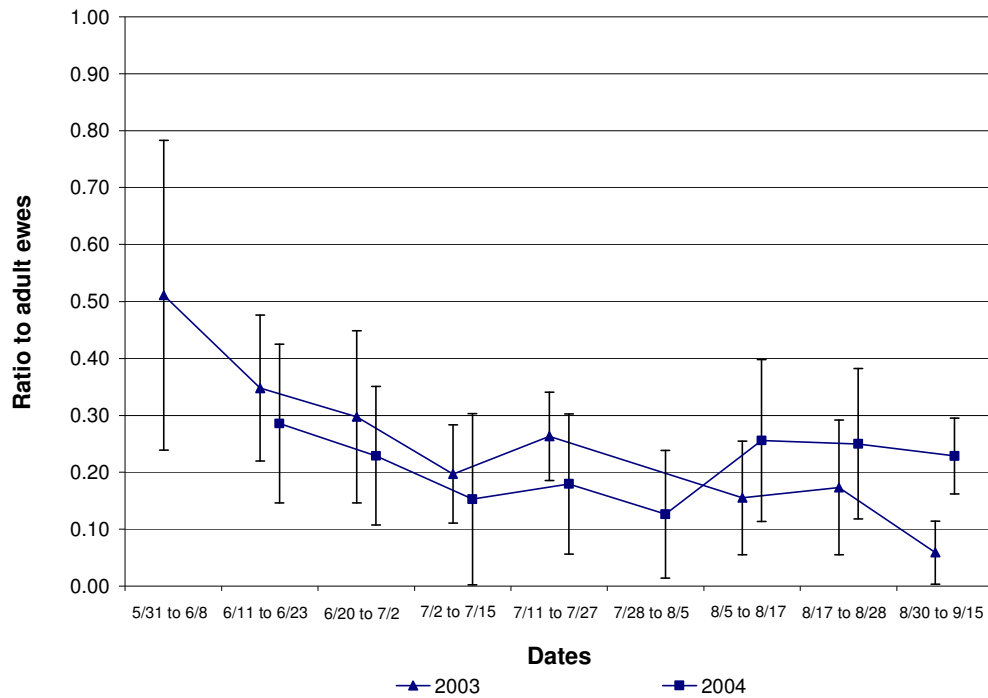


Figure 3. Observed ratios and 95% normal confidence intervals of bighorn sheep yearlings to adult ewes in Rocky Mountain National Park, Colo., across resighting periods between 31 May and 15 September 2003 – 2004.

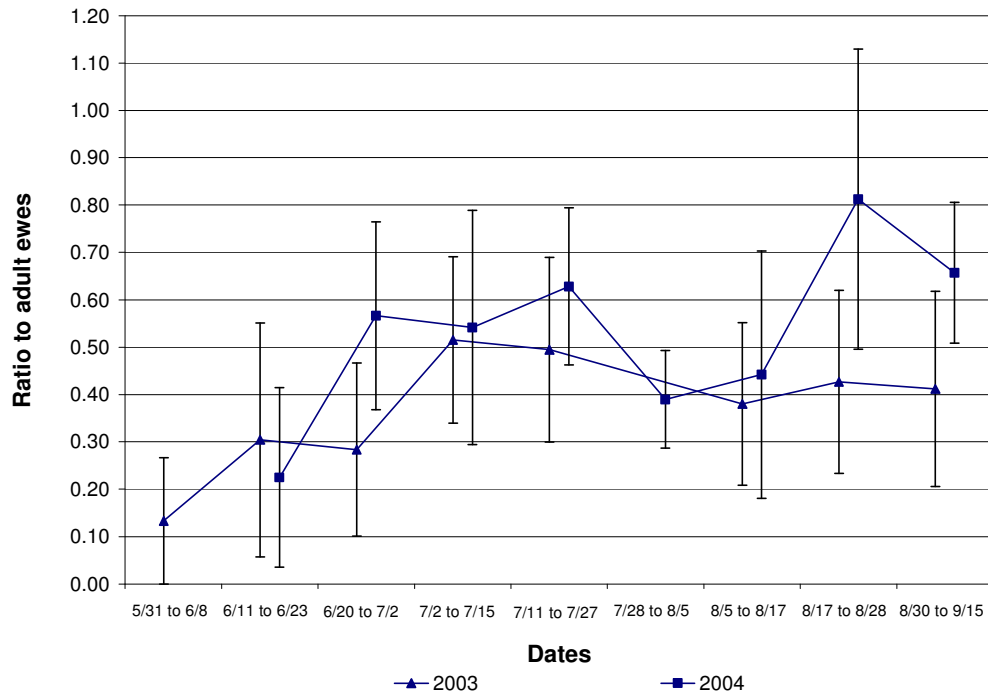


Figure 4. Observed ratios and 95% normal confidence intervals of bighorn sheep lambs to adult ewes in Rocky Mountain National Park, Colo., across resighting periods between 31 May and 15 September 2003 – 2004.

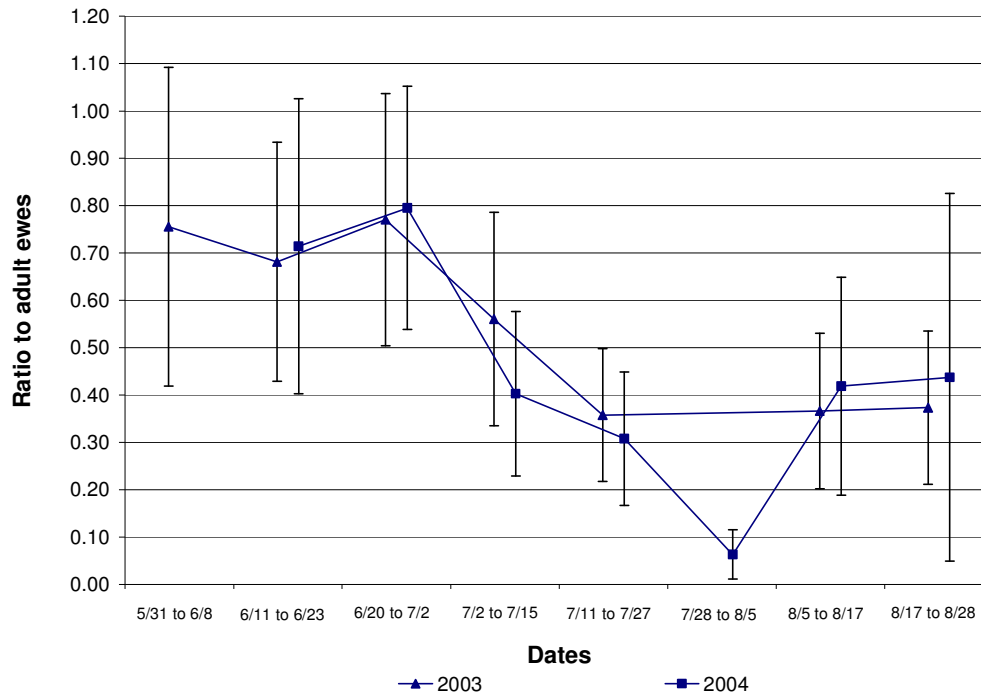


Figure 5. Observed ratios and 95% normal confidence intervals of bighorn sheep rams to adult ewes in Rocky Mountain National Park, Colo., across resighting periods between 31 May and 28 August 2003 – 2004.

East-side Herd

In 2003, 159 individual locations were recorded in the East-side study area during 7 resighting occasions (Figure 2). Of these, 19 were marked ewes ($\hat{\mu} = 0.302$, $SE = 0.058$), 60 were unmarked ewes, 9 were yearlings, 34 were lambs, and 37 were rams (15 class I, 6 class II, 12 class III, 4 class IV). No individuals were unclassified, and all marked sheep were positively identified. The 2003 East-side ewe population was estimated as 36.7 ($SE = 5.2$, $CI = 26.5 - 50.7$) with a confidence interval length of 66.0% (Table 4). The overall yearling:ewe ratio was 0.100 ($SE = 0.031$), lamb:ewe ratio was 0.547 ($SE = 0.118$), and ram:ewe ratio was 0.468 ($SE = 0.093$). These ratios (Table 2) produced estimates of 3.7 ($SE = 1.3$) yearlings, 20.1 ($SE = 5.2$) lambs, and 17.2 ($SE = 4.2$) rams for the herd, a total of 77.5 ($SE = 15.8$, $CI = 52.3 - 115.0$) sheep (Table 4).

During the 7 resighting occasions completed in 2004 for the East-side herd, 199 individual locations were made (Figure 2). Of these, 25 were marked ewes ($\hat{\mu} = 0.446$, $SE = 0.066$), 75 were unmarked ewes, 7 were yearlings, 57 were lambs, and 34 were rams (5 class I, 13 class II, 13 class III, 3 class IV). No individuals were unclassified, and 1 marked sheep was unidentified. The 2004 East-side ewe population was estimated as 30.8 ($SE = 2.8$, $CI = 27.0 - 38.3$, Table 4). The overall yearling:ewe ratio was 0.086 ($SE = 0.036$), the overall lamb:ewe ratio was 0.571 ($SE = 0.073$), and the overall ram:ewe ratio was 0.337 ($SE = 0.067$). These ratios (Table 2) produced estimates of 3.0 ($SE =$

Table 3. Population abundance estimates ($\hat{N}$), standard errors (SE), 95% log normal confidence intervals (CI), and percent confidence interval lengths [%CIL = 100*(UCI – LCI)/ $\hat{N}$] for big-horn sheep in the West-side herd from resighting surveys conducted in 2003 and 2004. Total ram estimate combines abundances for class I, II, III, and IV rams.

		$\hat{N}$	SE	Lower CI	Upper CI	% CIL
West-side Total						
	2003	312.3	30.9	257.3	378.9	38.9
	2004	305.5	34.2	245.6	380.2	44.1
Adult Ewes						
	2003	139.3	9.7	121.1	160.3	28.2
	2004	137.6	11.6	116.0	163.3	34.4
Yearlings						
	2003	37.1	4.9	28.7	48.0	52.2
	2004	32.1	4.8	24.1	42.9	58.6
Lambs						
	2003	60.1	8.1	46.2	78.3	53.4
	2004	73.8	9.8	56.9	95.6	52.4
Total Rams						
	2003	75.7	8.2	61.3	93.5	42.5
	2004	62.0	8.0	48.2	79.8	51.0
Class I						
	2003	26.8	3.8	20.4	35.2	55.5
	2004	15.6	3.0	10.8	22.6	75.8
Class II						
	2003	30.1	4.1	23.1	39.3	53.5
	2004	27.9	4.4	20.6	38.0	62.3
Class III						
	2003	13.4	2.4	9.4	19.0	71.2
	2004	14.0	2.8	11*	20.5	68.3
Class IV						
	2003	5.4	1.4	4*	8.9	91.7
	2004	4.5	1.4	3*	8.3	117.3

* Minimum number known alive.

Table 4. Population abundance estimates ($\hat{N}$), standard errors (SE), 95% log normal confidence intervals (CI), and percent confidence interval lengths [%CIL = 100*(UCI – LCI)/ $\hat{N}$] for big-horn sheep in the East-side herd from resighting surveys conducted in 2003 and 2004. Total ram estimate combines abundances for class I, II, III, and IV rams.

		$\hat{N}$	SE	Lower CI	Upper CI	% CIL
East-side Total						
	2003	77.5	15.8	52.3	115.0	80.9
	2004	61.4	9.0	56*	81.7	41.8
Adult Ewes						
	2003	36.7	5.2	26.5	50.7	66.0
	2004	30.8	2.8	27*	38.3	36.6
Yearlings						
	2003	3.7	1.3	3*	7.0	108.1
	2004	3*	1.1	3*	5.9	96.4
Lambs						
	2003	20.1	5.2	11*	32.9	109.0
	2004	17.6	2.8	17*	23.9	39.2
Total Rams						
	2003	17.2	4.2	17*	27.5	61.0
	2004	10.4	2.3	9*	15.8	65.9
Class I						
	2003	7.0	2.2	4*	12.7	124.3
	2004	1.5	0.7	1*	3.6	173.4
Class II						
	2003	5*	1.2	5*	6.4	28.0
	2004	4.0	1.2	4*	7.2	79.7
Class III						
	2003	6*	1.9	6*	10.7	78.3
	2004	4.0	1.2	3*	7.2	105.0
Class IV						
	2003	2*	1.0	2*	4.9	145.0
	2004	1*	0.5	1*	2.7	168.4

* Minimum number known alive.

1.1) yearlings, 17.6 (SE = 2.8) lambs, and 10.4 (SE = 2.3) rams for the East-side herd, a total of 61.4 (SE = 9.0, CI = 56.0 – 81.7, Table 4) sheep.

Distribution and Movements

Rocky Mountain National Park Population

All sheep sightings from the overflights and ground surveys were within the study area (Figure 1) and are plotted in Appendices G (2003) and H (2004). The current range of sheep in the Park includes all of the Never Summer Range, the Continental Divide from Thunder Pass southeast to Mount Alice, and the Mummy Range extending southeast to the Fall River Entrance Station (Figure 6). Ewe-juvenile bands (Appendices I and J) and ram bands (Appendices K and L) occupied the same general ranges in the Park, but at different times from one another for most of the year. No evidence of ewe movements between the West-side and East-side herds was recorded.

West-side Herd

Based on locations between capture and 11 September 2004, the 40 marked ewes in the West-side herd maintained 3 distinct but overlapping ranges (Figure 6). These ranges overlap at the Crater of Specimen Mountain, a known mineral lick for West-side sheep. Except when visiting the Crater, 20 of the 29 ewes captured in the Never Summer Range were located exclusively in the South Never Summers (SNS, Appendices M and N), and the other 9 were located only in the North Never Summers (NNS, Appendices O and P). The 11 ewes captured in the Continental Divide Range were located entirely along the Divide southeastward from the Crater to Long's Peak (Appendices Q and R). In addition to the range overlap at the Crater, the SNS and NNS ranges also overlap at Howard Mountain. No evidence of ewe movements between these 3 groups was observed.

The SNS ewes were constantly moving throughout their range over the duration of the field seasons. Fourteen of the 20 were captured in wintering grounds in the south portion of their range between Stratus and Bowen Mountains, and the remaining 6 were captured in wintering grounds between Howard Mountain and Mount Nimbus (Appendix A). In 2003, Baker Mountain was the lambing ground of at least 8 of these marked ewes, but Bowen Mountain and the Crater were used by 1 ewe each. In 2004, the Crater and adjacent Shipler Mountain were the lambing grounds of at least 7 SNS marked ewes, but Howard Mountain and Baker Mountain were used by at least 2 ewes each. Eight (2003) and 10 (2004) ewes temporarily migrated to the Crater at least once during the lambing season (late-May to mid-July). Three (2003) and 2 (2004) ewes visited the Crater at least twice during this period. A solitary ewe and lamb moved from Bowen Mountain to the Crater between 5 and 15 September 2003. This was the longest movement recorded for the SNS group.

The 9 marked ewes in the NNS group underwent the shortest movements between their similar winter, lambing, and summer ranges. All late-winter and summer locations were at the Crater or between Box Canyon and Lead Mountain (Appendices O and P). In 2003, Lead Mountain was used as a lambing ground by at least 3 marked ewes, and the

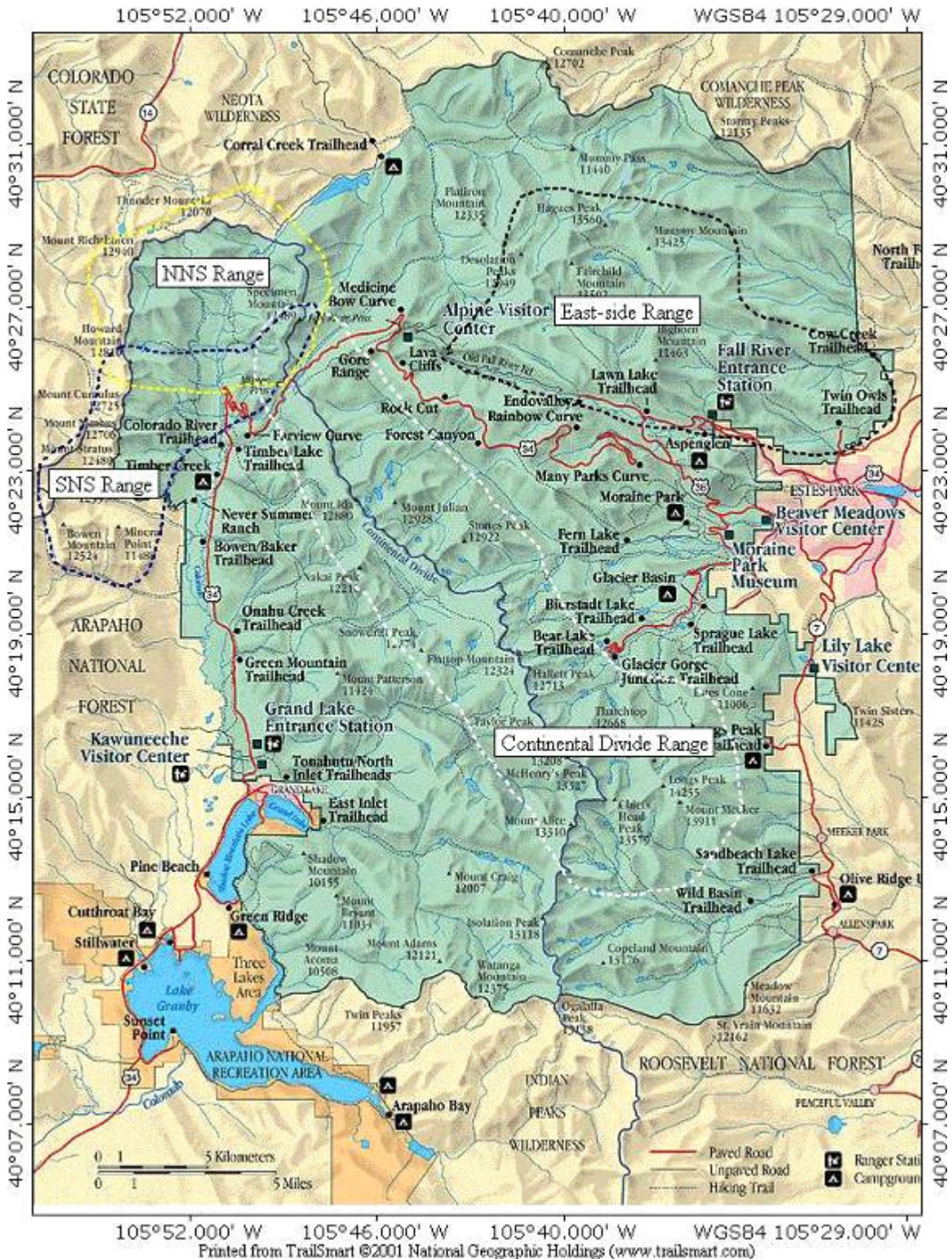


Figure 6. Observed ranges of RMNP bighorn sheep, 11 December 2002 to 11 September 2004. The North Never Summer (NNS), South Never Summer (SNS) and Continental Divide ranges comprise the West-side herd range.

Crater was used by another. In 2004, the Crater and Shipler Mountain were visited by at least 5 ewes during the lambing period. These brief movements to the Crater were the longest recorded for this group.

Contrary to the Never Summer groups, the 11 ewes of the CD group appear to use non-overlapping late-winter and summer ranges. In the southeast portion of the Divide that comprised their late-winter range, 8 ewes were captured on Battle Mountain, 2 on Thatchtop Mountain, and 1 on Mount Meeker (Appendix A). In 2003, the 2 ewes captured on Thatchtop Mountain also lambled in that area, and at least 3 others lambled in the Crater. In 2004, at least 2 ewes lambled in the Crater and adjacent Shipler Mountain. Sheep Rock, Chief Cheley Peak, and Terra Tomah Mountain were used as lambing grounds by 1 ewe each. As the lambing period progressed, fewer of the ewes were located in the winter range where they were captured. For the duration of the summer season, CD ewes were only found between Sprague Mountain and the Crater. Five (2003) and 3 (2004) ewes visited the Crater during the lambing season at least once. Another ewe visited at least twice during this period in 2003. The CD ewes were observed to move the greatest distances of all marked ewes in the Park, but were never located outside of their suspected range (Appendices Q and R).

East-side Herd

The 9 East-side ewes were located exclusively in the Mummy Range between capture and 11 September 2004 (Appendices S and T). The late-winter, lambing, and summer ranges of these ewes were found to completely overlap. Sheep were captured on winter ranges on Fairchild Mountain (3 ewes), Mummy Mountain (2 ewes), Mount Chapin (2 ewes), and Ypsilon Mountain (1 ewe, Appendix A). In 2003, 4 ewes were known to have lambled near Fairchild Mountain, and another lambled on Mount Chapin. In 2004, 2 ewes were known to have lambled in the cliffs north of Spectacle Lakes, and another 2 lambled on Mummy Mountain. All marked ewes surviving to 11 September 2004 moved throughout the Mummy Range during the course of the study. All ewes visited Sheep Lakes, an East-side mineral lick, at least once during the 2003 or 2004 field seasons.

Lambing Estimates

Rocky Mountain National Park Population

The 2003 and 2004 lambing seasons began in late-May and ended in early to mid-July. The first lamb of each season was witnessed on 31 May 2003 and 27 May 2004. Three-month recruitment was estimated from the marked population as 0.469 (SE = 0.088) lambs per ewe in 2003 and 0.781 (SE = 0.073) lambs per ewe in 2004. Minimum fecundity rates were estimated at 0.630 (SE = 0.071) lambs per ewe in 2003 and 0.860 (SE = 0.053) in 2004. Based on lambs whose fates were determined, the estimated 3-month survival rates were 0.750 (SE = 0.097) in 2003 and 0.893 (SE = 0.058) in 2004 (Table 5). Six yearlings born in 2003 were associated with marked ewes in 2004, providing a 1-year (July 2003 to July 2004) recruitment estimate of 0.146 (SE = 0.065).

Table 5. Lambs per ewe recruited to 3 months ($\hat{f}$), minimum fecundity per ewe ($\hat{f}$), and 3-month lamb survival ($\hat{S}$) for bighorn sheep observed in Rocky Mountain National Park (RMNP), Colo., May – September, 2003 – 2004. Estimates are for all of RMNP, the West-side herd, and East-side herd. Standard errors and sample size (n) are in parentheses.

		$\hat{f}$	$\hat{f}$	$\hat{S}$
RMNP	2003	0.469 (0.088, $n = 32$)	0.630 (0.071, $n = 46$)	0.750 (0.097, $n = 20$)
	2004	0.781 (0.073, $n = 32$)	0.860 (0.053, $n = 43$)	0.893 (0.058, $n = 28$)
West-side	2003	0.423 (0.097, $n = 26$)	0.622 (0.080, $n = 37$)	0.733 (0.114, $n = 15$)
	2004	0.769 (0.083, $n = 26$)	0.829 (0.064, $n = 35$)	0.909 (0.061, $n = 22$)
East-side	2003	0.667 (0.192, $n = 6$)	0.667 (0.157, $n = 9$)	0.800 (0.179, $n = 5$)
	2004	0.833 (0.152, $n = 6$)	1.00 (0.000, $n = 8$)	0.833 (0.152, $n = 6$)

From the 25 lambs born to marked ewes in 2003 whose fates were determined in 2004, 1-year survival was estimated at 0.240 (SE = 0.085, Table 6).

West-side Herd

Appendices U and V display plots of all West-side lambing grounds observed in 2003 and 2004, respectively. Marked and unmarked SNS sheep were observed lambing on Baker Mountain, Bowen Mountain, Howard Mountain, and the Crater. Lead Mountain, Howard Mountain, and the Crater were used by NNS sheep. Continental Divide sheep lambled in cliffs surrounding Thatchtop Mountain, Otis Peak, Stones Peak, Mount Ida, Chief Cheley Peak, Terra Tomah Mountain, Sheep Rock, and the Crater.

From the marked West-side ewes whose lambing status was determined, 3-month recruitment was estimated at 0.423 (SE = 0.097) in 2003 and 0.769 (SE = 0.083) in 2004. Minimum fecundity was estimated as 0.622 (SE = 0.080) in 2003 and 0.829 (SE = 0.064) in 2004. Based on lambs of marked ewes whose fates were determined, the estimated 3-month survival rate was 0.733 (SE = 0.114) for 2003 and 0.909 (SE = 0.061) for 2004 (Table 5). Five yearlings born in 2003 were confirmed to be associated with marked ewes in 2004, providing a 1-year recruitment estimate of 0.147 (SE = 0.071). From the 21 lambs born to marked ewes in 2003 whose fates were determined in 2004, the 5 remaining yearlings in 2004 provided a 1-year survival estimate of 0.238 (SE = 0.093, Table 6).

Table 6. Lambs per ewe recruited to 1 year ($\hat{r}$) and 1-year lamb survival ($\hat{S}$) for bighorn sheep observed in Rocky Mountain National Park (RMNP), Colo., July 2003 to July 2004. Estimates are for all of RMNP, the West-side herd, and East-side herd. Standard errors and sample size (n) are in parentheses.

	$\hat{r}$	$\hat{S}$
RMNP	0.146 (0.065, $n = 41$)	0.240 (0.085, $n = 25$)
West-side	0.147 (0.071, $n = 34$)	0.238 (0.093, $n = 21$)
East-side	0.143 (0.154, $n = 7$)	0.250 (0.217, $n = 4$)

East-side Herd

Ewes from the East-side herd were observed lambing on Mount Chapin, Mount Chiquita, Fairchild Mountain, Mummy Mountain, and cliffs north of Spectacle Lakes (Appendices W and X). The majority of lambs observed during the 2004 lambing period were seen at Sheep Lakes between 23 June and 8 July. Three-month recruitment was estimated as 0.667 (SE = 0.192) in 2003 and 0.833 (SE = 0.152) in 2004. Minimum fecundity estimates were 0.667 (SE = 0.157) in 2003 and 1.000 (SE = 0.000) in 2004. The estimated 3-month lamb survival rate was 0.800 (SE = 0.179) in 2003 and 0.833 (SE = 0.152) in 2004 (Table 5). One yearling born in 2003 was associated with a marked ewe in 2004, providing a 1-year recruitment estimate of 0.143 (SE = 0.154). Based on the 4 lambs born to marked ewes in 2003 whose fates were confirmed in 2004, 1-year survival was estimated at 0.250 (SE = 0.217, Table 6).

Disease and Mortality

Results from all pharyngeal, nasal, fecal, and serological analyses are presented in Appendices Y and Z. Twenty of 48 ewes indicated an exposure to or infection of chlamydia. All samples indicated a lack of exposure to IBR, and only 6% indicated an exposure to BVD. Twenty-one of 50 ewes indicated an exposure to or infection of BRSV, and 78% indicated an exposure to or infection of PI-3. Two sheep tested positive for BT exposure or infection. All fecal samples contained *Protostrongylus* spp. Larvae counts were highly variable, ranging from 32 to 3772 larvae/g. Only 3 ewes did not test positive for any *Pasteurella* spp. biovariants. *Pasteurella haemolytica* and *P. trehalosi* were the two species cultured from pharyngeal swabs, and 9 groups of biovariants were isolated. Five ewes carried biovariants considered to have the highest disease potential (A. C. S. Ward, University of Idaho, pers. comm., Appendices Y and Z). No samples indicated the presence of mycoplasma.

One collared ewe (F2) appeared emaciated with a nasal discharge at the time of capture. Nasal and pharyngeal samples indicated an exposure to or infection of chlamydia, BRSV, and PI-3. The ewe carried three biovariants of *Pasteurella* spp., none of which are considered to have a high disease potential. F2 was still alive as of 16 May 2005, and successfully recruited a lamb to 3 months in 2004, but not in 2003. No other noticeably ill sheep were observed throughout the field seasons. On 3 occasions in August 2003 some sneezing was seen. Two of these were adult ewes, and the third was a class IV ram.

Eleven of the 50 ewes from which serological and pharyngeal samples were collected in the first logistic regression analysis were mortalities. The AIC_c results of 24 models are presented in Table 7. The minimum AIC_c model (AIC_c weight = 0.195) included an additive December capture effect ($\hat{\beta}_D = -3.258$, SE = 1.428, CI = -6.056 to -0.46), an additive BT effect ($\hat{\beta}_{BT} = -3.258$, SE = 1.743, CI = -6.675 to 0.158), and an interaction effect of BRSV, PI-3, and *P. trehalosi* ($\hat{\beta}_{BPP} = -2.901$, SE = 1.132, CI = -5.12 to -0.683). $\hat{\beta}_D$ applies to ewes caught in December 2002, $\hat{\beta}_{BT}$ applies to ewes that tested positive for BT, and $\hat{\beta}_{BPP}$ applies to ewes that tested positive for BRSV, PI-3, and *P. trehalosi* biovariants. All 3 individual covariates had a negative effect on survival (Table 8). AIC_c weights indicate a degree of model selection uncertainty, and the model-averaged effect of BRSV*PI-3**P. trehalosi* was -2.064 (SE = 1.203, CI = -4.421 to 0.293).

The second logistic regression included the 27 ewes from which fecal, serological, and pharyngeal samples were collected. Five of these ewes were mortalities. None of the animals in this sample tested positive for BT or BVD, and no animals were captured after the March blizzard. AIC_c results for 28 models are presented in Table 9. The minimum AIC_c model (AIC_c weight = 0.125) included a Lungworm*PI-3**P. trehalosi* interaction effect ($\hat{\beta}_{LPP} = -2.507$, SE = 1.157, CI = -4.774 to -0.239) and a NS group effect ($\hat{\beta}_{NS} = 4.302$, SE = 2.111, CI = 0.164 to 8.440). Confidence interval lengths of real parameter estimates from this model are large, but NS ewes in this sample had higher survival point estimates than CD or East-side ewes. The lungworm, PI-3, and *P. trehalosi* interaction had increasingly negative effects on survival point estimates as lungworm larvae/g increased (Table 10). AIC_c weights indicate considerable model selection uncertainty between the 7 models with the lowest AIC_c values (Table 9), and we model-averaged parameter estimates from these models (Table 11).

Nine ewes captured during winter 2002 – 2003 were confirmed as mortalities in May 2003 and not included in the survival analysis for May 2003 to May 2005. An additional censored ewe reduced the sample size for this analysis to 49 ewes. Model selection results indicated substantial support for 2 competing models (Table 12). With an AIC_c weight of 0.448, the minimum AIC_c model {S(Et2+Age)} contained a negative East-side herd effect for May 2004 – 2005 ($\hat{\beta}_{Et2} = -2.646$, SE = 0.846, CI = -4.305 to -0.987) and an age effect ($\hat{\beta}_{AGE} = -0.576$, SE = 0.363, CI = -1.288 to 0.136). Model {S(Et2)} had an AIC_c weight of 0.334 and included only a negative East-side herd effect for May 2004 – 2005 ($\hat{\beta}_{Et2} = -2.775$, SE = 0.819, CI = -4.381 to -1.169). Model-

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Table 7. AIC_c model selection results for a logistic regression on bighorn sheep adult ewe ($n = 50$) survival 11 December 2002 to 15 September 2003 in Rocky Mountain National Park, Colo., with the known fate data type in Program MARK. Individual covariates include pathogens [bovine respiratory syncytial virus (BRSV), parainfluenza 3 (PI-3), blue tongue (BT), bovine viral diarrhea (BVD), *Pasteurella trehalosi* (P. t), and Chlamydia], December capture (December), age at time of capture (Age), ewe group [Never Summer (NS), Continental Divide (CD), and East-side], and interactions of these variables (*). Ewes were grouped based on proximity of capture date to a March 2003 blizzard (Blizzard). Intercept models no effects.

Model	AIC _c	ΔAIC _c	AIC _c Weight	Model Likelihood	Number of Parameters	Deviance
{December+BRSV*PI-3*P.t+BT}	48.796	0.000	0.195	1.000	4	39.907
{December+BRSV*PI-3*P.t}	49.657	0.862	0.127	0.650	3	43.135
{December+BRSV*PI-3}	50.534	1.738	0.082	0.419	3	44.012
{NS+December+BRSV*PI-3*P.t+BT}	50.765	1.969	0.073	0.374	5	39.401
{East-side+December+BRSV*PI-3*P.t+BT}	50.789	1.993	0.072	0.369	5	39.425
{December+BRSV*PI-3*P.t+BT+Chlamydia}	51.181	2.386	0.059	0.303	5	39.818
{CD+December+BRSV*PI-3*P.t+BT}	51.270	2.475	0.057	0.290	5	39.907
{BRSV*PI-3*P.t}	51.666	2.871	0.046	0.238	2	47.411
{December+Age+BRSV*PI-3*P.t}	51.967	3.171	0.040	0.205	4	43.078
{December+BRSV*PI-3*P.t+BVD}	52.001	3.205	0.039	0.201	4	43.112
{December+Blizzard+BRSV*PI-3*P.t}	52.022	3.226	0.039	0.199	4	43.133
{BRSV*PI-3*P.t+BT}	52.041	3.246	0.039	0.197	3	45.519
{BRSV*PI-3}	52.426	3.630	0.032	0.163	2	48.170
{December+BRSV}	52.739	3.943	0.027	0.139	3	46.217
{Blizzard}	54.001	5.205	0.014	0.074	2	49.746
{BRSV}	54.258	5.462	0.013	0.065	2	50.003
{Intercept}	54.774	5.979	0.010	0.050	1	52.691
{December}	55.278	6.482	0.008	0.039	2	51.022
{PI-3}	55.360	6.565	0.007	0.038	2	51.105
{Age}	56.056	7.260	0.005	0.027	2	51.800
{BT}	56.155	7.359	0.005	0.025	2	51.900
{December+BT}	56.564	7.768	0.004	0.021	3	50.042
{BVD}	56.729	7.933	0.004	0.019	2	52.473
{Chlamydia}	56.860	8.064	0.003	0.018	2	52.605

Table 8. Estimated effects of individual covariates on bighorn sheep adult ewe ($n = 50$) survival ($\hat{S}$) 11 December 2002 to 15 September 2003 in Rocky Mountain National Park, Colo., from minimum AIC_c model {December+BRSV*PI-3*P.t+BT}. The December covariate refers to ewes captured in December 2002, BRSV*PI-3*P.t refers to ewes testing positive for bovine respiratory syncytial virus (BRSV), parainfluenza 3 (PI-3), and *Pasteurella trehalosi* (P. t), and BT refers to ewes testing positive for blue tongue.

Individual Covariates	$\hat{S}$	SE($\hat{S}$)	95% CI	
			Lower	Upper
No Effects	0.963	0.036	0.779	0.995
BRSV*PI-3*P.t	0.588	0.119	0.352	0.790
BT	0.500	0.354	0.059	0.941
December	0.500	0.250	0.123	0.877
BRSV*PI-3*P.t and BT	0.052	0.089	0.002	0.657
BRSV*PI-3*P.t and December	0.052	0.075	0.003	0.515
BT and December	0.037	0.072	0.000	0.664
BRSV*PI-3*P.t, BT, and December	0.002	0.006	0.000	0.304

averaged survival estimates suggest a lower survival for East-side ewes in 2004 – 2005 (Table 13). The model-averaged effect of age across all candidate models was -0.320 (SE = 0.393, CI = -1.090 to 0.451). Point estimates for model-averaged age-specific survival suggest a decline in survival as age increases, but confidence intervals overlap within and between the 3 ewe groups (Figures 7 and 8).

Population Rate of Change

Based on the Monte Carlo simulations with model-averaged parameter and variance-covariance matrix estimates (Table 14), all estimates of the mean population rate of change ($\bar{\lambda}$) were <1 . Using the parameter estimates for 2003 – 2004, the East side herd's projected rate of change was 0.918 (SE = 0.093, CI = 0.734 to 1.101) with 17.5% of the simulations producing an estimate of $\lambda \geq 1$. For the CD group in 2003 – 2004, $\bar{\lambda} = 0.930$ (SE = 0.053, CI = 0.827 to 1.034) with 6.7% of simulations estimating $\lambda \geq 1$. For the 2003 – 2004 NS group, $\bar{\lambda} = 0.931$ (SE = 0.052, CI = 0.828 to 1.033) with 6.6% of simulations with $\hat{\lambda} \geq 1$. Using the 2004 – 2005 parameter estimates for the East-side herd, $\bar{\lambda} = 0.576$ (SE = 0.198, CI = 0.188 to 0.964) with 1.0% of simulations estimating $\lambda \geq 1$. For the 2004 – 2005 CD group, $\bar{\lambda} = 0.960$ (SE = 0.048, CI = 0.866 to 1.054) with 19.8% of simulations with $\hat{\lambda} \geq 1$. For the NS group in 2004 – 2005, $\bar{\lambda} = 0.960$ (SE = 0.048, CI = 0.867 to 1.054) and $\hat{\lambda} \geq 1$ in 19.7% of simulations. Parameter sensitivities were highest for $S_{>8}$ and S_L for all 3 groups in 2003 – 2004 and for the NS

Table 9. AIC_c model selection results for a logistic regression on bighorn sheep adult ewe ($n = 27$) survival 11 December 2002 to 15 September 2003 in Rocky Mountain National Park, Colo., with the known fate data type in Program MARK. Individual covariates include pathogens [bovine respiratory syncytial virus (BRSV), parainfluenza 3 (PI-3), *Pasteurella trehalosi* (P. t), Chlamydia, and Lungworm], December capture (December), age at time of capture (Age), ewe group [Never Summer (NS), Continental Divide (CD), and East-side], and interactions of these variables (*). Intercept models no effects.

Model	AIC _c	Δ AIC _c	AIC _c Weight	Model Likelihood	Number of Parameters	Deviance
{NS+Lungworm*PI-3*P.t}	20.766	0.000	0.125	1.000	3	13.722
{NS+BRSV*PI-3*P.t+Lungworm*PI-3*P.t}	21.059	0.290	0.108	0.864	4	11.241
{NS+BRSV*PI-3*P.t+Lungworm*PI-3}	21.070	0.300	0.107	0.859	4	11.251
{NS+BRSV*PI-3*P.t+Lungworm*P.t}	21.075	0.310	0.107	0.857	4	11.257
{NS+BRSV*PI-3*P.t+Lungworm}	21.144	0.380	0.103	0.828	4	11.325
{NS+Lungworm*PI-3}	21.156	0.390	0.103	0.823	3	14.113
{NS+Lungworm*P.t}	21.241	0.480	0.098	0.788	3	14.198
{NS+BRSV+Lungworm}	22.800	2.030	0.045	0.362	4	12.981
{NS+Lungworm*PI-3*P.t+Chlamydia}	23.271	2.510	0.036	0.286	4	13.452
{NS+Lungworm}	23.700	2.930	0.029	0.231	3	16.656
{NS+BRSV*Lungworm*PI-3*P.t}	24.030	3.260	0.024	0.196	3	16.986
{CD+Lungworm*PI-3*P.t}	24.584	3.820	0.018	0.148	3	17.541
{NS+BRSV*PI-3*P.t}	25.355	4.590	0.013	0.101	3	18.312
{NS+BRSV*PI-3}	25.558	4.790	0.011	0.091	3	18.514
{Lungworm*PI-3*P.t}	25.579	4.810	0.011	0.090	2	21.079
{Lungworm*P.t}	25.816	5.050	0.010	0.080	2	21.316
{BRSV*PI-3*P.t+Lungworm*PI-3*P.t}	26.161	5.390	0.008	0.067	3	19.117
{Lungworm*PI-3}	26.380	5.610	0.008	0.060	2	21.880
{NS}	26.402	5.640	0.007	0.060	2	21.902
{Lungworm}	26.851	6.090	0.006	0.048	2	22.351
{East-side+Lungworm*PI-3*P.t}	27.119	6.350	0.005	0.042	3	20.076
{BRSV*PI-3*P.t}	27.124	6.360	0.005	0.042	2	22.624
{NS+BRSV}	27.990	7.220	0.003	0.027	3	20.946
{INTERCEPT}	28.035	7.270	0.003	0.026	1	25.875
{BRSV}	29.197	8.430	0.002	0.015	2	24.697
{December}	29.946	9.180	0.001	0.010	2	25.446
{Chlamydia}	30.203	9.440	0.001	0.009	2	25.703
{Age}	30.247	9.480	0.001	0.009	2	25.747

Table 10. Estimated effects of individual covariates on bighorn sheep adult ewe ($n = 27$) survival ($\hat{S}$) 11 December 2002 to 15 September 2003 in Rocky Mountain National Park, Colo., from minimum AIC_c model {NS+Lungworm*PI-3*P.t}. The individual covariate NS refers to sheep in the Never Summer group, and the Lungworm*PI-3*P.t interaction refers to ewes testing positive for parainfluenza 3 (PI-3), *Pasteurella trehalosi* (P. t), and various infection levels of lungworm (larvae/g). No interaction refers to ewes not infected with all 3 pathogens.

	$\hat{S}$	SE($\hat{S}$)	95% CI	
			Lower	Upper
<u>Never Summer Ewes</u>				
No interaction	0.998	0.005	0.786	1.000
100 larvae/g*PI-3*P.t	0.997	0.006	0.778	1.000
500 larvae/g *PI-3*P.t	0.993	0.014	0.740	1.000
1000 larvae/g*PI-3*P.t	0.976	0.036	0.665	0.999
2000 larvae/g*PI-3*P.t	0.740	0.223	0.228	0.965
2500 larvae/g*PI-3*P.t	0.349	0.427	0.013	0.955
3000 larvae/g*PI-3*P.t	0.025	0.143	0.000	1.000
<u>All Other Ewes</u>				
No interaction	0.863	0.108	0.512	0.974
100 larvae/g*PI-3*P.t	0.827	0.122	0.472	0.962
500 larvae/g *PI-3*P.t	0.597	0.199	0.226	0.882
1000 larvae/g*PI-3*P.t	0.164	0.262	0.005	0.892
2000 larvae/g*PI-3*P.t	0.000	0.000	0.000	0.000
2500 larvae/g*PI-3*P.t	0.000	0.000	0.000	0.000
3000 larvae/g*PI-3*P.t	0.000	0.000	0.000	0.000

Table 11. AIC_c model-averaged estimated effects ($\hat{\beta}$) of lungworm and interactions (*) with parainfluenza 3 (PI-3), *Pasteurella trehalosi* (P. t), and bovine respiratory syncytial virus (BRSV) on bighorn sheep adult ewe ($n = 27$) survival 11 December 2002 to 15 September 2003 in Rocky Mountain National Park, Colo. Effects were selected among 7 models with the greatest AIC_c weights from a logistic regression analysis using the known fate data type in Program MARK.

Parameter	$\hat{\beta}$	SE($\hat{\beta}$)	95% CI	
			Lower	Upper
Lungworm*PI-3*P.t	-2.042	1.152	-4.299	0.215
Lungworm*PI-3	-2.068	1.165	-4.350	0.215
Lungworm*P.t	-2.043	1.145	-4.288	0.202
Lungworm	-1.826	1.029	-3.841	0.190
BRSV*PI-3*P.t	-3.817	3.100	-9.894	2.259

Table 12. AIC_c model selection results for known fate analysis of bighorn sheep marked ewe ($n = 49$) survival in Rocky Mountain National Park, Colo., May 2003 – May 2004. Ewes were grouped by location of capture (Never Summer, Continental Divide, or East-side) and modeled with effects for all 3 (Group) or for the East-side and West-side herds (EW). Time (t) and age at time of capture (Age) were modeled as additive (+) or interactive (*). Intercept models no effects. The minimum AIC_c model {S(ES_t2+Age)} includes an East-side herd effect for 2004 – 2005 and an additive age effect. Model {S(Age1+Age2)} includes different age effects for 2003 – 2004 (Age1) and 2004 – 2005 (Age2).

Model	AIC _c	Δ AIC _c	AIC _c Weight	Model Likelihood	Number of Parameters	Deviance
{S(ES _t 2+Age)}	67.161	0.000	0.448	1.000	3	60.892
{S(ES _t 2)}	67.752	0.590	0.334	0.744	2	63.619
{S(EW*t+Age)}	71.521	4.360	0.051	0.113	5	60.832
{S(EW*t)}	71.977	4.820	0.040	0.090	4	63.523
{S(EW+Age)}	72.618	5.460	0.029	0.065	3	66.348
{S(EW)}	72.930	5.770	0.025	0.056	2	68.796
{S(EW+t+Age)}	73.360	6.200	0.020	0.045	4	64.905
{S(EW+t)}	73.703	6.540	0.017	0.038	3	67.433
{S(Group)}	75.046	7.880	0.009	0.019	3	68.777
{S(Age)}	75.064	7.900	0.009	0.019	2	70.931
{S(Age1+Age2)}	75.198	8.040	0.008	0.018	3	68.928
{S(Group+t)}	75.859	8.700	0.006	0.013	4	67.405
{S(Intercept)}	77.295	10.130	0.003	0.006	1	75.251
{S(t)}	78.153	10.990	0.002	0.004	2	74.020

Table 13. AIC_c model-averaged survival estimates for bighorn sheep adult ewes ($n = 49$) May 2003 to May 2005 in Rocky Mountain National Park, Colo. Estimates are for ewes of average age (5.75 years) in the East-side, Continental Divide (CD), and Never Summer (NS) groups.

Time Interval	Ewe Group	$\hat{S}$	SE($\hat{S}$)	95% CI	
				Lower	Upper
May 2003 – May 2004	East-side	0.888	0.085	0.597	0.977
	CD	0.910	0.035	0.813	0.959
	NS	0.910	0.035	0.815	0.959
May 2004 – May 2005	East-side	0.441	0.202	0.137	0.797
	CD	0.909	0.037	0.807	0.960
	NS	0.909	0.036	0.810	0.959

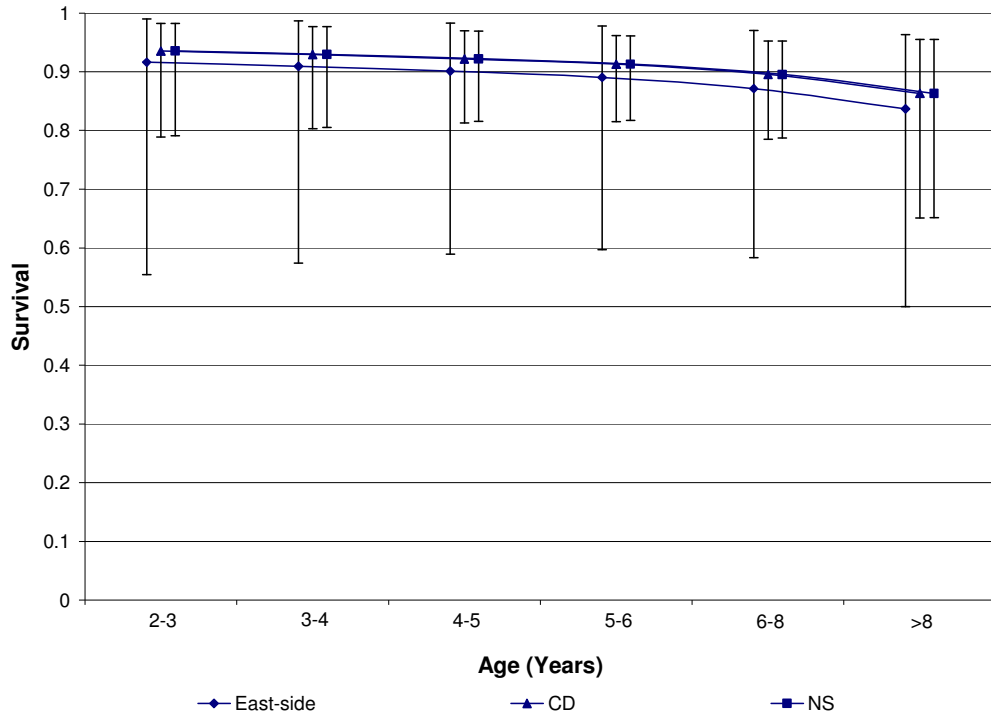


Figure 7. Model-averaged age-specific survival estimates for bighorn sheep adult ewes ($n = 49$) May 2003 to May 2004 in Rocky Mountain National Park, Colo. Estimates are for ewes in the East-side, Continental Divide (CD) and Never Summer (NS) groups.

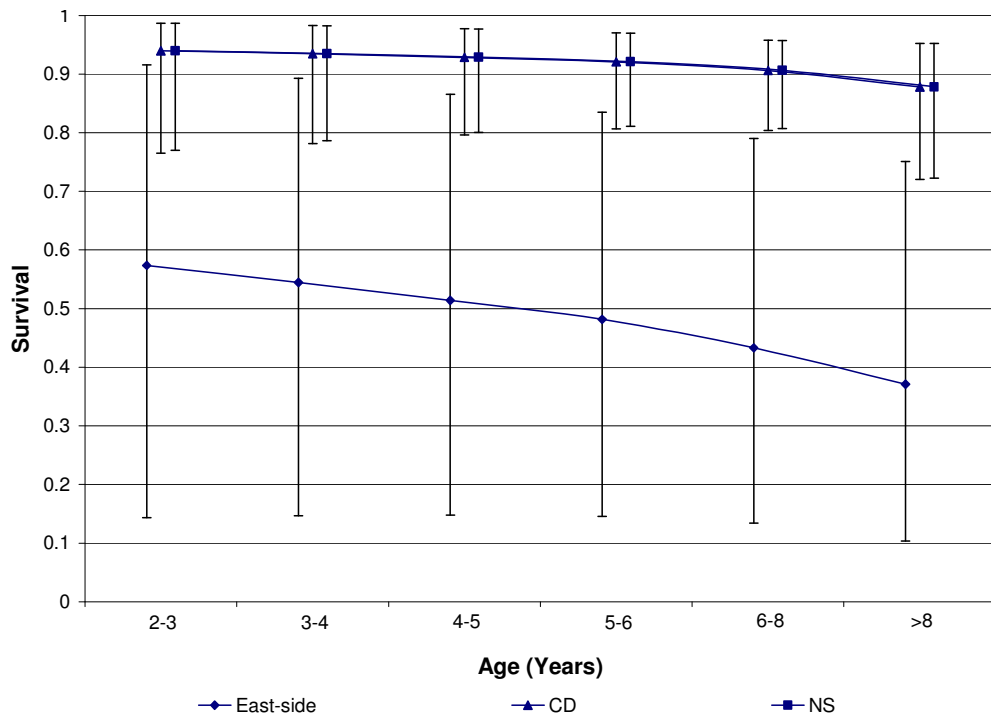


Figure 8. Model-averaged age-specific survival estimates for bighorn sheep adult ewes ($n = 49$) May 2004 to May 2005 in Rocky Mountain National Park, Colo. Estimates are for ewes in the East-side, Continental Divide (CD) and Never Summer (NS) groups.

Table 14. Logit-scaled model-averaged parameter estimates ($\hat{\beta}$) and unconditional variance-covariance (VC) matrix for bighorn ewe survival rates in Rocky Mountain National Park, Colo., May 2003 to May 2005. Values were used to estimate population rate of change (λ) via Monte Carlo simulation. Model-averaged parameters included effects for the East-side (ES) herd, the Continental Divide (CD) group, time (t1, May 2003 – May 2004), an interaction of the East-side herd and time (ES* t1), the East-side herd May 2004 – 2005 (ES2), and an intercept (INT) term. Age effects included separate terms for May 2003 – May 2004 (Age1) and May 2004 – 2005 (Age2) or one term for May 2003 – May 2005 (Age).

Parameter	$\hat{\beta}$	VC Matrix								
		INT	ES	CD	t1	ES*t1	ES2	Age1	Age2	Age
INT	2.306	0.187	-0.059	-0.003	-0.054	0.067	-0.136	0.000	0.002	-0.040
ES	-0.425	-0.059	0.943	0.006	0.036	-0.704	-0.898	-0.001	-0.004	-0.019
CD	-0.002	-0.003	0.006	0.012	-0.001	0.001	-0.004	0.000	0.000	-0.001
t1	0.016	-0.054	0.036	-0.001	0.107	-0.114	0.034	0.000	0.000	0.002
ES*t1	0.260	0.067	-0.704	0.001	-0.114	0.889	0.549	0.001	0.002	-0.005
ES2	-2.111	-0.136	-0.898	-0.004	0.034	0.549	1.793	-0.004	-0.019	0.009
Age1	-0.002	0.000	-0.001	0.000	0.000	0.001	-0.004	0.002	0.002	-0.001
Age2	-0.009	0.002	-0.004	0.000	0.000	0.002	-0.019	0.002	0.012	-0.003
Age	-0.320	-0.040	-0.019	-0.001	0.002	-0.005	0.009	-0.001	-0.003	0.155

and CD groups in 2004 – 2005 (Table 15). The East-side group in 2004 – 2005 was most sensitive to S_L and S_Y . For all groups and years, S_{7-8} was the least sensitive.

DISCUSSION

Abundance Estimates

Based on simulations with Bowden's Estimator in Program NOREMARK, our design goals to attain a confidence interval length of 20% for the RMNP adult ewe population were $k = 8$ resighting occasions, $\mu = 0.40$ mean sighting probability, and 60 marked sheep. In 2003, 8 resighting occasions were attempted, but the first and sixth resighting occasions were incomplete due to trail closings following the breach of the Grand Ditch in late-May and the death of a field technician in late-July, respectively. This reduced the number of occasions for RMNP ($k = 6$), the West-side herd ($k = 6$), and the East-side herd ($k = 7$). With an achieved $\hat{\mu} = 0.39$, the goal for mean sighting probability was nearly met. Fifty-nine ewes were marked, but mortalities reduced the sample for population estimation to 49 sheep (40 West-side, 9 East-side). The estimated confidence interval length of 25.5% did not meet our goal, but the loss of 2 resighting occasions and 10 marked sheep most likely prevented this. In 2004, 8 resighting surveys were also attempted, but an incomplete survey due to poor weather conditions in early

Table 15. Sensitivities of the rate of population change (λ) to 11 parameters included in the population models of bighorn ewes in the East-side, Continental Divide (CD), and Never Summer (NS) groups of Rocky Mountain National Park, Colo. Separate models for each group using 2003 – 2004 and 2004 – 2005 parameter estimates were examined.

	2003 – 2004			2004 – 2005		
	East-side	CD	NS	East-side	CD	NS
Lamb survival	0.262	0.255	0.255	0.368	0.304	0.304
Yearling survival	0.122	0.098	0.098	0.273	0.117	0.117
2-3 year survival	0.079	0.065	0.065	0.160	0.076	0.076
3-4 year survival	0.074	0.061	0.061	0.136	0.070	0.070
4-5 year survival	0.068	0.058	0.058	0.112	0.065	0.065
5-6 year survival	0.063	0.054	0.054	0.089	0.060	0.060
6-7 year survival	0.058	0.051	0.051	0.068	0.056	0.056
7-8 year survival	0.053	0.048	0.048	0.050	0.051	0.051
>8 year survival	0.500	0.579	0.579	0.112	0.528	0.528
Fecundity	0.119	0.103	0.103	0.117	0.093	0.093
Proportion of female lambs	0.155	0.127	0.127	0.217	0.152	0.152

June reduced the number of occasions ($k = 7$). With an achieved $\hat{\mu} = 0.33$, the goal for mean sighting probability was not met. Additional mortalities and a censored animal in 2004 reduced the sample for population estimation to 44 sheep (36 West-side, 8 East-side). The achieved percent confidence interval length of 28.4% did not meet our goal and is the result of a smaller sample size than was expected.

The 2003 and 2004 total RMNP bighorn population estimates of 390 and 366 sheep, respectively, appear average and not at the extremes the population has apparently been capable of in the past (Figure 9). Although the abundance point estimate was lower in 2004, no statistically significant decline was detected between years. Previous estimates suggest the population may have been approaching 700 sheep in the late-1980s before the suspected die-off in the mid-1990s (Goodson and Stevens 1991, Goodson et al. 1991). If those estimates were accurate, the current estimates imply a considerable decline since the suspected pneumonia epidemic. However, these estimates are greater than the 200 believed to remain in RMNP after the supposed die-off between 1920 and 1958 (Packard 1946, Contor 1958, Harrington 1969). Prior to this, Packard estimated the population to number 1,000 sheep when the Park was designated in 1915.

Goodson and Stevens (1991) estimated the West-side herd at 452 – 502 sheep between 1986 and 1989. A West-side decline is apparent, but the 2003 and 2004 estimates of 312 and 305, respectively, are greater than the 96 sheep believed in the herd

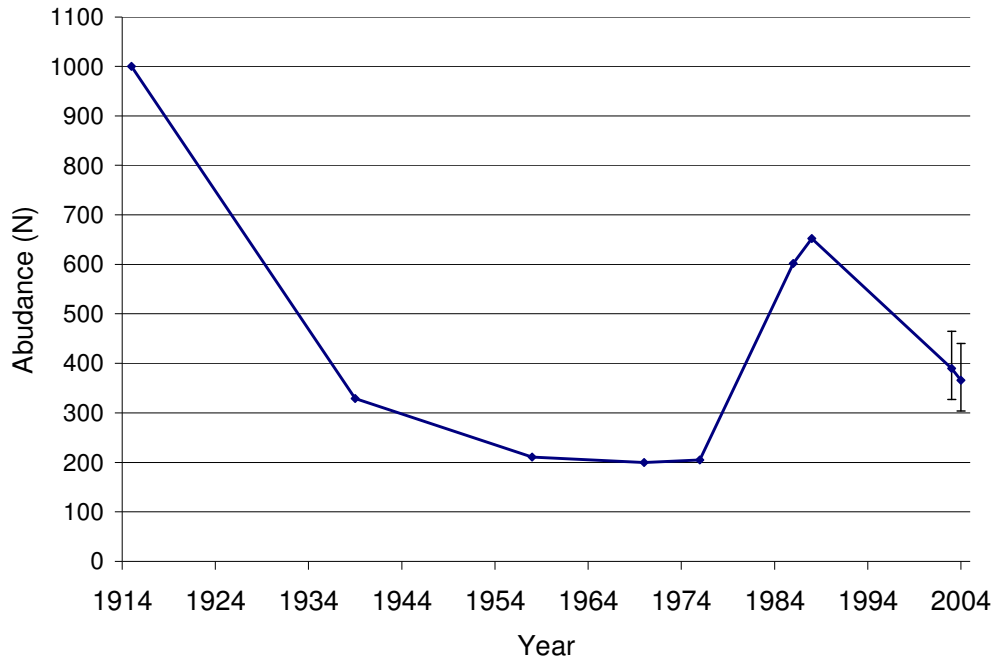


Figure 9. Total bighorn sheep population abundance estimates for Rocky Mountain National Park, Colorado, 1915 – 2004. Log normal confidence intervals (95%) are included for the 2003 and 2004 estimates.

in 1968 (Harrington 1978, Figure 10). A greater relative decline may have occurred in the East-side herd, estimated in the late-1980s to be 200 sheep (Goodson et al. 1991). The current estimates (78 sheep in 2003, 61 sheep in 2004) are similar to that of 81 sheep in 1976 (Goodson 1978), but the 2004 confidence intervals of 47 – 81 sheep suggest this herd may be approaching its lowest numbers in the Park's recorded history (Figure 11). We are unable to determine what effect the removal of 87 sheep between 1987 and 1991 has had on the East-side herd, but it is reasonable to suspect that it may have played a role in the herd's decline since the late-1980s.

With respect to observed ratios, point estimates for yearlings varied slightly during the summer (Figure 3), but no statistically significant differences were observed except for the last period 30 August to 15 September 2003. The overall yearling:ewe ratio in 2004 (0.20) is lower than the overall ratio observed in 2003 (0.24), but the difference is not statistically significant. Current yearling ratios are smaller than previous mean ratios of 0.54 for RMNP (Goodson 1978) and 0.32 for the West-side herd (Goodson and Stevens 1991).

As expected, lamb:ewe ratios increased as lambs were born late-May until mid-July (Figure 4). A large number of unmarked ewes were observed without lambs between 28 July and 5 August 2004, resulting in a lower ratio than was expected for this period. While lamb mortality is typical in the first 2 weeks after birth (Shackleton et al. 1999), we believe the observed ratio for this period may be somewhat biased low due to sampling variation. This is supported by the higher ratios observed after 8 August when

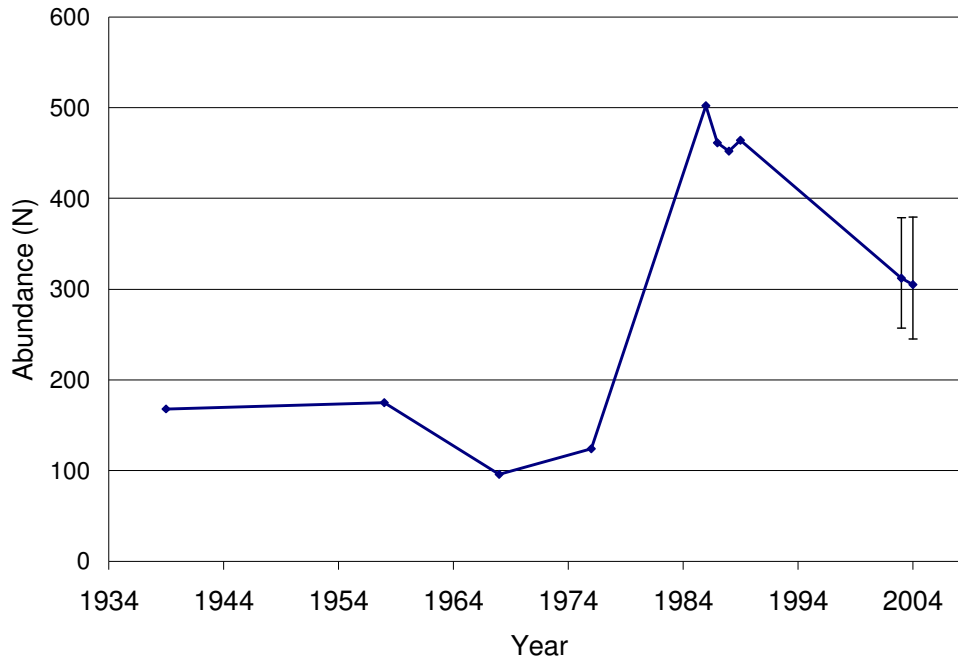


Figure 10. Total bighorn sheep population abundance estimates for the West-side herd of Rocky Mountain National Park, Colorado, 1939 – 2004. Log normal confidence intervals (95%) are included for the 2003 and 2004 estimates.

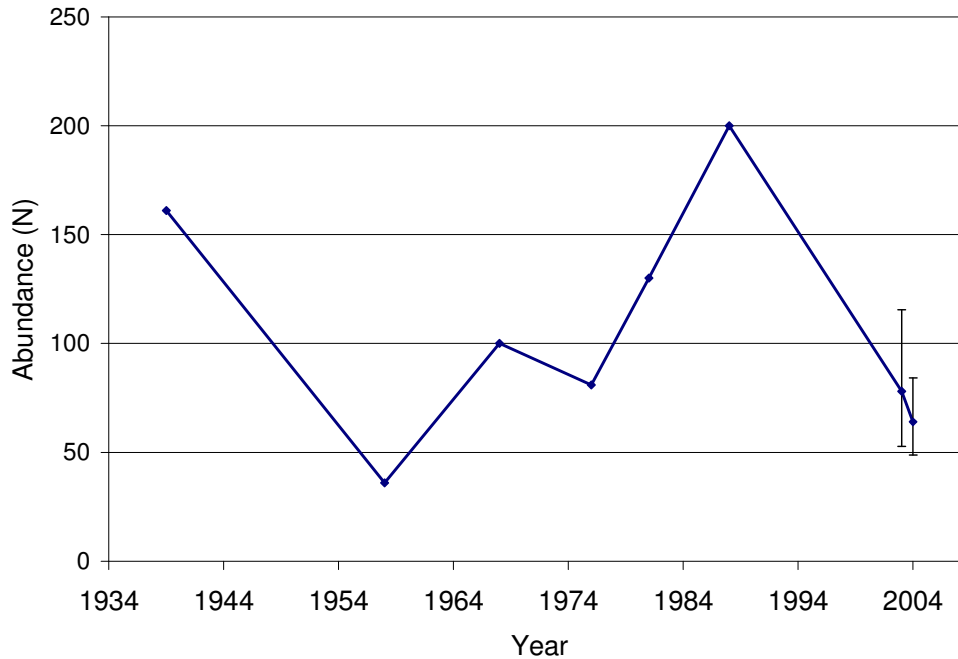


Figure 11. Total bighorn sheep population abundance estimates for the East-side herd of Rocky Mountain National Park, Colorado, 1939 – 2004. Log normal confidence intervals (95%) are included for the 2003 and 2004 estimates.

the lambing season had already been completed. The 2004 overall lamb ratio of 0.55 was similar to previous mean ratios of 0.55 for RMNP (Goodson 1978) and 0.57 for the West-side herd (Goodson and Stevens 1991), but confidence intervals indicate the 2003 ratio of 0.46 was lower than these previous mean ratios. Confidence intervals indicate no statistically significant difference between lamb ratios of 2003 and 2004.

Ram ratios were highly variable, with the largest ratios observed in early summer (Figure 5). The high levels of variation may be a result of ram movements to summer ranges (both inside and outside the study area) as ewes remained in habitat more suitable to lambing. The overall ram:ewe ratios for 2003 (0.53) and 2004 (0.42) are much smaller than the 1:1 ratios assumed in previous estimates, but these studies lacked strong evidence for such assumptions (Goodson 1978, Goodson and Stevens 1991). If rams are occupying ranges outside the 2 study sites, the current ratios may be biased low. As a result, the population decline observed since the late-1980s may be somewhat exaggerated, but not to the extent that leads us to question whether or not a decline has in fact occurred. Rams are known to move greater distances than females, so it is likely that the range of rams extends to other areas. They may also move between the West-side and East-side herds, but we are unable to discern what (if any) effect these have had on observed ratios because our study focuses on the adult ewe population.

Disease and Mortality

In the first logistic regression, the December 2002 capture effect was found to be important because 2 of the 4 ewes caught during this month died. Similarly, BT was selected because 1 of the 2 ewes that tested positive for it died in late-May. While these effects explained some of the variation in survival, the BRSV*PI-3**P. trehalosi* interaction effect deserves the most focus because it applies more broadly to the entire population. Confidence intervals for this interaction from the minimum AIC_c model did not include zero, providing some evidence of a negative effect on survival. When taking model selection uncertainty into account, the model-averaged confidence interval did marginally include zero. However, the interaction of these pathogens was overwhelmingly selected over the pathogens acting alone. Taking all evidence into account, we believe that there may be such an interaction occurring. This could be indicative of the pneumonia-complex often associated with massive sheep die-offs.

There was considerable model selection uncertainty in the second logistic regression, but lungworm and lungworm interactions negatively affected survival point estimates across all models. There is some additional evidence of a negative BRSV*PI-3**P. trehalosi* interaction effect, but the magnitude of this effect cannot be compared to that of the previous because this sample is a subset of the first. The NS group effect is an artifact of a limited sample size containing only 1 of 6 NS mortalities and is not strong evidence of higher survival in NS sheep of the RMNP population. A limited sample size also caused imprecise parameter estimates, with all confidence intervals for model-averaged parameter estimates marginally covering zero. Thus, there may have been no real effects, but the vast majority of each interval was negative. The weight of evidence from this analysis does suggest lungworm and its interactions with other pathogens as a possible cause of ewe mortality. In the absence of other pathogens, lungworm is believed

relatively harmless to bighorn (Miller et al. 2000). If such interaction effects are occurring, this analysis further supports the pneumonia-complex hypothesis.

While the 2 disease analyses offer some insight into current diseases threatening the ewe population, there are several important limitations. A significant titer concentration for BRSV, PI-3, BVD, or BT does not necessarily mean infection. The animal may not be (or may never have been) afflicted, but has been exposed to the virus in the past and carries antibodies. If this is the case, then the effects found in these analyses may be spurious. In addition to poor precision, the particularly small sample size of the second analysis also increases the chances of finding spurious effects. Regardless, numerous pathogens are apparently present in and remain a possible threat to the population.

We had anticipated a lower survival for ewes captured immediately prior to the March 2003 blizzard, but found no evidence of support. An additional variable that may have played a role in mortalities of marked ewes was the helicopter capture itself. However, this effect cannot be tested because all ewes were captured using this method. While helicopter capture is considered the safest method for most small ungulates, capture-related mortalities do occur (Barrett et al. 1982, White and Bartmann 1994). We have no conclusive evidence, but suspect 2 East-side mortalities may have been capture-related. One was an older, weaker ewe caught in December 2002. The other ewe was netted in extremely steep terrain and rolled downhill 30 to 40 feet moments after release. She recovered her footing and walked away, but injuries were likely. Because no samples were collected from this ewe, we did not include her in the analyses.

Although adult ewe survival was similar for the West-side herd from May 2003 to May 2005 and the East-side herd from May 2003 to May 2004, survival of the East-side herd appears to have declined to very low levels from May 2004 to May 2005. The small sample size for the East-side herd resulted in survival estimates with rather poor precision. However, because virtually all of the models with any support included an East-side effect, the model selection results provide strong evidence of lower survival for this herd, particularly for 2004 – 2005. We found some evidence of a negative age effect on survival for all ewe groups, and Stewart (1980) also observed such an effect. Although data on age-specific survival of bighorn sheep are limited, Jorgenson et al. (1997) found average yearling and adult ewe (2 – 7 years) survival in a healthy population to be 0.829 (SE = 0.026) and 0.945 (SE = 0.009), respectively. For the same population, they estimated survival for ewes >8 years old as 0.850 (SE = 0.022).

Population Rate of Change

The combination of relatively low adult ewe and lamb survival for the duration of this study resulted in no estimates of $\bar{\lambda} \geq 1$ for any of the ewe groups. The large sampling variances associated with the parameter estimates of both years are reflected in the large SE estimates for $\bar{\lambda}$, and confidence intervals for all $\bar{\lambda}$ include 1.0 except for the East-side group 2004 – 2005. Despite this, if reproductive and survivorship conditions remain constant, there is at most a 20% chance of the NS and CD remaining stable or increasing based on parameter estimates for 2004 – 2005, and a 7% chance of this based on parameter estimates from 2003 – 2004. Similarly, there is a 99% chance of the East-side herd going extinct based on estimates for 2004 – 2005, and an 82% chance of this

based on estimates from 2003 – 2004. If sampling variances were ignored and parameter estimates for 2004 – 2005 were used in a deterministic Leslie matrix model, the current East-side population is projected to be extinct (<1 individual in each age class) within 10 years, and the West-side herd is projected to be extinct within 150 years. Increases in adult ewe survival or lamb survival are needed to slow the current rate of decline, and these must be substantial for a stable or increasing RMNP population. Based on 2004 – 2005 parameter estimates for the East-side herd, an increase in yearling survival would also heavily contribute to a reversal of λ .

Using the deterministic model and estimates from 2003 – 2004, increases in survival rates for all age classes of 9.2% for the East-side herd and 8.0% for the West-side herd predict population stability. With estimates from 2004 – 2005, increases of 100.0% and 4.4% predict stability for the East-side and West-side herds, respectively. Any percent increases above these values predict population growth. If yearling and adult survival do not increase, 2003 – 2004 lamb survival would need to increase 123% in the East-side herd and 128% in the West-side herd for stability. For 2004 – 2005 estimates, no increase in lamb survival is capable of achieving stability for the East-side herd without an increase in adult survival. Without increases in yearling and adult survival, 2004 – 2005 West-side lamb survival would need to increase 58% for stability.

Given the nature of our population model, some important limitations must be addressed. Firstly, our projection models assume reproductive and survivorship conditions during the 2 years of this study will remain constant. This is an unlikely event given the temporal variability observed in these parameters during this and previous studies. Temporal variations are particularly large between years prior to, during, and following pneumonia-related die-offs (Jorgenson et al. 1997, Monello et al. 2001). However, if these parameters do remain constant or decline further, the persistence of the herds, particularly the East-side herd, is in doubt. Another limitation of the model was our lack of data on age-specific fecundity, yearling survival, and the proportion of births that are female. We modeled these based on previous studies and the data available, but these assumptions cost the models a degree of realism. Although we assumed fecundity rates were constant for all ewes >2 years old, we suspect fecundity rates are actually lower for ewes 2 – 3 years of age. Such an overestimation of f_{2-3} would result in overestimation of λ . Lastly, because our study design only allowed the estimation of *minimum* fecundity, it is likely that actual fecundity is higher. However, fecundity was not found to be a particularly sensitive parameter, and when fecundity rates were assumed 1 lamb per ewe, the herds were still projected to decline to extinction based on our estimates.

It is possible that, by chance alone, the 2 years of this study were poor years for lamb, yearling, and adult survival. However, given the tendency of post-die-off populations to exhibit low recruitment for at least 5 years (Monello et al. 2001), we believe the RMNP population may still be exhibiting residual effects of the suspected die-off. If the current survival and recruitment estimates are the result of such residual effects, the population would be expected to eventually recover. Studies are currently underway in Wyoming, Utah, Colorado, Nevada, Idaho, and Montana to examine whether low lamb recruitment may be related to selenium deficiencies of plants in high-elevation granitic soils due to nitrate pollution (Mionczynski 2003). This ongoing research is unpublished to date, but includes sheep populations adjacent to RMNP in the

Big Thompson Canyon extending south to the St. Vrain River. Little is currently known of the nutritional quality of sheep forage in the Park, but if nutritional deficiencies are the cause of low lamb recruitment, these conditions would be expected to continue.

CONCLUSIONS

Population estimates imply that a Park-wide decline in sheep numbers has occurred between the late-1980s and the suspected die-off of the mid-1990s. Given the population's history of massive die-offs over the last century, the combined inferences from this study suggest that the decline was most likely pneumonia-related. The decline may have been more severe in the East-side herd due to the removal of sheep for transplantation immediately prior to the suspected die-off. However, the Park-wide decline was either not as severe as other documented bighorn die-offs, or the population has somewhat recovered in terms of abundance in recent years.

Monello et al. (2001) found bighorn populations to be particularly vulnerable to pneumonia outbreaks through density-dependent forces and proximities to domestic sheep. The suspected die-off of the mid-1990s occurred after the RMNP population had reached its highest observed numbers since the establishment of the Park in 1915. A number of factors could be causing the carrying-capacity of RMNP to be considerably lower than it had been in 1915 and prior to European settlement in the area. Development, particularly in the Estes Valley and around Grand Lake, has restricted the herds to mostly high-elevation ranges year-round. In addition to potentially increasing intra-species competition, this restricted range is likely to increase competition with the rapidly growing elk population now occupying much of the sheep habitat within RMNP. In response to increasing population densities, bighorn may be more likely to move greater distances and increase the potential for contact with domestic sheep serving as reservoir hosts. As sheep habitat became restricted due to development in the early to mid-1900s, transmission of disease from contact with domestic sheep was believed the cause of at least 2 outbreaks that drastically reduced the population (Packard 1946, Contor 1958). Grazing of domestic sheep along Park borders is no longer allowed, but it is not unreasonable to speculate that contact between dispersing bighorn and domestic sheep is still possible. Furthermore, the restricted range in RMNP is likely to limit an increasing population from permanently expanding into new ranges, resulting in high densities that may facilitate the rapid spread of pneumonia between sheep.

Stress and malnutrition due to density-dependent forces are probably the most important causes of outbreaks, and there is ample evidence suggesting this may be the case for RMNP bighorn. Other causes of stress for bighorn may be the increasing numbers of tourists visiting the Park, currently at over 3 million per year. This is of highest concern at the East-side and West-side mineral-licks that are easily accessible to visitors at Sheep Lakes and the Crater, respectively. Being restricted to high-elevation winter ranges may induce further stress to RMNP sheep during particularly harsh winters. Combined, these factors can reduce immunity and make the population particularly susceptible to pneumonia outbreaks. In our study, all major pathogens associated with bronchopneumonia were found to be present in the population, suggesting continued exposure of the herds to these pathogens. It is therefore logical to conclude that if the

RMNP bighorn population begins to increase, it will remain at high-risk for future pneumonia epidemics. Identifying which agents play the largest role in the pneumonia-complex of RMNP is essential if managers wish to prevent future outbreaks.

At present, low reproductive and survival rates are of highest concern, and it is essential for the driving forces behind these rates to become better understood. Our estimates indicate that the herds may not be recruiting at levels needed for population growth, and we suggest continued monitoring of lamb and yearling ratios to detect any changes in population dynamics. With its low abundance, the persistence of the East-side herd is most in question. This herd has been maintained by transplanted individuals in the past (Stevens and Hanson 1986), and it is possible that the East-side is no longer capable of sustaining a natural population without management. Although the 2 years of data from this study are not enough to predict whether or not the herds are capable of recovering to previous levels, they provide RMNP officials the tools necessary to make the most informed decisions for future monitoring and management of this fragile species. The continuation of this and related work is critical to achieving this goal.

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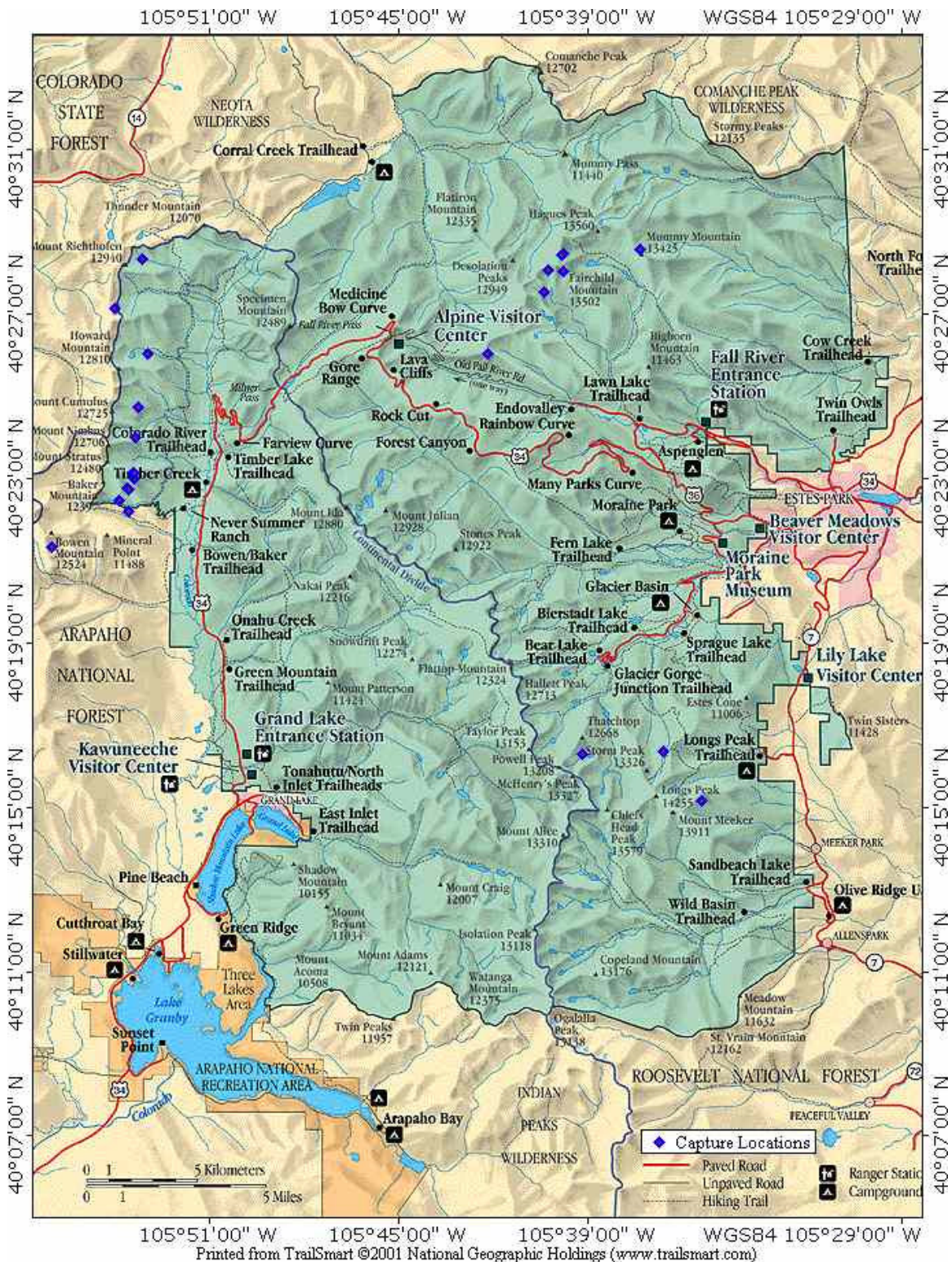
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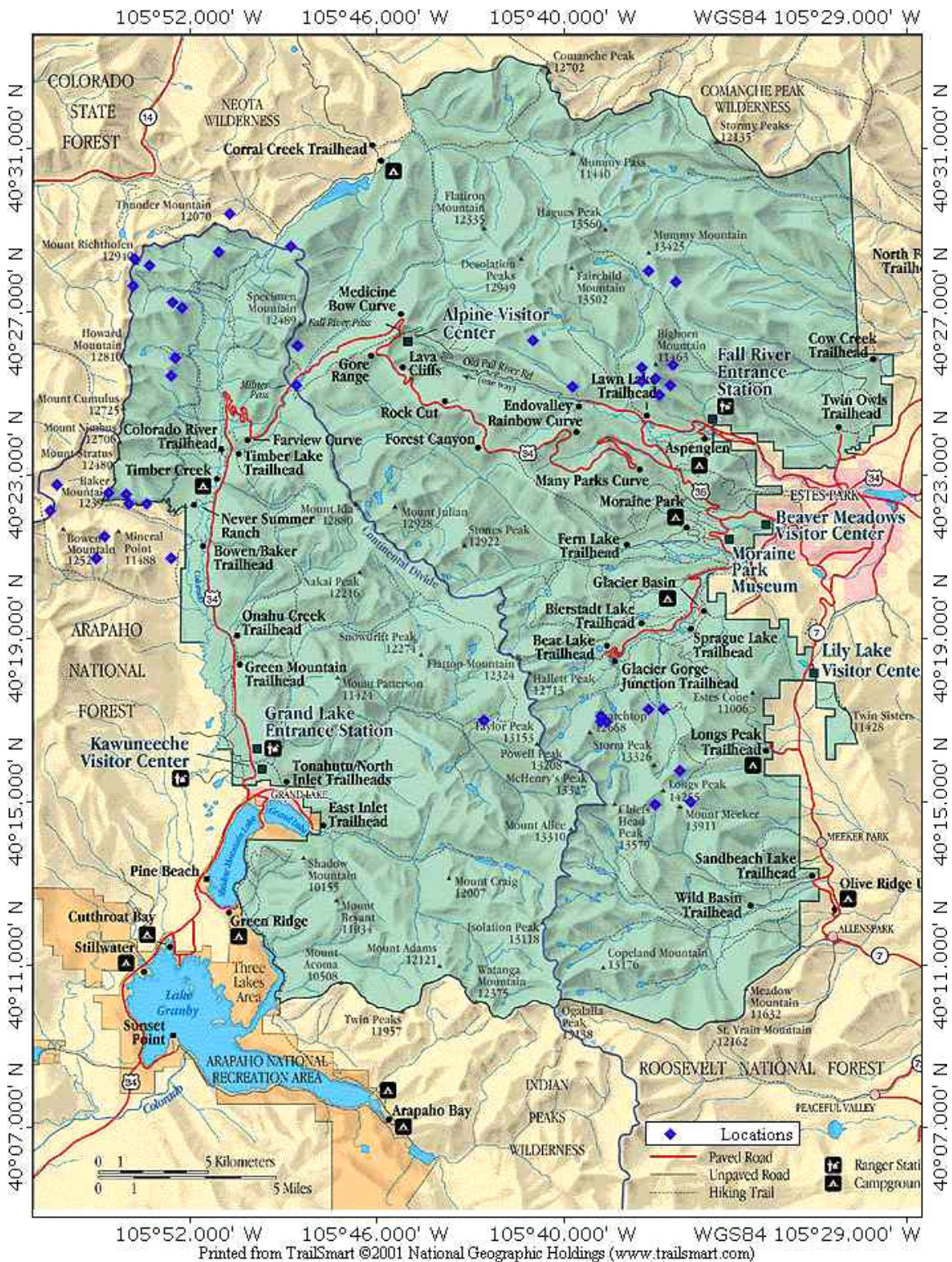
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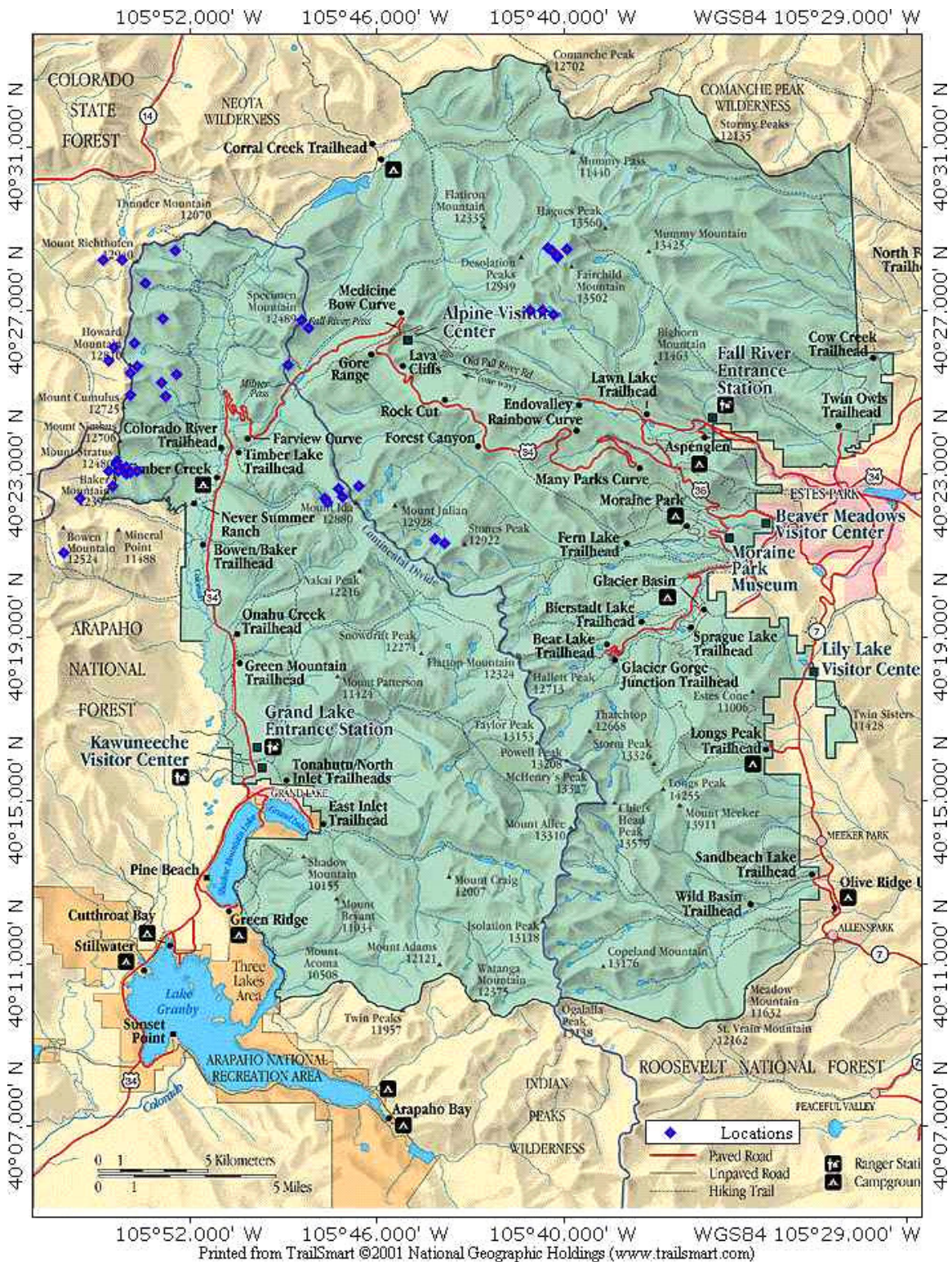
Appendix A. Bighorn sheep adult ewe helicopter capture locations 11 December 2002 to 2 April 2003 in mid- to late-winter ranges of Rocky Mountain National Park, Colo.



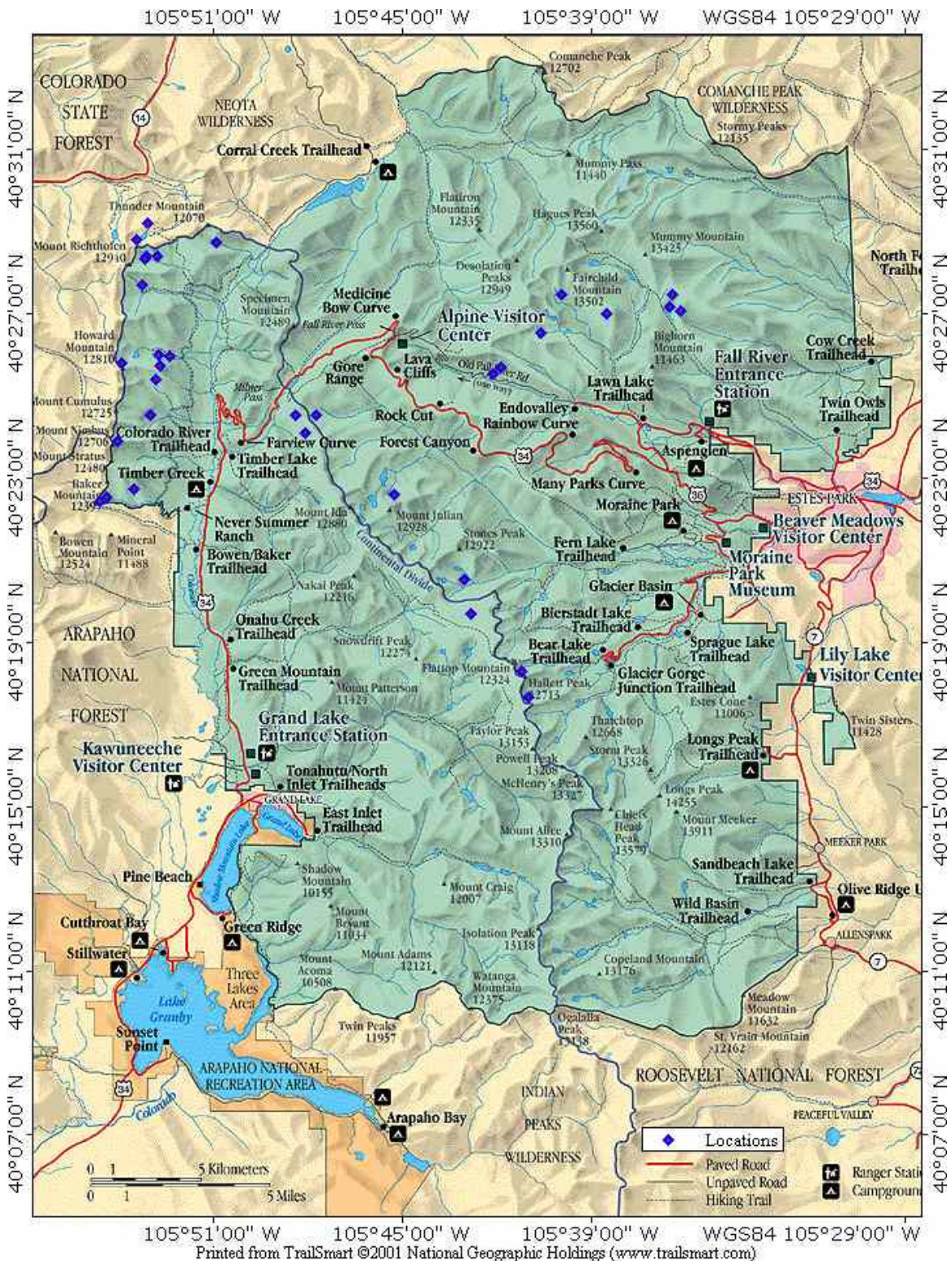
Appendix B. Aerial radio-locations of marked bighorn sheep adult ewes in Rocky Mountain National Park, Colo., 23 May 2003.



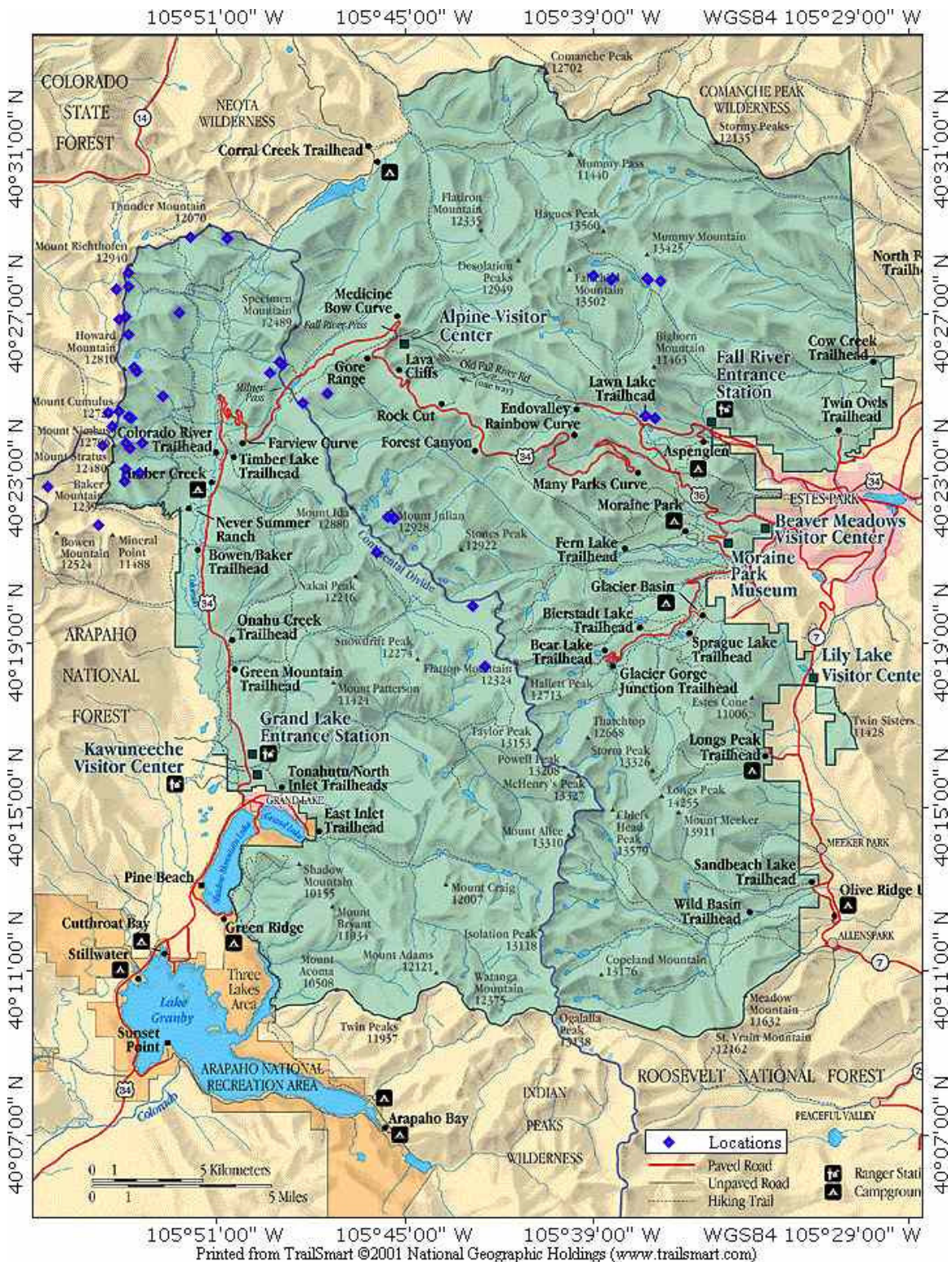
Appendix C. Aerial radio-locations of marked bighorn sheep adult ewes in Rocky Mountain National Park, Colo., 16 July 2003.



Appendix D. Aerial radio-locations of marked bighorn sheep adult ewes in Rocky Mountain National Park, Colo., 7 June 2004.



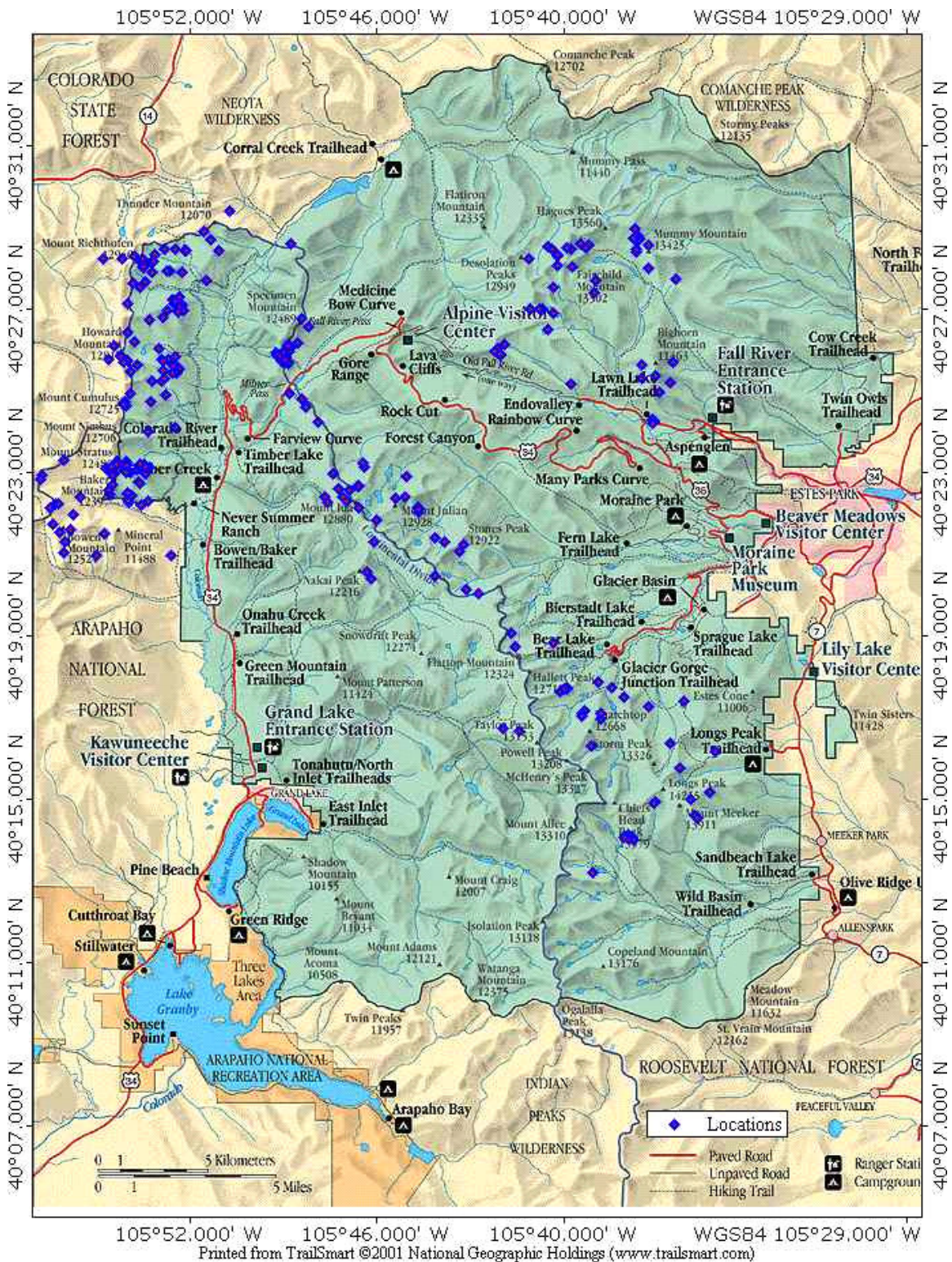
Appendix E. Aerial radio-locations of marked bighorn sheep adult ewes in Rocky Mountain National Park, Colo., 26 July 2004.



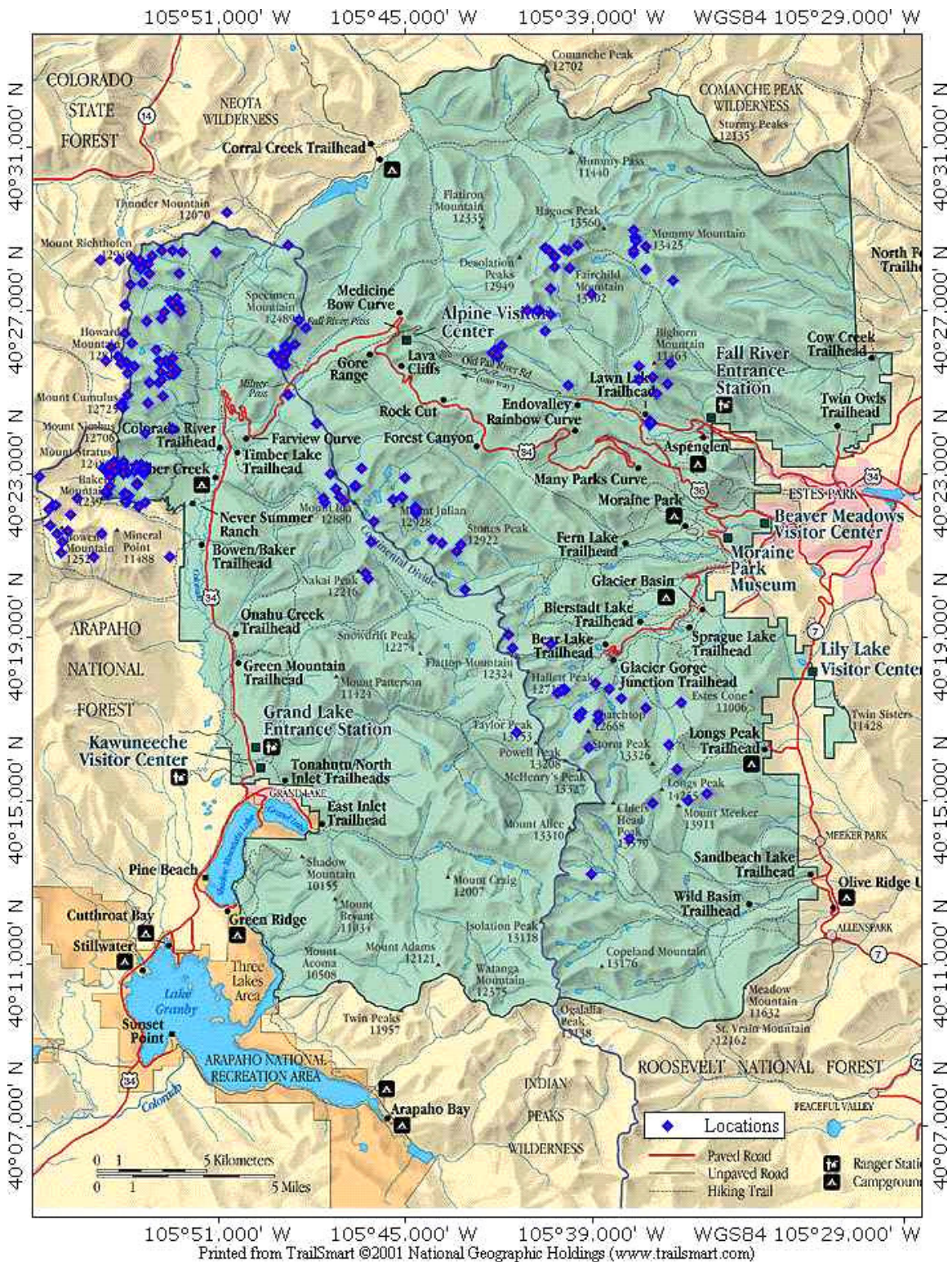
Appendix F. Locations of 22 marked bighorn sheep adult ewe mortalities in Rocky Mountain National Park, Colo., between 11 December 2002 and 16 May 2005. Locations are labeled with animal identification numbers.



Appendix G. All bighorn sheep observations from capture, overflights, and ground resighting surveys in Rocky Mountain National Park, Colo., 11 December 2002 to 15 September 2003.



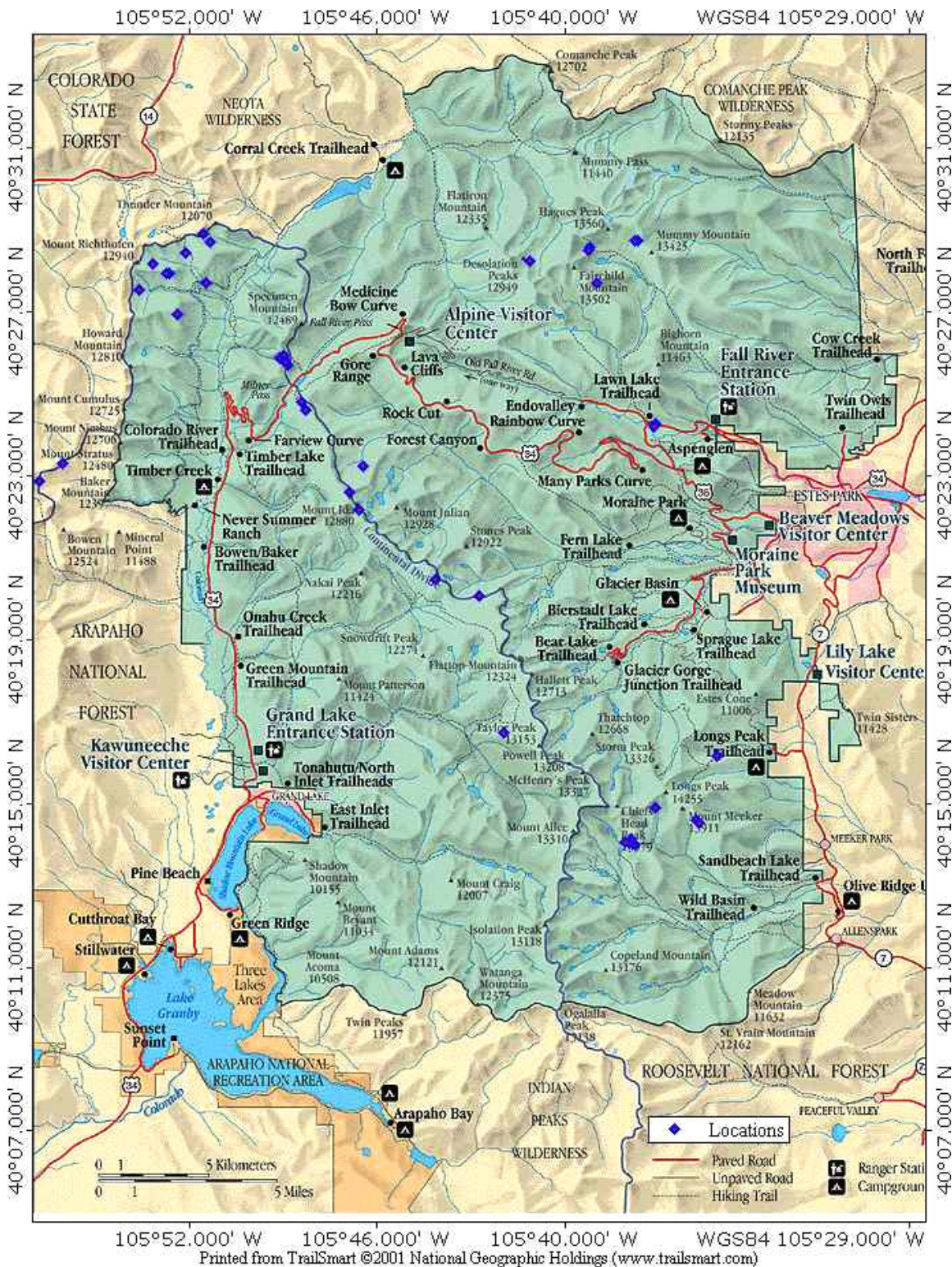
Appendix I. All bighorn sheep ewe-juvenile band observations from capture, overflights, and ground resighting surveys in Rocky Mountain National Park, Colo., 11 December 2002 to 15 September 2003.



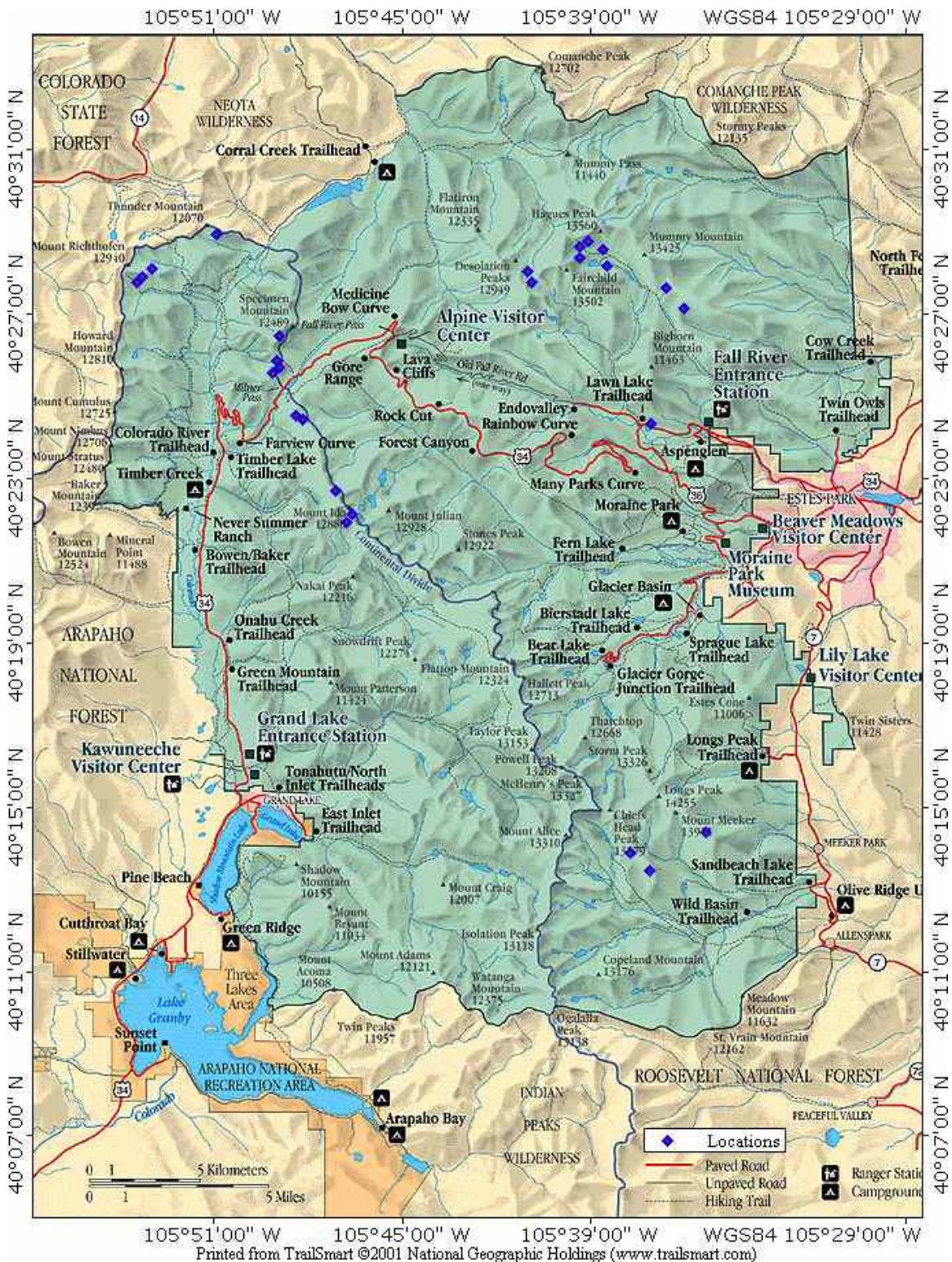
Appendix J. All bighorn sheep ewe-juvenile band observations from overflights and ground resighting surveys in Rocky Mountain National Park, Colo., 27 May to 11 September 2004.



Appendix K. All bighorn sheep ram band observations from ground resighting surveys in Rocky Mountain National Park, Colo., 1 June to 15 September 2003.

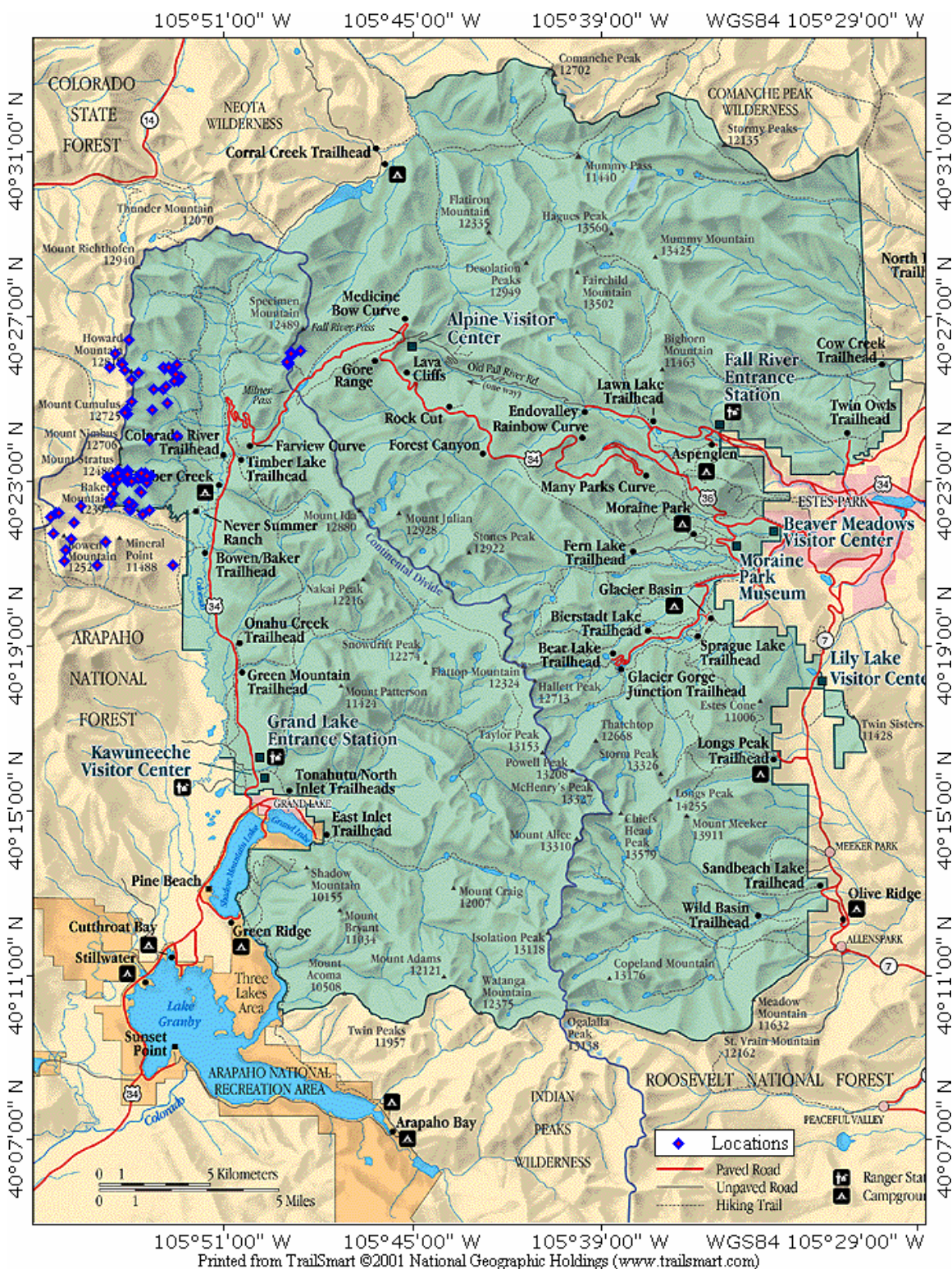


Appendix L. All bighorn sheep ram band observations from ground resighting surveys in Rocky Mountain National Park, Colo., 2 June to 23 August 2004.

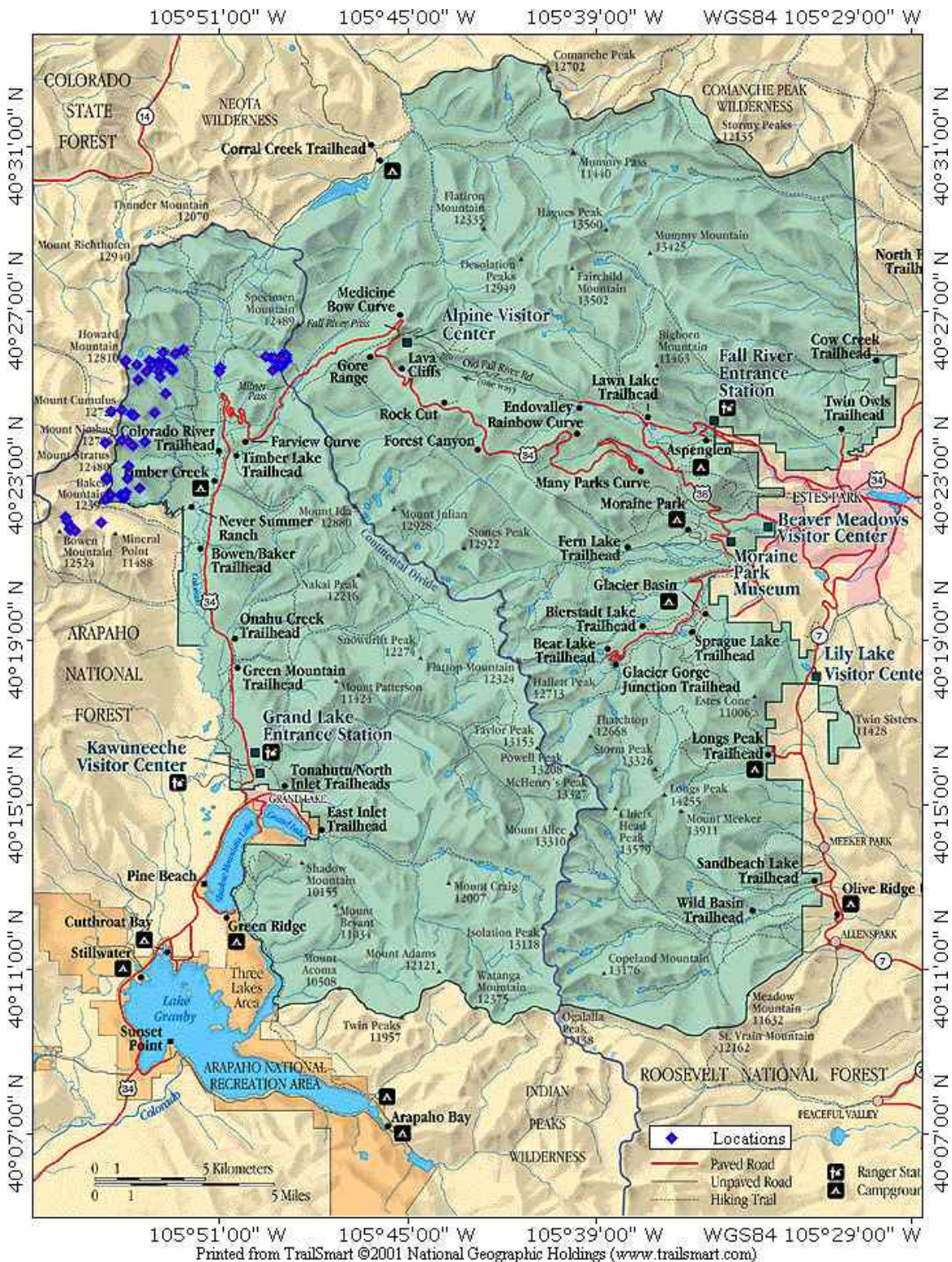


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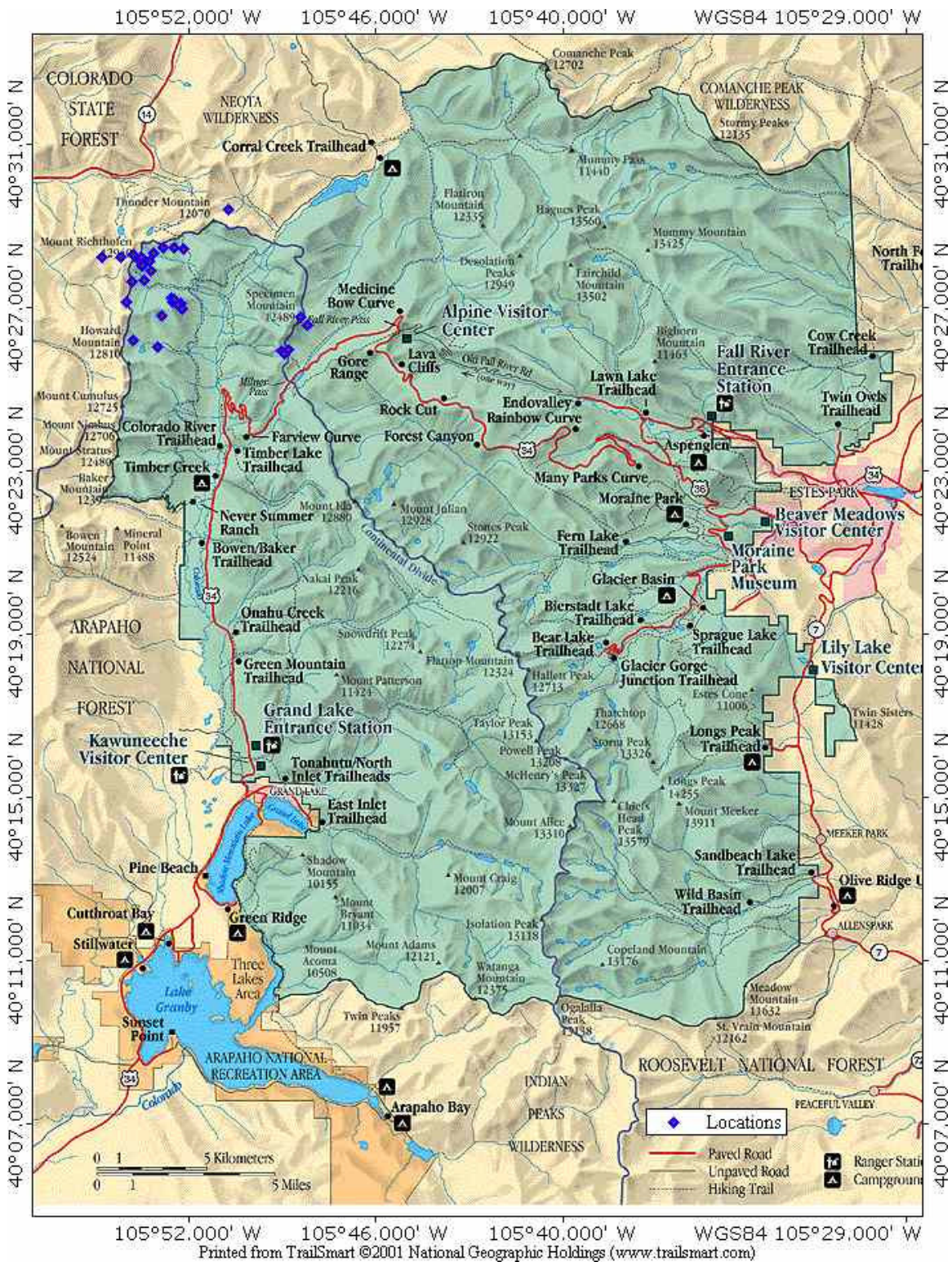
Appendix M. All South Never Summer marked bighorn sheep adult ewe locations from capture, overflights, and ground resighting surveys in Rocky Mountain National Park, Colo., 13 March to 15 September 2003.



Appendix N. All South Never Summer marked bighorn sheep adult ewe locations from overflights and ground resighting surveys in Rocky Mountain National Park, Colo., 2 June to 9 September 2004.



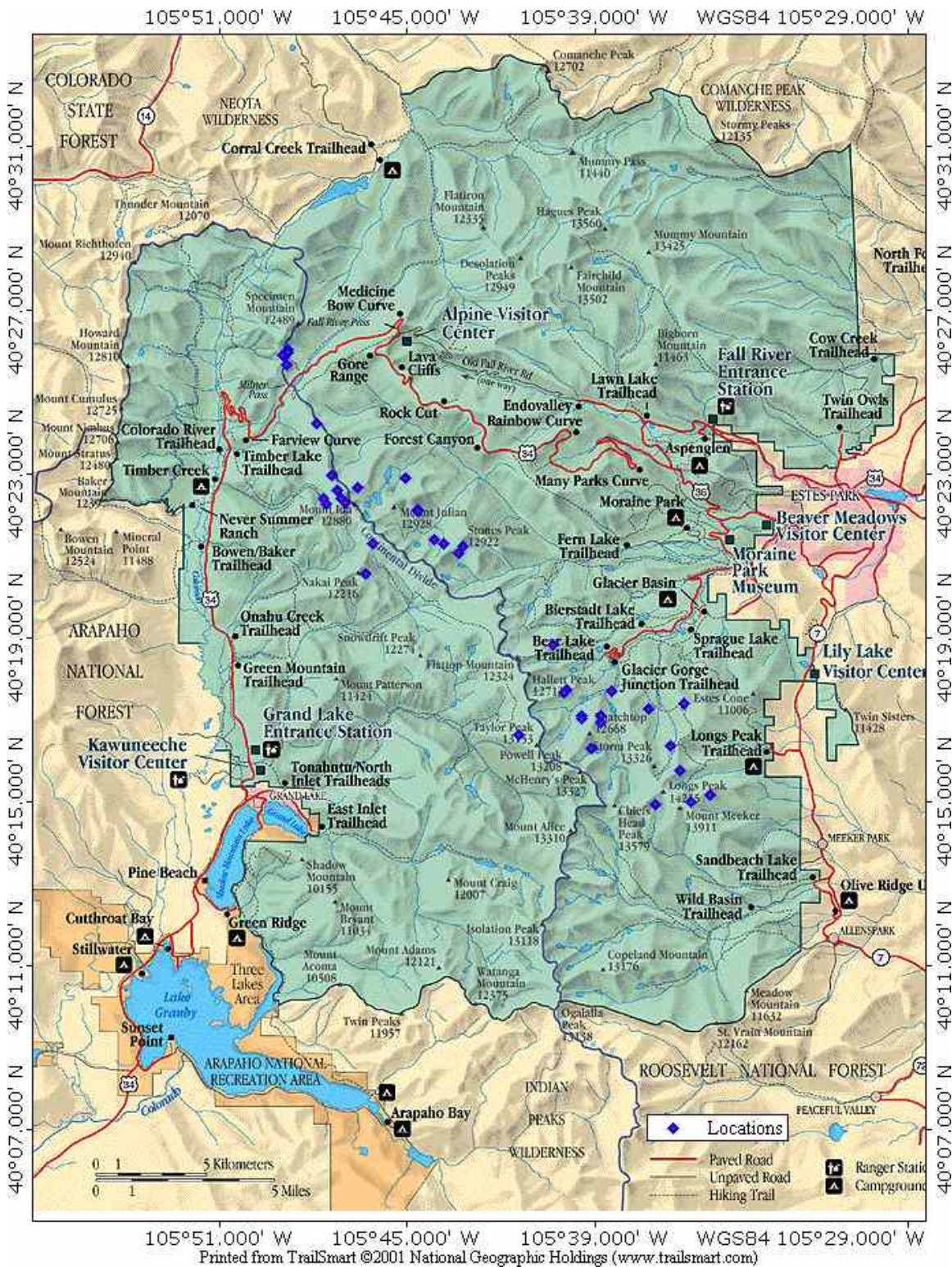
Appendix O. All North Never Summer marked bighorn sheep adult ewe locations from capture, overflights, and ground resighting surveys in Rocky Mountain National Park, Colo., 15 March to 4 September 2003.



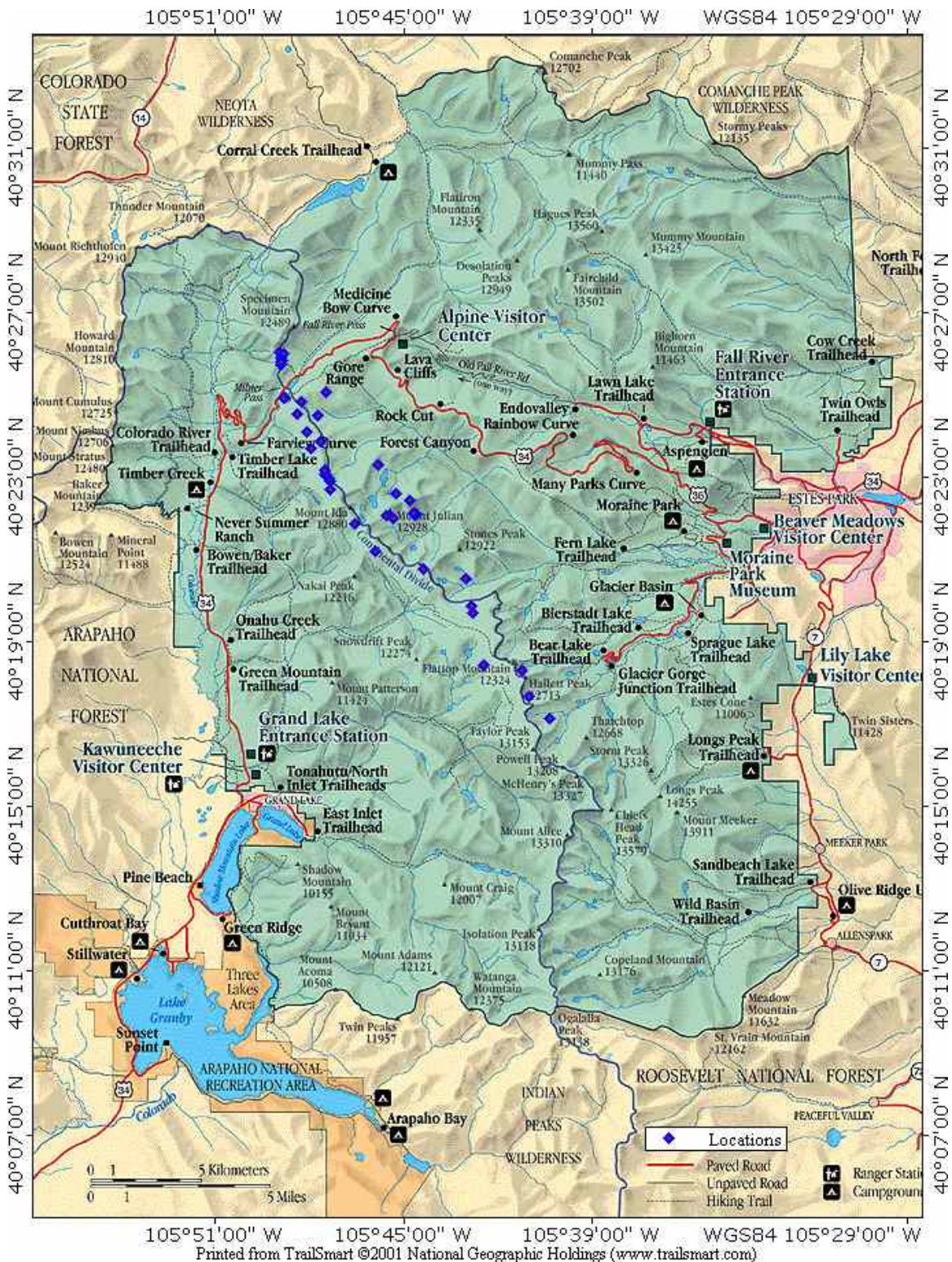
Appendix P. All North Never Summer marked bighorn sheep adult ewe locations from overflights and ground resighting surveys in Rocky Mountain National Park, Colo., 7 June to 6 September 2004.



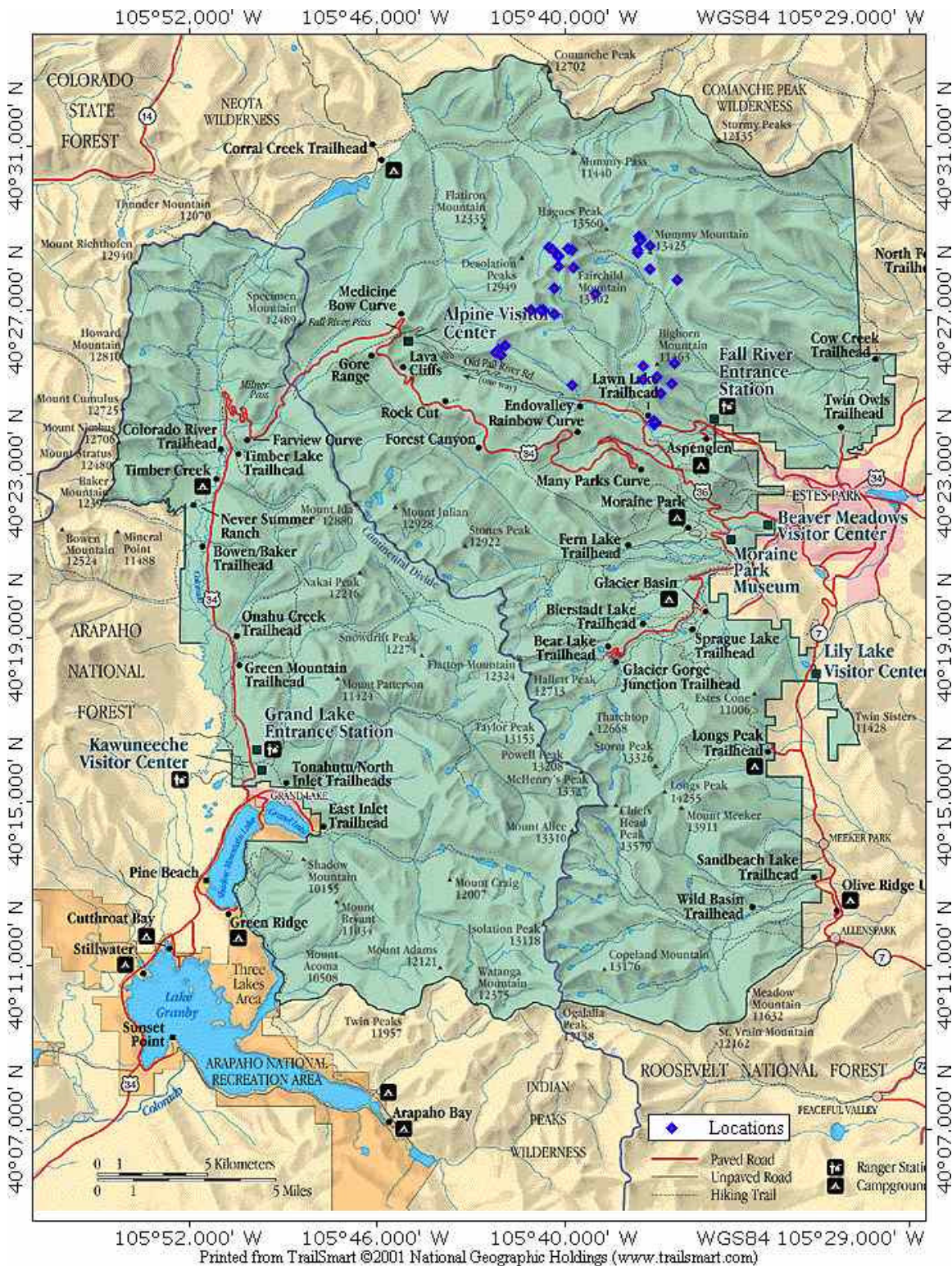
Appendix Q. All Continental Divide marked bighorn sheep adult ewe locations from capture, overflights, and ground resighting surveys in Rocky Mountain National Park, Colo., 11 December 2002 to 8 September 2003.



Appendix R. All Continental Divide marked bighorn sheep adult ewe locations from overflights and ground resighting surveys in Rocky Mountain National Park, Colo., 7 June to 11 September 2004.

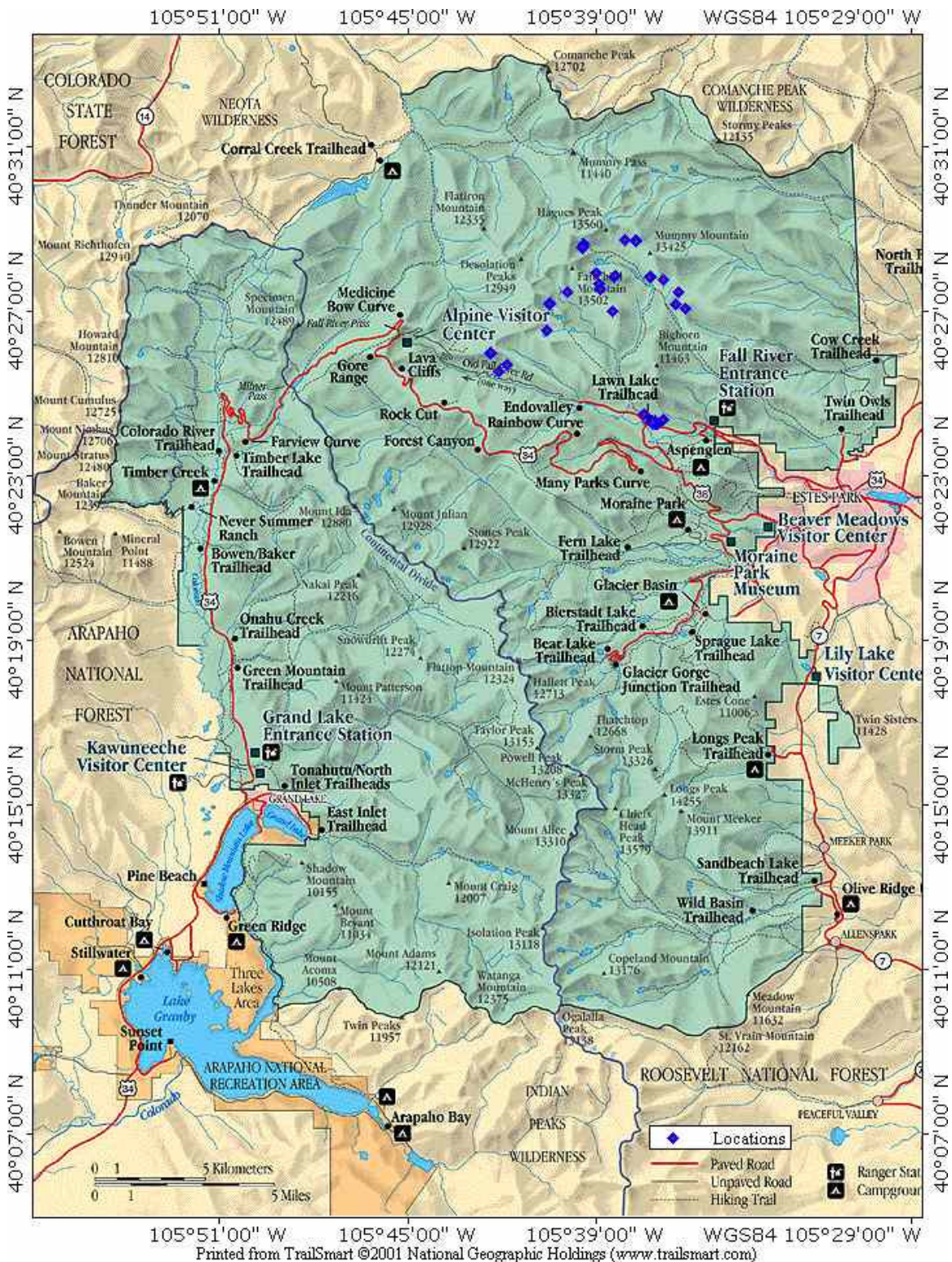


Appendix S. All East-side marked bighorn sheep adult ewe locations from capture, overflights, and ground resighting surveys in Rocky Mountain National Park, Colo., 11 December 2002 to 12 September 2003.

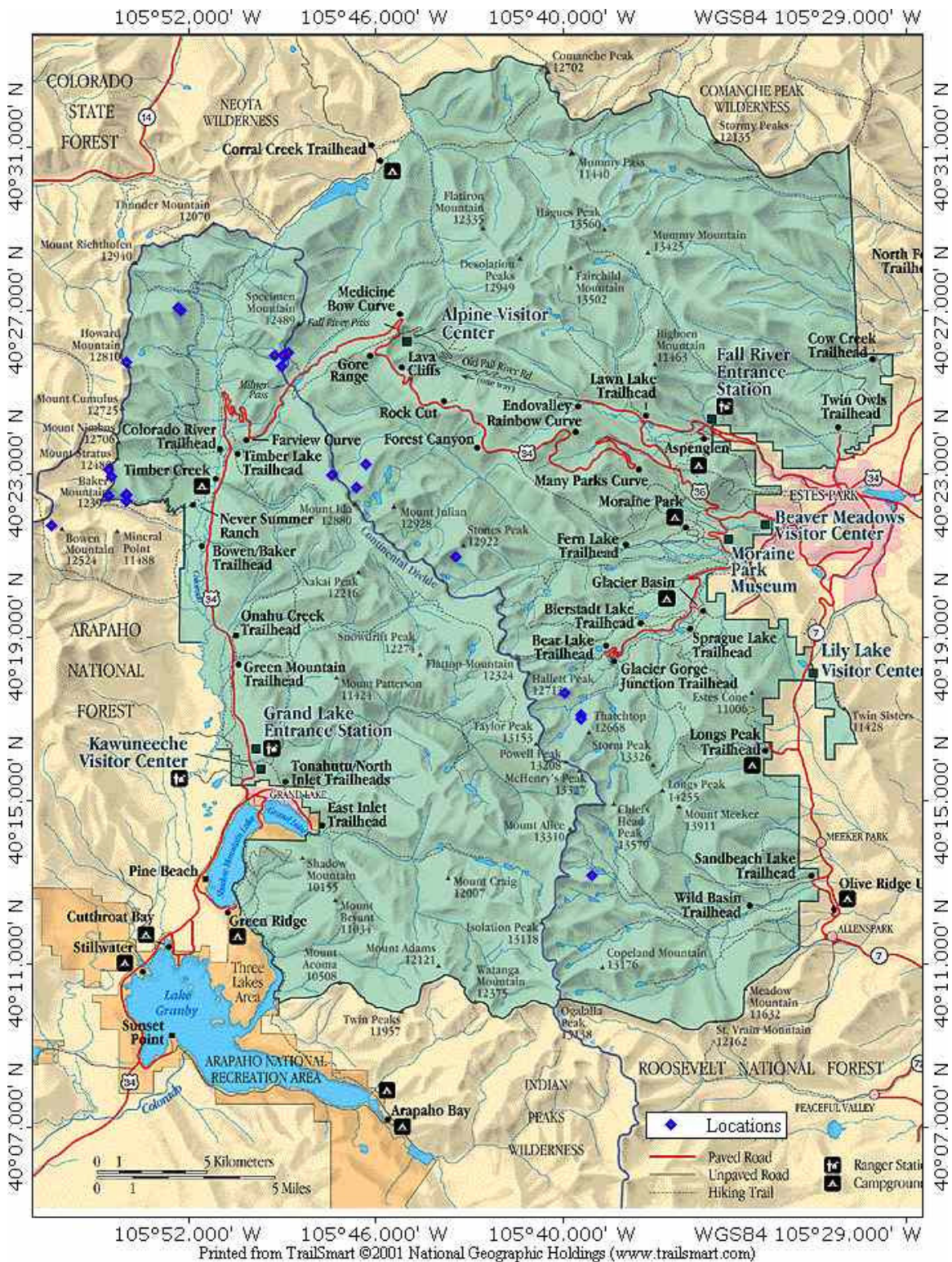


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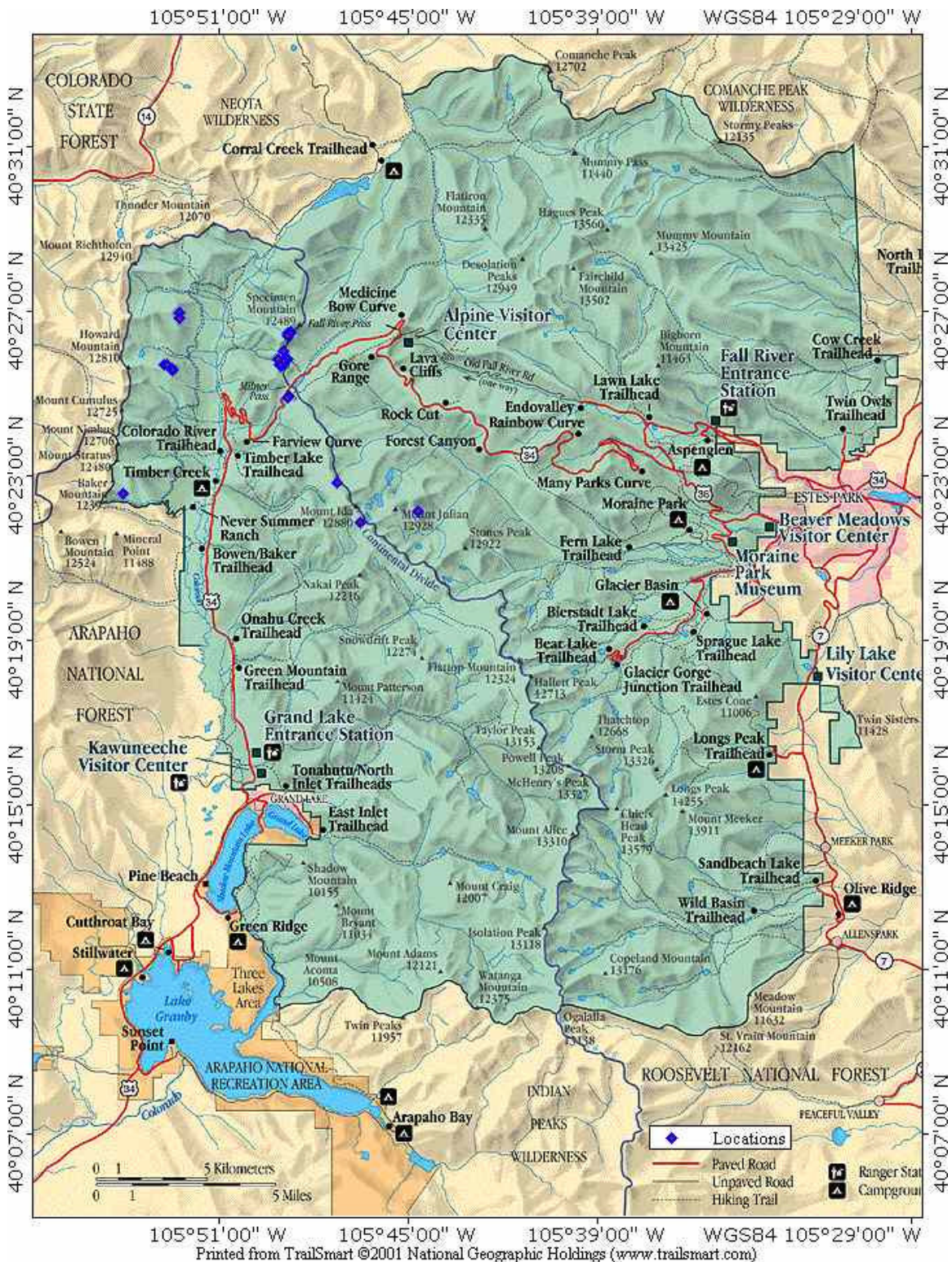
Appendix T. All East-side marked bighorn sheep adult ewe locations from overflights and ground resighting surveys in Rocky Mountain National Park, Colo., 7 June to 7 September 2004.



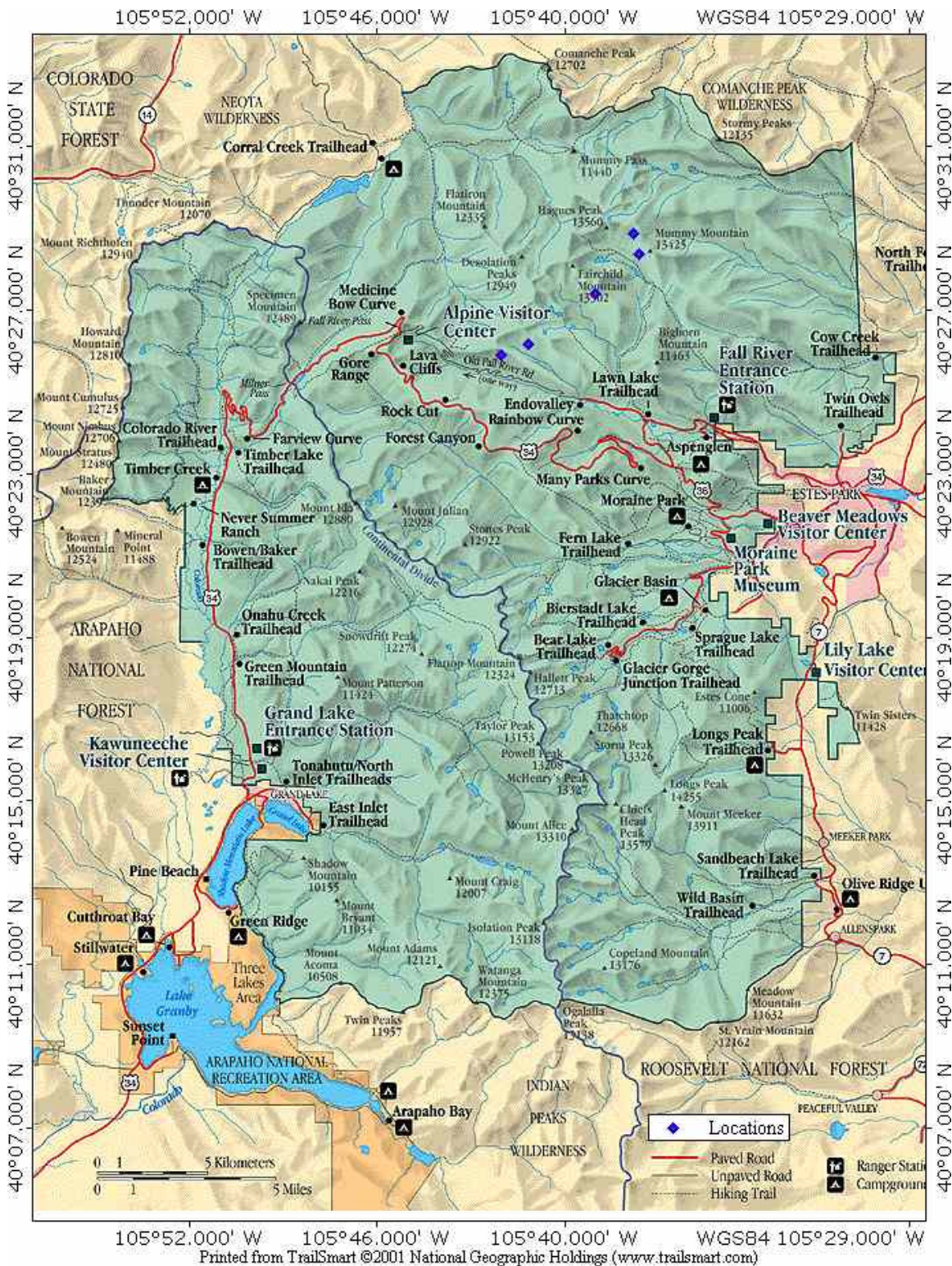
Appendix U. West-side bighorn sheep lambing grounds observed in Rocky Mountain National Park, Colo., 31 May to 13 July 2003.



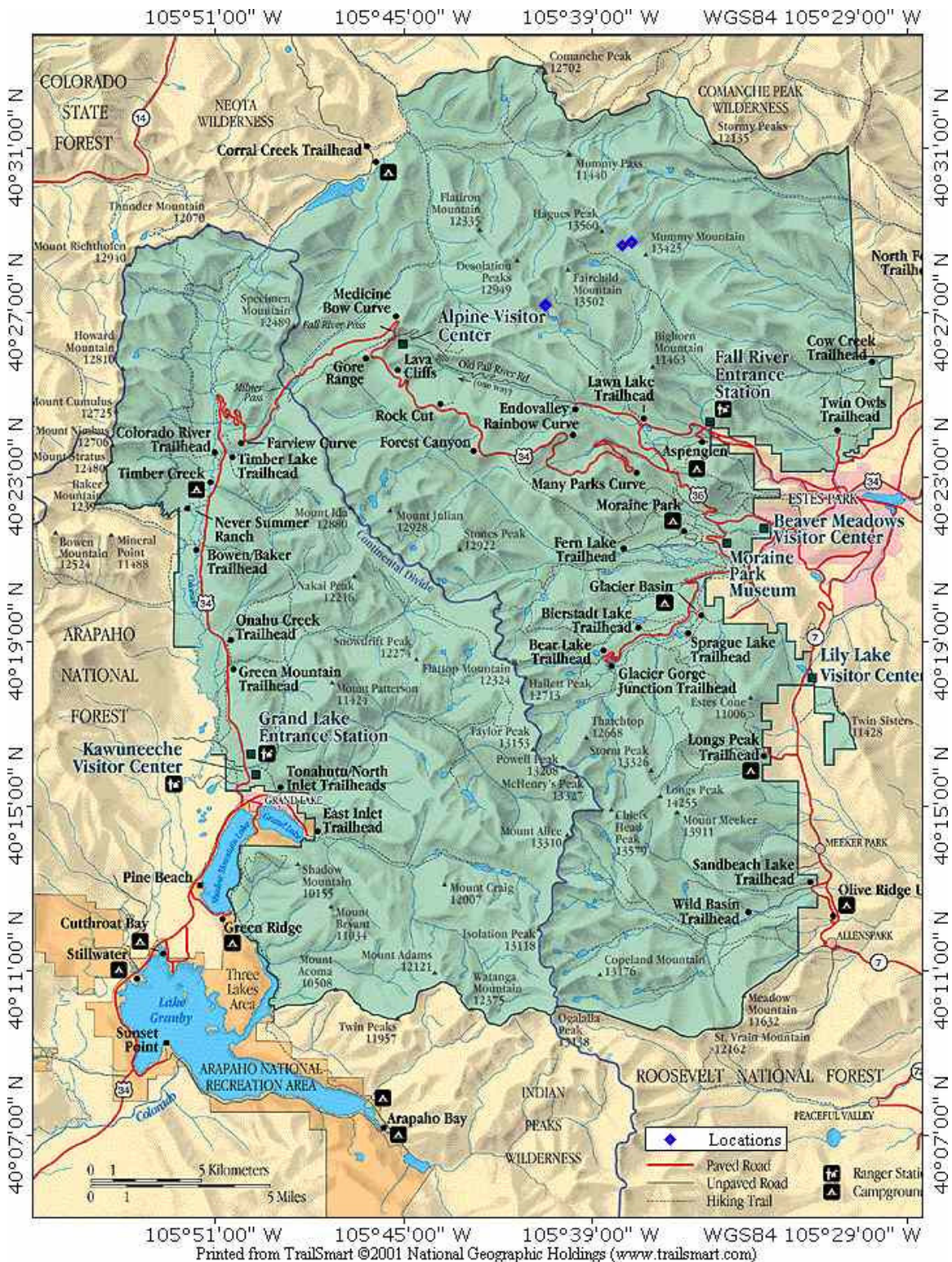
Appendix V. West-side bighorn sheep lambing grounds observed in Rocky Mountain National Park, Colo., 2 June to 19 July 2004.



Appendix W. East-side bighorn sheep lambing grounds observed in Rocky Mountain National Park, Colo., 5 June to 14 July 2003.



Appendix X. East-side bighorn sheep lambing grounds observed in Rocky Mountain National Park, Colo., 27 May to 12 July 2004.



Appendix Y. Sample analyses for various pathogens of marked bighorn sheep adult ewes collected 11 December 2002 to 15 March 2003 in 3 ranges [Never Summer (NS), Continental Divide (CD), and East-side (ES)] of Rocky Mountain National Park, Colo. Pathogens include chlamydia, infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), bovine respiratory syncytial virus (BRSV), parainfluenza 3 (PI-3), lungworm, *Pasteurella haemolytica*, and *P. trehalosi*. Ewes with identification (ID) labels in bold died during the 2003 field season. Serological titer concentrations apply to chlamydia, IBR, BVD, BRSV, and PI-3. Concentrations in bold indicate exposure or infection. *Pasteurella* spp. biovariants [beta-hemolytic (BHB) or non-hemolytic (NHB)] in bold have the highest disease potential. The biovariant typing system used to identify *Pasteurella* spp. isolates was developed by Jaworski et al. (1998: 49–55).

Ewe ID	Date	Range	Age (years)	Chlamydia	IBR	BVD	BRSV	PI-3	Lungworm (larvae/g)	<i>P. haemolytica</i>		<i>P. trehalosi</i>	
										BHB	NHB	BHB	NHB
F6	12/11/02	CD	4 – 6	negative	(<1:2)	(<1:8)	(<1:2)	(<1:2)	174	9 ^{adH}	none	9 ^{adH}	none
H3	12/11/02	CD	4 – 6	N/A	(<1:2)	(<1:8)	(<1:2)	(<1:2)	1016	6 ^a	3 ^a	6 ^a	3 ^a
J1	12/11/02	ES	>6	negative	(<1:2)	(<1:8)	(<1:2)	(1:64)	N/A	6R	16	6R	16
P3	12/11/02	ES	4 – 6	negative	(<1:2)	(<1:8)	(<1:2)	(1:128)	3772	none	1 ^a	none	4
H7	3/13/03	CD	4 – 6	(1:16)	(<1:2)	(<1:8)	(1:16)	(1:256)	988	3 ^a	none	3 ^a	none
P6	3/13/03	CD	2 – 3	(1:8)	(<1:2)	(<1:8)	(1:8)	(<1:2)	50	8 ^B , 16 ^a	none	4 ^{CDS}	none
X3	3/13/03	CD	2 – 3	(1:16)	(<1:2)	(<1:8)	(<1:2)	(<1:2)	252	none	none	4 ^{CDS}	none
A4	3/13/03	NS	3 – 4	negative	(<1:2)	(<1:8)	(1:2)	(1:64)	958	6 ^a	none	6 ^a	none
C1	3/13/03	NS	>6	negative	(<1:2)	(<1:8)	(1:4)	(1:64)	1270	none	3 ^{abE}	none	3 ^{abE}
C3	3/13/03	NS	>6	negative	(<1:2)	(<1:8)	(<1:2)	(1:128)	350	9 ^H	none	9 ^H	none
F2	3/13/03	NS	3 – 4	(1:8)	(<1:2)	(<1:8)	(1:32)	(1:128)	1730	6 ^a	6 ^a	6 ^a	6 ^a
H5	3/13/03	NS	>6	negative	(<1:2)	(<1:8)	(1:32)	(1:128)	1870	6 ^a	none	6 ^a	none
J2	3/13/03	NS	3 – 4	(1:8)	(<1:2)	(<1:8)	(<1:2)	(1:8)	725	none	none	none	none
K2	3/13/03	NS	3 – 4	N/A	(<1:2)	(<1:8)	(1:16)	(1:128)	940	none	1, 7 ^X	none	2 ^B , 4 ^{CDS}
P4	3/13/03	NS	2 – 3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
X1	3/13/03	NS	3 – 4	(1:8)	(<1:2)	(<1:8)	(<1:2)	(1:32)	1236	none	none	none	2
N1	3/14/03	CD	2 – 3	(1:16)	(<1:2)	(<1:8)	(1:8)	(1:128)	1108	none	none	none	4 ^{CDS}
C2	3/15/03	ES	3 – 4	negative	(<1:2)	(<1:8)	(1:64)	(1:2)	416	6 ^a	16 ^{ae}	6 ^a	16 ^{ae}
C6	3/15/03	ES	4 – 6	(1:16)	(<1:2)	(<1:8)	(1:32)	(<1:2)	32	none	none	none	none
A2	3/15/03	NS	>6	negative	(<1:2)	(<1:8)	(1:16)	(1:32)	908	6 ^H	none	6 ^H	none
A7	3/15/03	NS	>6	(1:8)	(<1:2)	(<1:8)	(<1:2)	(<1:2)	396	none	none	none	none
C7	3/15/03	NS	3 – 4	negative	(<1:2)	(<1:8)	(<1:2)	(<1:2)	N/A	3 ^{abCDEs}	none	3 ^{abCDEs}	none
F4	3/15/03	NS	2 – 3	(1:8)	(<1:2)	(<1:8)	(1:16)	(1:512)	430	7	3 ^{abG}	7	3 ^{abG}
H1	3/15/03	NS	4 – 6	negative	(<1:2)	(<1:8)	(1:32)	(1:64)	N/A	7	3 ^{abE}	7	3 ^{abE}
J6	3/15/03	NS	>6	negative	(<1:2)	(<1:8)	(1:128)	(1:256)	2320	none	16 ^{ae}	none	2 ^B
K4	3/15/03	NS	2 – 3	negative	(<1:2)	(1:8)	(<1:2)	(<1:2)	N/A	7	none	none	2 ^B
N3	3/15/03	NS	2 – 3	negative	(<1:2)	(<1:8)	(<1:2)	(1:128)	185	none	none	none	none
N5	3/15/03	NS	4 – 6	negative	(<1:2)	(<1:8)	(<1:2)	(<1:2)	120	none	3 ^a , 11 ^a	none	none
N7	3/15/03	NS	4 – 6	negative	(<1:2)	(<1:8)	(1:2)	(1:64)	N/A	6 ^H	3 ^{ae}	2 ^{CDS}	none
X5	3/15/03	NS	3 – 4	negative	(<1:2)	(<1:8)	(1:16)	(<1:2)	385	3 ^{abCDEs} , 11 ^{ab}	none	none	2, 2 ^B
X7	3/15/03	NS	2 – 3	negative	(<1:2)	(<1:8)	(<1:2)	(<1:2)	N/A	7	3 ^{abE} , 3 ^{abCDE} , 3 ^{abCDEs}	none	none

Appendix Z. Sample analyses for various pathogens of marked bighorn sheep adult ewes collected 16 March 2003 to 2 April 2003 in 3 ranges [Never Summer (NS), Continental Divide (CD), and East-side (ES)] of Rocky Mountain National Park, Colo. Pathogens include chlamydia, infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), bovine respiratory syncytial virus (BRSV), parainfluenza 3 (PI-3), lungworm, *Pasteurella haemolytica*, and *P. trehalosi*. Ewes with identification (ID) labels in bold died during the 2003 field season. Serological titer concentrations apply to chlamydia, IBR, BVD, BRSV, and PI-3. Concentrations in bold indicate exposure or infection. *Pasteurella* spp. biovariants [beta-hemolytic (BHB) or non-hemolytic (NHB)] in bold have the highest disease potential. The biovariant typing system used to identify *Pasteurella* spp. isolates was developed by Jaworski et al. (1998: 49–55). Ewes J3 and X2 tested positive for exposure to or infection of blue tongue.

Ewe ID	Date	Range	Age (years)	Chlamydia	IBR	BVD	BRSV	PI-3	Lungworm (larvae/g)	<i>P. haemolytica</i>		<i>P. trehalosi</i>	
										BHB	NHB	BHB	NHB
A1	3/16/03	ES	2 – 3	(1:8)	(<1:2)	(<1:8)	(1:64)	(1:128)	395	6 ^{aR}	none	6 ^{aR}	none
A5	3/16/03	ES	>6	negative	(<1:2)	(1:32)	(1:32)	(1:32)	N/A	none	none	none	none
H4	3/16/03	ES	>6	(1:16)	(<1:2)	(<1:8)	(1:64)	(1:128)	240	6 ^a	none	6 ^a	none
J7	3/16/03	ES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
K1	3/16/03	ES	>6	(1:8)	(<1:2)	(1:8)	(1:32)	(1:128)	N/A	6 ^a	none	none	2 ^c , 2 ^{CDs} , 4 ^{BCDS}
P7	3/16/03	ES	4 – 6	negative	(<1:2)	(<1:8)	(1:32)	(1:64)	N/A	none	none	none	2, 2 ^{CDs}
C5	3/16/03	NS	2 – 3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J4	3/16/03	NS	3 – 4	(1:8)	(<1:2)	(<1:8)	(<1:2)	(1:128)	760	none	none	none	none
P2	3/16/03	NS	3 – 4	N/A	N/A	N/A	N/A	N/A	720	3 ^{BCDES}	10	none	2 ^{BG}
N6	3/27/03	CD	3 – 4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
A3	3/28/03	CD	>6	negative	(<1:2)	(<1:8)	(<1:2)	(1:8)	N/A	none	16 ^{aE}	none	16 ^{aE}
F1	3/28/03	CD	3 – 4	negative	(<1:2)	(<1:8)	(<1:2)	(1:4)	N/A	none	16 ^E	none	16 ^E
F7	3/28/03	CD	3 – 4	negative	(<1:2)	(<1:8)	(<1:2)	(1:8)	N/A	6 ^R , 6 ^a	U ^{aERX}	6 ^R , 6 ^a	U ^{aERX}
N2	3/28/03	CD	2 – 3	N/A	N/A	N/A	N/A	N/A	N/A	6 ^a	10 ^{ab} , 16 ^{abE}	none	2 ^B
F3	3/31/03	ES	>6	(1:64)	(<1:2)	(<1:8)	(<1:2)	(1:64)	N/A	1^E, 10^E	none	1^E, 10^E	none
J5	3/31/03	ES	4 – 6	(1:32)	(<1:2)	(<1:8)	(<1:2)	(1:64)	N/A	10^{aE}	3 ^{aCD}	none	2, 2 ^{CD}
N4	3/31/03	ES	4 – 6	(1:32)	(<1:2)	(<1:8)	(<1:2)	(1:64)	N/A	none	none	none	2
X4	3/31/03	ES	4 – 6	(1:32)	(<1:2)	(<1:8)	(<1:2)	(1:2)	N/A	3 ^{aCDE}	none	none	2, 2 ^B , 2 ^{CD}
J3	4/2/03	ES	2 – 3	(1:16)	(<1:2)	(<1:8)	(<1:2)	(1:64)	N/A	none	none	none	none
A6	4/2/03	NS	>6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C4	4/2/03	NS	4 – 6	negative	(<1:2)	(<1:8)	(<1:2)	(1:64)	N/A	6 ^R	none	6 ^R	none
H2	4/2/03	NS	4 – 6	N/A	N/A	N/A	N/A	N/A	N/A	none	16 ^{aE}	none	16 ^{aE}
H6	4/2/03	NS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	none	none	none	none
K7	4/2/03	NS	2 – 3	negative	(<1:2)	(<1:8)	(<1:2)	(1:32)	N/A	none	none	none	2 ^B
P1	4/2/03	NS	4 – 6	negative	(<1:2)	(<1:8)	(<1:2)	(1:64)	N/A	none	none	none	none
P5	4/2/03	NS	2 – 3	negative	(<1:2)	(<1:8)	(<1:2)	(1:4)	N/A	none	none	none	2 ^B
X2	4/2/03	NS	>6	(1:16)	(<1:2)	(<1:8)	(<1:2)	(1:32)	N/A	none	3 ^{abE} , 16 ^{aE}	none	2 ^B
X6	4/2/03	NS	4 – 6	negative	(<1:2)	(<1:8)	(<1:2)	(1:8)	N/A	none	10 ^{BCDEX}	none	none

