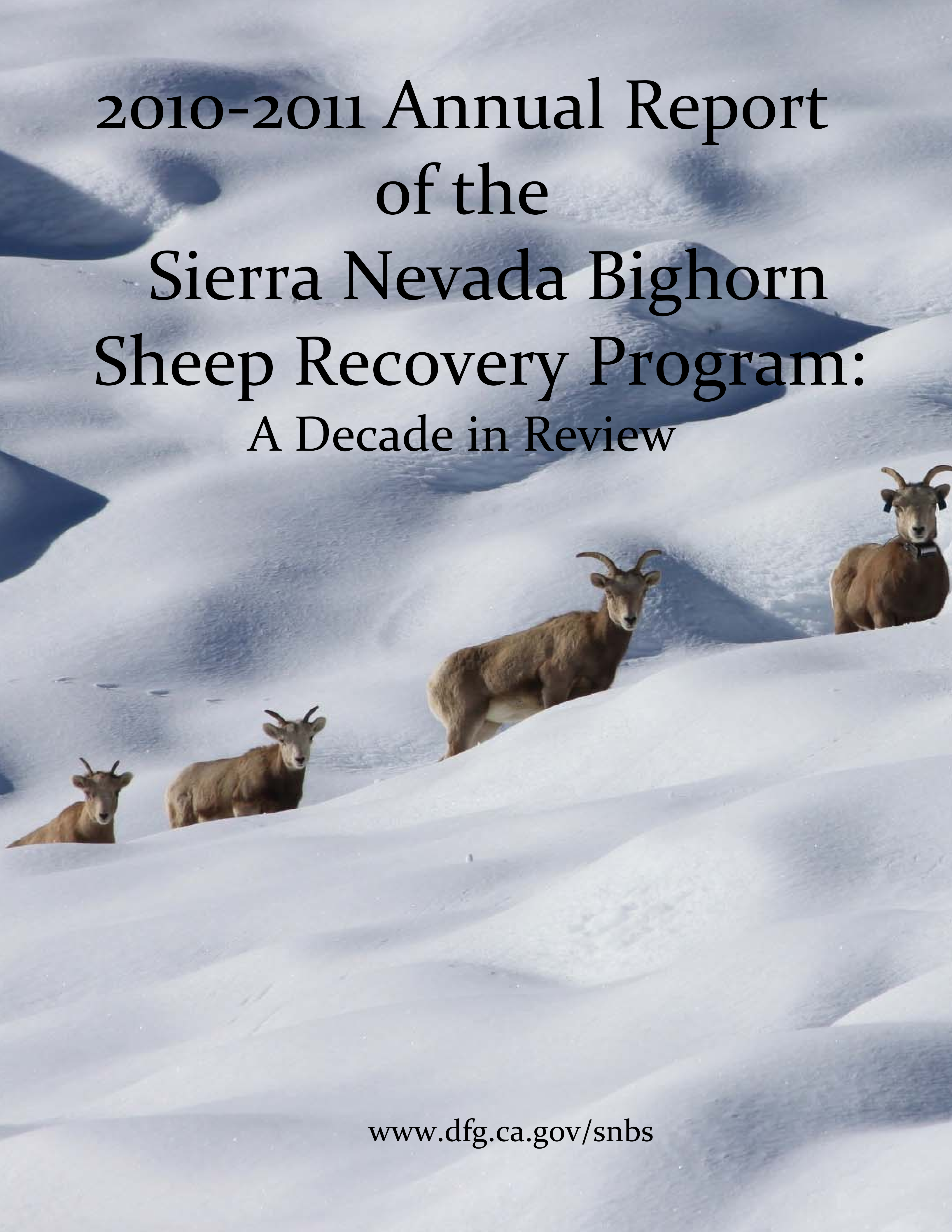
2010-2011 Annual Report of the Sierra Nevada Bighorn Sheep Recovery Program:

A Decade in Review



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2010-2011 Annual Report of the Sierra Nevada Bighorn Sheep Recovery Program: A Decade in Review

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An electronic version of this monitoring report also will be made available at http://www.dfg.ca.gov/snbs/Literature.html

Results reported here are preliminary and, in some cases, represent findings of collaborators; please do not cite without consulting the authors.

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Summary

This report presents a review of the Sierra Nevada Bighorn Sheep Recovery Program from 1999, when Sierra Nevada bighorn sheep were placed on the federal endangered species list, to June 30, 2011. For a detailed summary of recovery actions carried out and data collected from 2010-2011 see Appendices C and D.

Since 1999, Sierra bighorn numbers have increased from just over 100 animals to about 400. The current reproductive base of almost 200 females over 1 year old is about two-thirds of the numerical recovery goal of 305 females (Figure 1). Of the 12 herd units required for recovery (USFWS 2007), only 4 remain vacant as of the 2010-2011 reporting year.

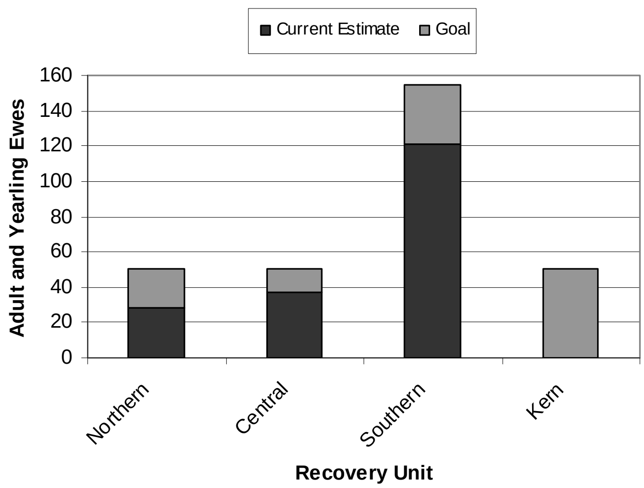

Figure 1. Proximity to downlisting criteria for each Sierra Nevada bighorn sheep recovery unit based on number of adult ewes over 1 year old.

Herds that grew substantially since listing (Wheeler Ridge, Mount Langley, Sawmill Canyon, and Mount Baxter) tended to have the highest growth rates early in the decade. During periods of high growth, survival rates of adult females generally exceeded 90%. Periods of slowed population growth were accompanied by more variable and poorer adult female survival and declining recruitment of yearling females. Mountain lion predation was the highest known cause of mortality and was concentrated in herds in proximity to dense mule deer winter ranges (Johnson 2010a).

The Recovery Program is directed by the Recovery Plan for Sierra Nevada bighorn sheep drafted in 2001 (USFWS 2007) which presents the conservation strategies that California's Department of Fish and Game (DFG) has employed over the last decade. The Recovery Plan has a 20-year implementation schedule beginning when the plan was released in 2007. The stated goal for downlisting is 2017. Considerable progress has been made in implementing the Recovery Plan conservation strategies. These strategies focus on 1) increasing the number and distribution of bighorn sheep through augmentations and habitat enhancement projects and 2) reducing threats that limit their survival by managing predators and reducing the proximity of domestic sheep grazing allotments. Based on the first strategy, we implemented three translocations to augment small herds. Additionally, we planned prescribed burns and initiated two to enhance the quality of habitat for bighorn sheep. Following the second strategy, we removed mountain lions when they posed an imminent threat to bighorn sheep, and land management agencies worked to shift grazing away from areas near bighorn recovery units.

After reviewing 11 years of progress, we are optimistic that we could meet the goals for downlisting to threatened status within the next decade, barring any catastrophes. If we are to meet this ambitious timeline, key recovery strategies need to continue. Implementing translocations for reintroductions to vacant herd units is essential to achieve the distribution required to meet recovery goals. This necessitates adaptive management and a predator management program to protect herds used as a source of translocation stock so that reintroductions and augmentations can occur.

For more information on Sierra Nevada bighorn sheep, please visit our new website at www.dfg.ca.gov/snbs.

The Last Decade: From Listing toward Recovery

In 1999 Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*), a genetically and morphometrically distinct subspecies of bighorn (Wehausen et al. 2005), were granted emergency endangered status under the federal Endangered Species Act (ESA). In the same year they were also upgraded from threatened to endangered under the California Endangered Species Act (CESA). Early in 2000 these bighorn sheep were granted full federal endangered status. Following the 1999 endangered listings, the California Legislature asked the California Department of Fish and Game (CDFG) to administer a funded recovery program for bighorn sheep. CDFG has remained the lead agency implementing this recovery effort.

The first task undertaken by this program was the drafting of a recovery plan for Sierra Nevada bighorn sheep, which was completed in 2001 and released by the U.S. Fish and Wildlife Service in 2007. As the document guiding the recovery effort, this plan identifies key issues, sets recovery goals, and lists recommended recovery actions. Federal endangered status was sought for Sierra Nevada bighorn sheep because of a dangerously low population size and the inadequacy of existing regulatory mechanisms relative to two concerns: negative effects of mountain lion predation, and the threat of a major respiratory disease epizootic that could result from contact with domestic sheep grazed on public lands adjacent to bighorn sheep ranges.

The Recovery Plan for Sierra Nevada bighorn sheep identifies 16 historic herd units (populations) and groups these into 4 recovery units (metapopulations; Figure 2). Bighorn in the Sierra reside almost entirely

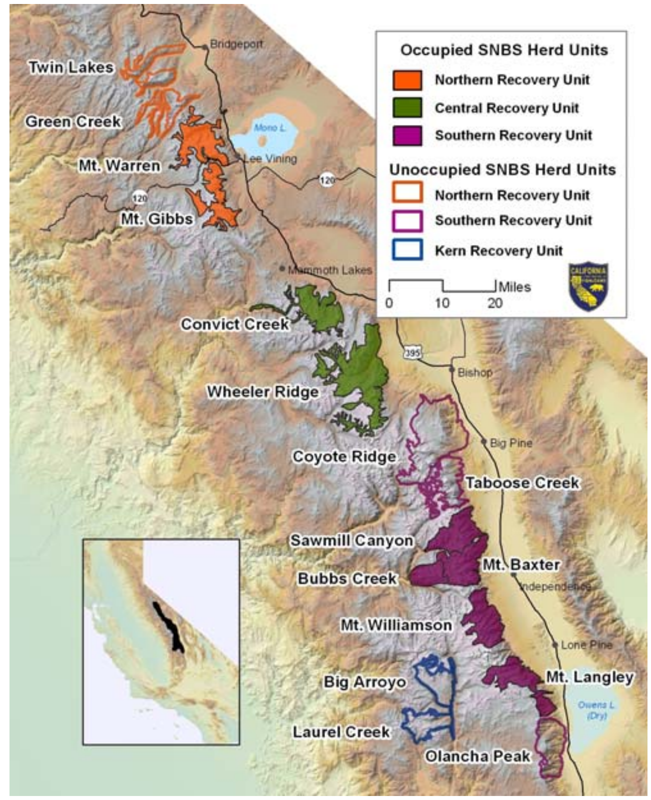

Figure 2. Locations of 16 historic herd units in 4 Recovery Units. All occupied herd units are required for recovery (USFWS 2007) except Bubbs Creek. Four vacant herd units (Olancha Peak, Laurel Creek, Big Arroyo, and Taboose Creek) must be reoccupied to meet recovery goals.

in multiple National Parks and National Forests, but herd units are adjacent to land with many other public and private owners. Two herd units in the Northern Recovery Unit, Mount Gibbs and Mount Warren, lie partially within the boundaries of Yosemite National Park. All of the occupied herd units in the Southern Recovery Unit lie at least partially within Sequoia and Kings Canyon National Parks. All low-elevation winter ranges are on the Inyo National Forest. Downlisting and delisting criteria specify herd units that need to be occupied (Figure 2) as well as minimum numbers of females required in each recovery unit (Figure 1). Issues identified for management actions include predation, bighorn use of low elevation winter ranges, domestic sheep grazing, and reintroduction of bighorn to unoccupied herd units. The Recovery Plan also calls for the development of regular demographic data on bighorn sheep herds and identified areas of desired research (USFWS 2007).

The Recovery Plan states that "recovery of bighorn sheep in the Sierra Nevada will require an adaptive approach, one in which decisions made will depend on current information about key resources. An adaptive approach to management will require development or continuation of existing research." The program is identifying resource selection patterns across the Sierra Nevada, determining patterns of genetic variation across the subspecies, modeling the risk of disease transmission from domestic sheep and goats, quantifying the effects of natural and prescribed fire on bighorn forage and habitat use, monitoring mountain lion movements, predation rates, and population numbers, implementing and monitoring translocation efforts, and modeling bighorn sheep response to various management actions. We use information acquired through these studies to direct recovery activities.

This year marks 11 years since full federal endangered status was granted. This report traces trajectories of Sierra Nevada bighorn sheep herds over that time period, reviews accomplishments of the Recovery Program, and outlines future management

actions needed. Beginning in the early 1980s, monitoring reports were written summarizing demographic information on bighorn sheep herds in the Sierra Nevada. Those reports have been produced on an annual basis for the past decade. Summaries of demographic data and important events from those reports can be found in Appendices A and B. Detailed information for the past year can be found in Appendices C and D.

Monitoring Bighorn Populations

We have attempted to collect annual demographic data for all occupied herds in an effort to track population trends. This has not always been successful for all occupied herds every year. However, there have been enough years in which adequate information exists for every herd to track the overall population trend. Counts have focused on females because they are the reproductive base of the population; consequently, there are even fewer years in which it has been possible to develop a defensible size estimate for the entire population (i.e., including rams).

We have followed two approaches in determining sizes of herds. First are minimum counts, the basis of recovery goals. Bighorn sheep in the Sierra Nevada offer a rare situation wherein focused efforts at the right time can produce relatively complete counts of all females and associates up to herds that number 30–35 ewes. Occasionally, males can be counted by a similar method. The addition of telemetry collars has increased the frequency of relatively complete minimum counts and the population size at which relatively complete counts can be obtained. Second has been the use of collared bighorn to generate mark-resight (MR) population estimates, which are presented in this report with 95% confidence intervals in parentheses. Where MR estimates and minimum counts occur in the same herd in the same year, minimum counts are evaluated for their completeness by comparing to MR estimates. Also, counts from subsequent years and known mortalities occurring between counts are used to evaluate previous counts.

As the Recovery Plan recognizes, the capture of Sierra Nevada bighorn sheep and the deployment of collars are essential for implementing the recovery of this federally endangered species (USFWS 2007). One emphasis of this Recovery Program has been the deployment of telemetry collars on bighorn sheep, including both traditional VHF collars and GPS collars that record multiple GPS locations daily. In addition to their use for MR population estimates and minimum counts, collars have provided important information relative to a variety of questions. First, collars shed light on spatial patterns of habitat use by sheep. This information has led to refinement of herd unit boundaries and has helped document population substructuring (different home range patterns) between sexes (Schroeder et al. 2010) and within sexes, seasonal migratory patterns, and occasional extreme movements that have bridged herd units or taken animals outside of herd unit boundaries. Second, collars can be used to measure survival rates by sex and herd and to assess cause-specific mortality. Telemetry collars include mortality sensors that make it possible for some mortalities to be investigated soon after death, when the cause of mortality is often more evident. This has been particularly useful for identifying deaths due to predation, physical injury (e.g., falls, avalanches), and malnutrition. Third, collared females provide an opportunity to measure reproductive success through repeated observations of known individuals. Finally, captures necessary to deploy collars have provided an essential opportunity to conduct disease surveillance and determine the nutritional condition and reproductive status of individuals within populations. Data obtained from collared bighorn sheep have been and will continue to be used to guide recovery actions.

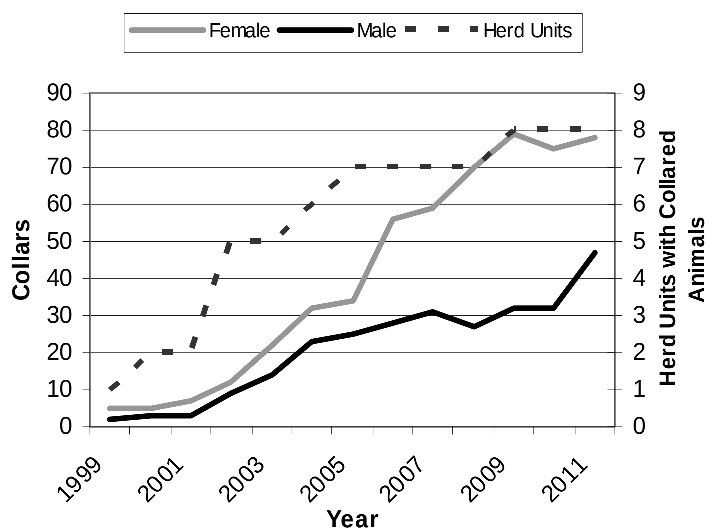

Figure 3. Collar history for Sierra Nevada Bighorn Sheep Program during 1999-2011.

During January 1999 to June 2011, we deployed a total of 212 GPS collars and 239 VHF collars from 258 captures, representing 180 individual animals; a VHF and a GPS collar are deployed on most captured bighorn. To date, no more than 79 females and 47 males have carried collars at any one time (Figure 3). We take great care during captures to minimize the risk of injury and mortality to Sierra bighorn. During 258 captures of which 249 were by helicopter net-gun, 8 direct mortalities occurred over an 11 year period; 2 additional animals died of unknown causes and were scavenged within 2 weeks of moving away from their release site. Thus far, we have retrieved GPS data from 159 collar deployments on 124 different animals. Additional GPS collars remain deployed. Efforts are currently underway to use these data to understand habitat selection, identify the disease risk posed by adjacent domestic sheep allotments, and determine optimal locations for future reintroductions and augmentations.

Following listing, most captures focused on collaring bighorn sheep in herd units adjacent to active domestic sheep allotments in an effort to assess the risk of disease transmission. Consequently, Wheeler Ridge and Mount Warren were the focus of collaring efforts during 1999–2005 with most captures occurring on lower-elevation winter ranges. Beginning in 2005, most captures occurred during autumn on alpine ranges to avoid disturbing bighorn on their winter ranges. Collars are currently deployed in all occupied herd units except the newly colonized Convict Creek herd.

Bighorn Sheep Population Dynamics

Populations change over time due to the difference between gains from successful reproduction (recruitment) and immigration and losses due to mortality and emigration.

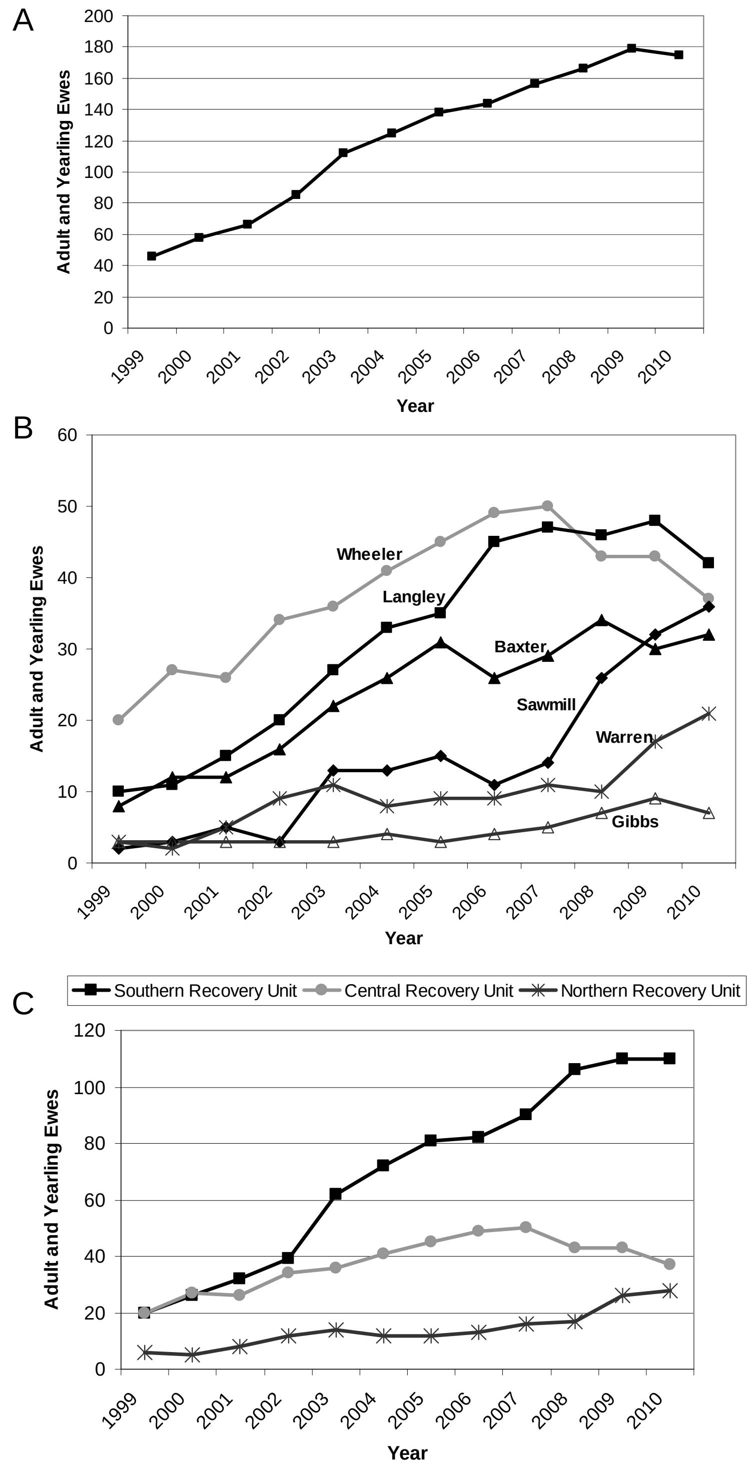

Figure 4. Population trajectories for adult and yearling ewes during 1999–2010 based on a combination of minimum counts, mark-resight estimates, and reconstructed data. All data for the Mount Baxter herd is derived from winter counts except for data from 2002 which are from a summer count. **A.** Total population trajectory for 6 herds in the Sierra (Mount Langley, Mount Baxter, Sawmill Canyon, Wheeler Ridge, Mount Gibbs, and Mount Warren) with annual population estimates. **B.** Population trajectories by herd unit. **C.** Population trajectories by recovery unit.

Because immigration and emigration are rare events in bighorn sheep herds and involve few sheep, they can be largely ignored in considerations of population dynamics. Consequently, we first consider overall population dynamics, and then mortality and recruitment patterns that influence those dynamics.

Population Changes over Time

The total population of bighorn sheep in the Sierra Nevada has made large gains since listing. The number of females has nearly quadrupled from a low of about 50 in 1995 (USFWS 2007) to almost 200, but has shown no gains for the past year (Figure 4A and Appendix A). Within that larger pattern, however, are a variety of trends at the level of individual herd units, varying from herds that have remained static at low numbers to herds that have grown dramatically and are largely responsible for the overall gains (Figure 4B). For a more detailed description of demographic trends within individual herds, see Appendix B.

Overall population gains for Sierra Nevada bighorn have been driven primarily by 3 of 5 occupied herd units in the Southern Recovery Unit (SRU) and one herd in the Central Recovery Unit (CRU), whereas the 2 herds (Mount Gibbs and Mount Warren) making up the Northern Recovery Unit (NRU) have shown only modest increases in population growth (Figure 4B and C). The increase in total ewes in the Northern Recovery Unit in 2009 (Figure 4C) was largely caused by the translocation of 6 ewes that spring and an increase in our ability to detect animals that had recently expanded their range in the Mount Warren herd (Figure 4B). Population size in recent years correlates well with the extent of the habitat bighorn use. The largest populations in the SRU are using a combined 381 km^2, whereas herds in the CRU and NRU are using 126 km^2 and 107 km^2, respectively.

In recent years Mount Langley and Wheeler Ridge accounted for about half of the total population, and the Mount Baxter and Sawmill Canyon herd units together account for another third of the total population (Figure 4B). These 4 herds are intended to serve as sources of stock for translocations to augment small existing herds and to reintroduce bighorn to historic ranges; therefore, maintaining healthy demographic trends in these populations is critical for recovery. The Mount Langley and Wheeler Ridge herd units have not grown since 2007 (Figure 4B), and the population growth rate indicates a clear decline over time (Figure 5). The Mount Baxter herd has not gained any females for 5 years (Figure 4B) and numbers less than half its size in the late 1970s. In contrast, in the past year the adjacent Sawmill Canyon herd has been found to be almost 3 times the size recorded 3 years ago (Figure 4B). This increase can be attributed in part to greatly improved data collection made possible by the deployment of more collars in this herd. Notwithstanding

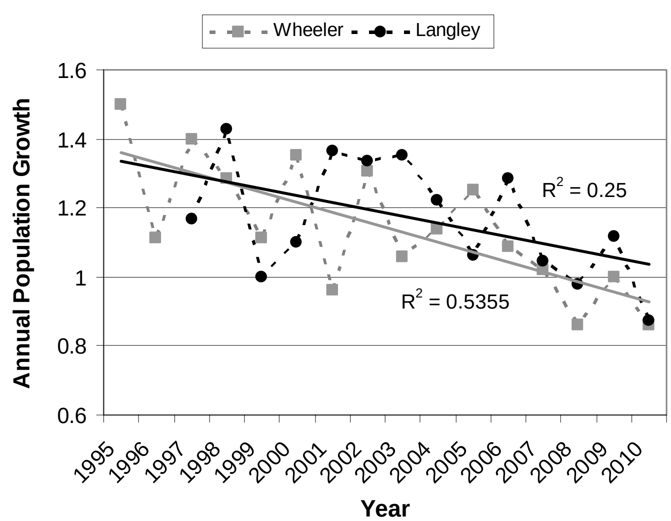

Figure 5. Population growth rate (lambda measured as N_{t+1}/N_t) for the Mount Langley and Wheeler Ridge herds during 1995–2010.

this apparent increase, the total adult and yearling females in the 2 recovery units containing source populations for translocations, the SRU and CRU, exhibit a lack of gains over the last 2 to 3 years (Figure 4C). The next two sections explore the recruitment and mortality patterns underlying these recent dynamics.

Cause-Specific Mortality and Survival

Sensitivity analyses of Sierra Nevada bighorn sheep demographic parameters showed that changes in adult female survival will have the largest impact on population growth (Johnson et al. 2010c), as with other large ungulates. It is therefore important to understand the factors affecting adult survival, which vary spatially within the Sierra Nevada. Here we examine natural causes of mortality determined by investigation of freshly-dead female bighorn. Over the past 11 years these causes included snow avalanches (hereafter referred to as avalanches), physical injury from rock fall or falling from cliffs, mountain lion predation, bobcat predation (1 instance), coyote predation (1 instance), and unknown (Figure 6A).

Because the change in the number of females determines the rate of population growth, limiting female mortality is an important management goal. From 1999 to 2010, 70 female mortalities from natural causes have been recorded; 51 of these females were radio-collared. The cause-specific mortality analysis presented here (Figure 6A) is limited to radio-collared females to avoid bias toward mountain lion predation in the uncollared subpopulation, as tracking of collared lions makes lion predation easier to detect than other causes of death among uncollared bighorn.

Southern Recovery Unit

In the SRU, mountain lion predation is

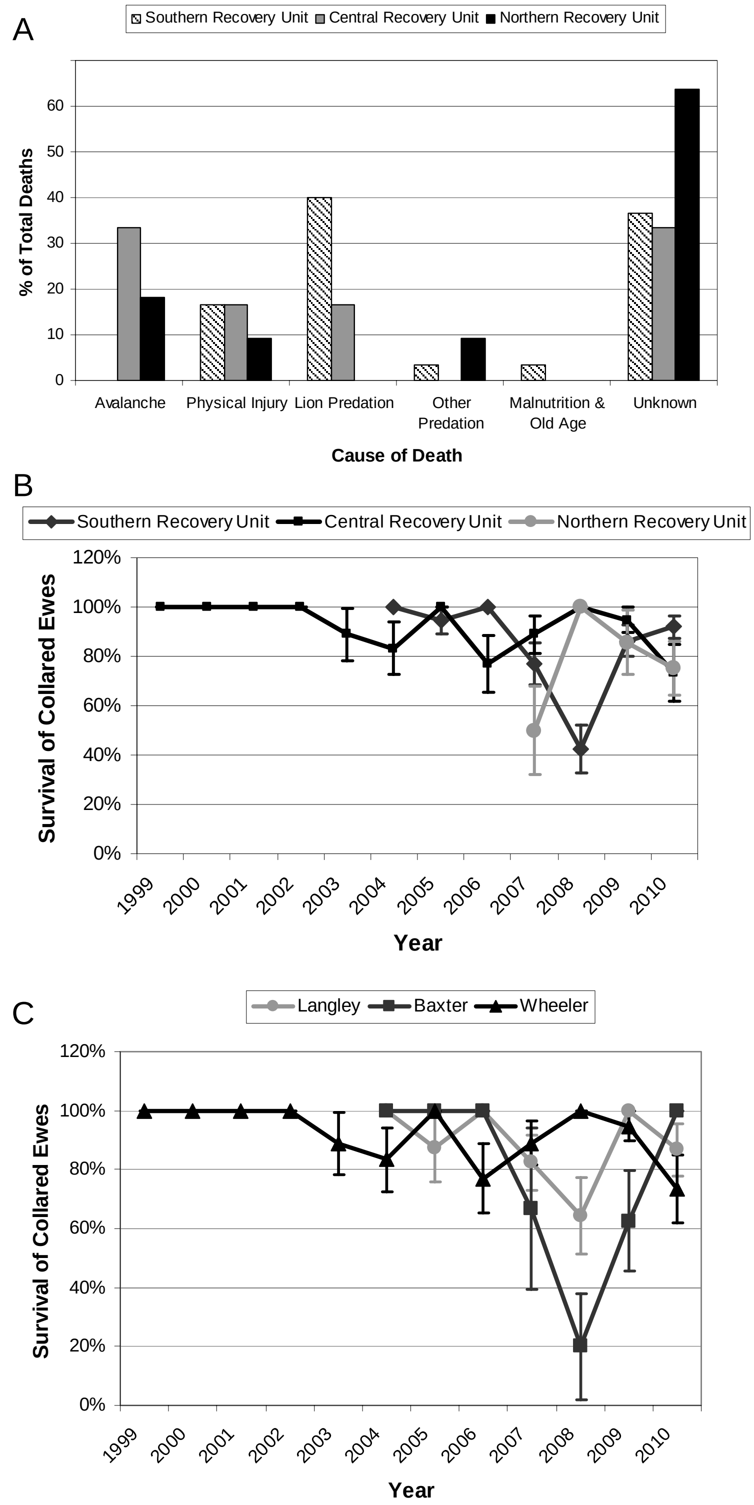

Figure 6. Cause-specific mortalities and survival of collared ewes from 1999–2010. **A.** Cause-specific mortalities of collared ewes by recovery unit. **B.** Annual Kaplan-Meyer survival rates of collared ewes for 1999–2010 by recovery unit. **C.** Annual Kaplan-Meyer survival rates of collared ewes for 1999–2010 for three herds.

the largest known cause of death among ewes (Figure 6A), accounting for 40% (12 out of 30) of the total mortalities. Most lion kills occurred in the Mount Baxter and Sawmill Canyon herds, but several also occurred in the Mount Langley and Mount Williamson herds. This is a conservative estimate of mountain lion predation because many carcasses investigated were not intact enough to be assigned a cause of death and were included in the unknown category.

The annual survival rate of collared ewes is inversely related to mortalities for a given year. In the SRU annual survival rates of collared ewes have varied between 42 and 100% (Figure 6B). The survival rate declined precipitously in 2007 and 2008 (Figure 6B). This rapid decline in survival was caused largely by an increase in mountain lion predation. Out of 12 known mountain lion kills of collared ewes in the SRU between 1999 and 2010, 8 occurred during 2007 and 2008. Among 18 collared and uncollared ewes in the SRU killed by mountain lions between 1999 and 2010, 13 were killed during 2007 and 2008. In those 2 years, 11 of the 13 lion kills in the SRU occurred in the Mount Baxter and Sawmill Canyon herds, and in 2008 the annual survival rate of collared ewes at Mount Baxter declined to 20% (Figure 6C). In those 2 winters, 5 different mountain lions were known to use the Baxter-Sawmill winter range for varying lengths of time. It appears that this predation has prevented growth of the Mount Baxter herd in recent years (Figure 4B). During 2008 and 2009, lion trackers working for USDA Wildlife Services selectively killed 9 lions in the SRU that targeted bighorn sheep as prey. This management effort likely prevented a decline in these populations.

Because many of the herds in the SRU (Mount Langley, Mount Baxter, and Sawmill Canyon) will serve as source populations for future reintroductions and augmentations, manageable causes of mortality must be reduced. In a nutritionally-limited population in which predation replaces other forms of mortality such as starvation, mountain lion predation can be compensatory, leading to no net loss in numbers. In populations that are not nutritionally limited, predation can be additive, resulting in additional mortalities. Because translocations remove animals from source populations, thereby reducing competition for forage, predation losses are not likely to be compensatory. Instead, those losses will limit availability of bighorn for translocations.

Central Recovery Unit

In the CRU, Wheeler Ridge is the only herd with long-term demographic data. Here, survival of collared ewes has varied between 73 and 100% with an average annual survival rate of 93% (Figure 6B). Avalanches have caused the majority of collared ewe mortalities (33.3% of 12 mortalities, Figure 6A). Within the last decade, all 10 avalanche mortalities of collared and uncollared bighorn (6 ewes, 3 rams, and 1 juvenile) occurred in 3 separate avalanches in the 2010-2011, winter resulting in a significant decline in annual female survival for that year (Figure 6B). Avalanche deaths from prior decades occurred in 1980 and 1995 (Appendix B) and indicate that avalanches, which are larger and more frequent in heavy snow years, regularly kill bighorn in this herd.

When cause of mortality is analyzed for both collared males and females, the largest cause of death at Wheeler Ridge is mountain lion predation (32%, 10 of 31 collared bighorn mortalities, data not shown). Detected mountain lions kills in this herd have been predominantly rams. This is in contrast to predation in the SRU where mountain lion predation has been biased toward ewes (60% of 30 lion kills detected are ewes in the SRU; 21% of 33 lion kills detected are ewes at Wheeler Ridge). Although Wheeler Ridge is a source population for translocations, mountain lion control need not be as aggressive if predation continues to be focused on rams. It is important to monitor mountain lion activity in this area and respond if necessary to prevent heavy predation of females. Conservative predator management is only possible if bighorn survival is monitored intensively and with a high level of confidence.

Northern Recovery Unit

The NRU is currently composed of 2 small herds (Mount Gibbs and Mount Warren) with very different dynamics. The collared ewes at Mount Gibbs, which winter almost exclusively on high-elevation (>11,000 feet) windswept ridges, had a 100% survival rate regardless of winter severity (Appendix B). In stark contrast, the survival rate of ewes in the Mount Warren population varied between 20 and 100% (Appendix B). Overall survival in the NRU has varied between 50 and 100% with an average survival rate of 78% (Figure 6B). Because these herds winter at high elevation, mortalities often cannot be investigated quickly enough to determine a cause of death. Thus, 64% of these mortalities are attributed to an unknown cause.

A significant source of mortality in this herd is avalanches (18% of 11 collared ewe mortalities). As at Wheeler Ridge, all avalanche deaths in the last decade occurred in the 2010–2011 winter. The carcasses of 2 collared ewes were recovered in avalanche paths. Three additional collared ewes died in the 2010–2011 winter, but the cause of death could not be determined. The 2010–2011 heavy winter resulted in a loss of one-third of the ewes observed the previous year. The 180% winter of 2010–2011 explains the temporal variation in avalanche deaths (Figure 19).

Reproduction and Recruitment

The recruitment rate must increase to maintain the population at a given size as the survival rate declines. Specifically, models show that high recruitment rates (female yearling:ewe >0.2) are required for bighorn when survival falls below 87% (data not shown). While the total number of ewes in the Sierra has increased dramatically in the last decade (Figure 4A), the total number of ewes in 3 herds, Mt. Langley, Mt. Baxter, and Wheeler Ridge, important sources for translocations, has not grown in the last 3 to 5 years (Figure 4B). Unlike the population at Mount Baxter where mountain lion predation resulted in a decrease in ewe survival (Figure 6C), for several years the survival rates of the Mount Langley and Wheeler Ridge populations do not show a consistent decline (Figure 6C). However, population growth rates at Mount Langley and Wheeler Ridge indicate a clear decrease over time (Figure 5) suggesting that inadequate conception, fecundity (births), or

lamb survival is causing a decline in recruitment (the replacement rate of the reproducing segment of the population) and population growth. Pregnancy rates of adult females measured throughout the recovery area during captures were between 80 and 90%, indicating that conception rates are not limiting population growth. Below we will discuss fecundity and recruitment patterns that contribute to population growth at Wheeler Ridge and Mount Langley, the 2 herds with the best long-term data.

Both Wheeler Ridge and Mount Langley have experienced periods of decreased fecundity and recruitment while the total population increased (Figures 7 and 8). This suggests that population density contributed to a decline in fecundity and recruitment. There are three possible density-dependent mechanisms that may account for this decline. First, herbivores typically show decreases in recruitment followed by decreases in fecundity as the availability of nutrients decreases with increasing population density (Bonenfant et al. 2009). Second, predation (e.g., by coyotes, golden eagles, bobcats, and mountain lions) on juveniles (lambs and yearlings) can increase with population density (a Type II functional response; Mills 2007), resulting in decreased fecundity and recruitment. Third, predation can lead to indirect effects on bighorn such as decreased foraging efficiency leading to reduced fecundity or recruitment (Bourbeau-Lemieux et al. 2011). At present we have no reliable way to detect predation on juvenile bighorn (evidence for hypothesis 2) as none are collared; thus we will examine evidence for nutritional deficiencies (hypothesis 1) and indirect effects of predation (hypothesis 3) on fecundity and recruitment.

Wheeler Ridge

At Wheeler Ridge fecundity, best estimated as the lamb to ewe ratio, declined from 2000 to 2006 (Figure 7A), and recruitment, best estimated as the yearling to ewe ratio, declined similarly (Figure 7B). Interestingly, this pattern of decline occurred while the population was steadily increasing (Figure 7C), suggesting that population density contributed to a decline in fecundity and recruitment. The threshold of body fat required to maintain pregnancy is near 10% and probably does not vary among herds. Lactating ewes at Wheeler Ridge captured in the fall average 12% body fat and non-lactating ewes average 17% body fat, suggesting that adult ewes are not nutritionally limited. During the first half of the decade, mountain lions were present at

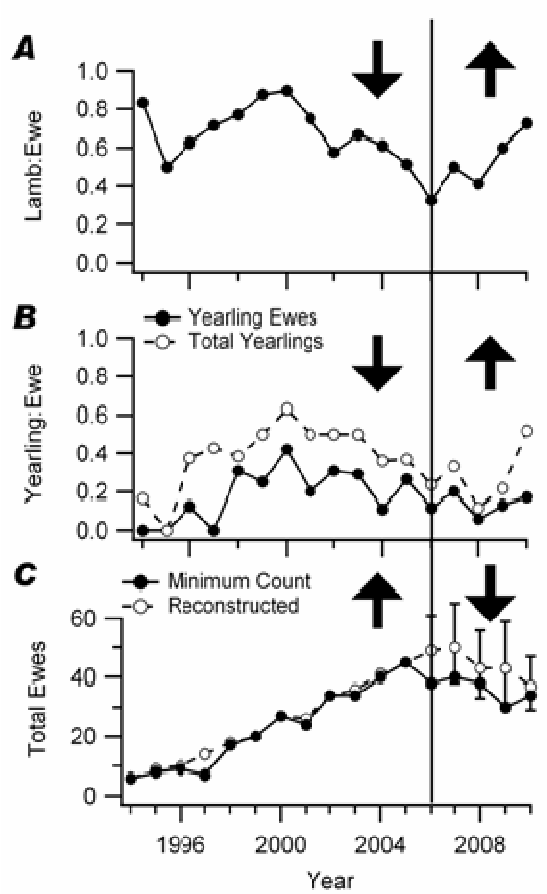

Figure 7. Annual demographic data for Wheeler Ridge from 1994–2010 collected during winter counts. **A.** Fecundity by year measured as the number of observed lambs:adult ewes. **B.** Recruitment by year measured as the number of observed yearlings:adult ewes. **C.** Adult and yearling ewes by year. Arrow indicates population trend.

Wheeler Ridge in higher numbers than they have been since (Figures 13 and 14), suggesting that predation may have affected fecundity and recruitment.

Fecundity and recruitment have increased since 2006 and 2008, respectively (Figures 7A and B). This upward trend may reflect an increase in available forage caused by a range expansion (see Geographic Distribution and Natural Range Expansions below), an increase in the use of low-elevation winter range, or an increase in the amount of precipitation (Figure 19). Alternatively, population growth earlier in the decade or the decline in mountain lions in the area (Figures 13 and 14) may have led to more efficient vigilance behavior and thus more efficient foraging. It remains to be seen whether this increase in recruitment will result in population growth (Figure 7C).

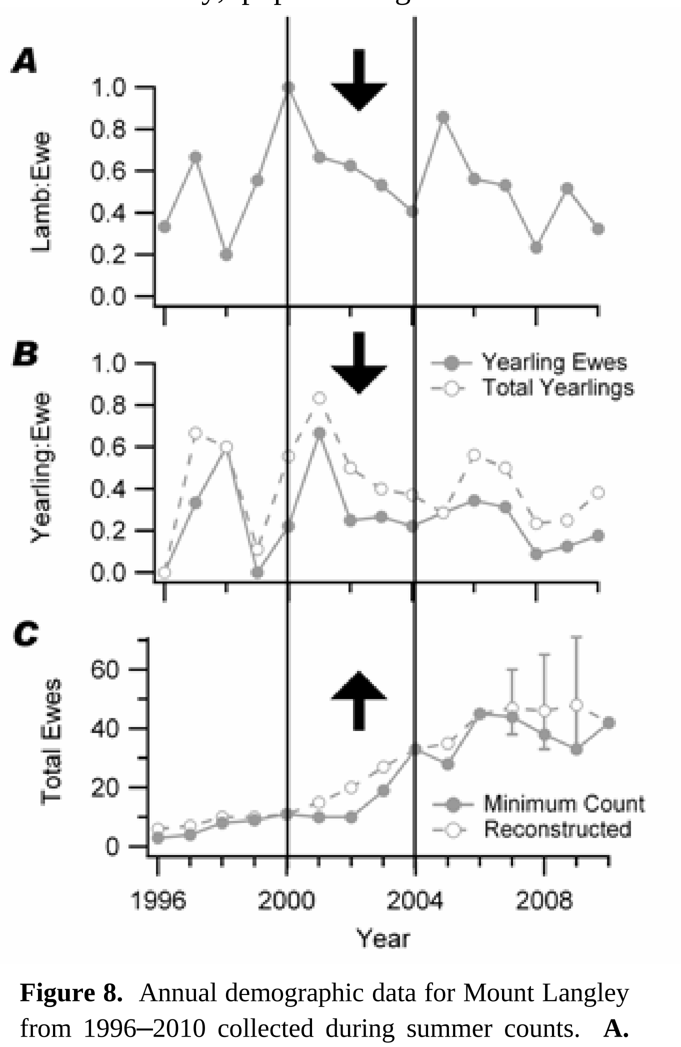

Figure 8. Annual demographic data for Mount Langley from 1996–2010 collected during summer counts. **A.** Fecundity by year measured as the number of observed lambs:adult ewes. **B.** Recruitment by year measured as the number of observed yearlings:adult ewes. **C.** Adult and yearling ewes by year. Arrow indicates population trend.

Mount Langley

The data from Mount Langley are somewhat more variable, but a clear decline in fecundity can be seen in the first half of this decade (Figure 8A) as the population increased (Figure 8C). Whether this was caused by density-dependent changes in forage availability or by predation is not clear. Body condition data collected during fall captures suggest that lactating ewes in this population are not nutritionally limited (15% body fat), similar to ewes at Wheeler Ridge. However, the declines in fecundity and recruitment in 2008 (Figure 8A and B) are likely multiyear effects of the 2006–2007 winter, which was the driest in the last 4 decades. For bighorn a significant effect of that winter was decreased nutrient availability the following summer, because forage growth is so dependent on soil moisture from snow melt. Although the dry 2006–2007 winter did not affect the fecundity or recruitment recorded in 2007, it likely caused the decrease in fecundity and recruitment measured in 2008 (Figure 8A and B). Presumably the 2006–2007 winter affected the ability of ewes either to become pregnant, to carry a pregnancy to term, or to nurse newborn lambs the following year, resulting in a lower lamb to ewe ratio for 2008 (Figure 8A). A decline in body fat to 10.7% in lactating ewes in the fall of 2007 supports this hypothesis. This dry winter also likely affected the survival of lambs in 2007 such that the ratio of yearlings to ewes decreased in 2008 (Figure 8B). The same decline in fecundity and recruitment, although much smaller in magnitude, can be seen at Wheeler Ridge in 2008, suggesting that the drought had repercussions across the Sierra. The effects of this dry winter indicate that under extreme conditions these small, endangered populations may experience nutritional limits on reproduction.

Summary

In summary, it appears that predation and stochastic weather events such as avalanches account for much of the spatial and temporal variation in survival rates. Mountain lion predation is a significant cause of ewe mortality in the SRU, but avalanche is the most significant natural cause of ewe mortality in the CRU and NRU. Reproduction and recruitment in the 2 largest herds, Wheeler Ridge and Mount Langley, have declined with increasing population size, suggesting that density-dependent mechanisms may affect small endangered populations. The static population growth at Mount Baxter or the potential population decline at Wheeler Ridge over the last 4 years (Figure 4B) may also reflect emigration events leading to natural colonization of adjacent habitat (see below).

Geographic Distribution and Natural Range Expansions

Sierra Nevada bighorn sheep are alpine specialists. They are adapted to life at elevations above tree-line (>11,000 feet) for much of the year. Essentially all Sierra bighorn spend most of the summer in the alpine, where they find forage that grows sparsely over much of the landscape but also in lush meadows. As winter snows arrive, most animals migrate to lower-elevation (<9,000 feet) winter ranges some time after December to avoid snow and find forage that greens up earlier at lower elevations. We observed increasing use of low-elevation winter range at Wheeler Ridge in the late 1990s, at Mount Baxter on Sand Mountain in 2003, and at Mount Langley in 2004. At Wheeler Ridge and Mount Langley, this expanded habitat use coincided with periods of increased fecundity and recruitment (Figures 7 and 8), suggesting the additional forage on low-elevation winter range enhanced reproductive output. Some herd units have minimal access to low-elevation winter range; these animals spend almost 12 months per year in the alpine environment. In particular, the Mount Gibbs and Convict Creek herds are living in the alpine year-round and spending the winter on snow-free wind-scoured ridges. Natural colonizations and range expansions have occurred in recent years, and some bighorn are persisting in environments where they are primarily using alpine winter ranges.

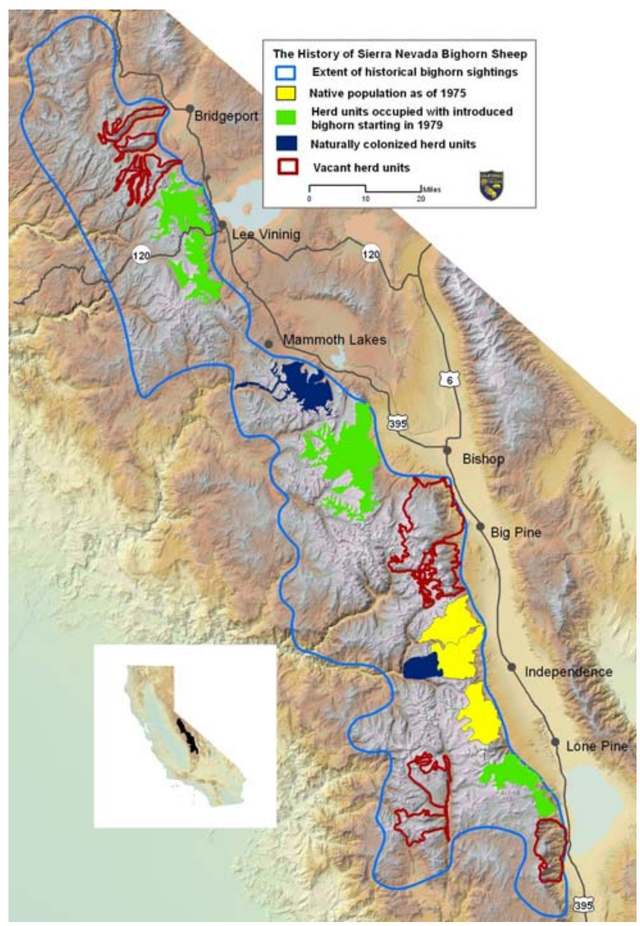

Figure 9. Temporal changes in the distribution of Sierra Nevada bighorn during 1975-2011. Herd units identified in the Recovery Plan are shown.

Historically, bighorn sheep occupied a broad region of the central and southern Sierra Nevada (note area outline in blue in Figure 9). Much of the historic range included groups of bighorn sheep that likely wintered in areas with little to no low-elevation winter range. GPS collar data collected in the last decade has shown that bighorn persist in the Sierra without low-elevation winter range by using high, windswept ridges and mid-elevation winter ranges.

The Recovery Plan for Sierra Nevada bighorn sheep identifies 16 areas across the Sierra Nevada that were likely occupied by separate bighorn herds during the last 2 centuries from Twin Lakes near Bridgeport to Olancha Peak south of Lone Pine. Of those 16 herd units, occupation of 12 is required before Sierra Nevada bighorn can be removed from the endangered species list. In the 1970s, only 3 herd units were occupied. Translocation efforts by DFG between 1979 and 1988 resulted in the establishment of 4 additional herds (Figure 9) and provided a geographic distribution sufficient to protect this unique subspecies should one population experience a disease outbreak. In the last decade natural range expansions have resulted in a multiyear occupation of an additional 2 herd units (Bubbs Creek and Convict Creek), 1 of which is required for delisting.

Long-distance movements of rams, particularly during the rut, are a mechanism mediating genetic diversity within otherwise small, geographically-isolated populations prone to erosion of genetic diversity by genetic drift. However, these movements are transient and are not considered range expansions. For a population to expand its range, a reproducing population (ewes and rams) must take up residence in a new location. In the last 11 years, the Sierra Nevada Bighorn Sheep Recovery Program has documented 6 range expansions from the Mount Baxter, Wheeler Ridge, and Mount Warren populations, challenging the long-held belief that bighorn populations are poor colonizers of available habitat (Geist 1971).

In August 2002 a local mountain guide, S.P. Parker, observed 11 bighorn sheep including ewes and lambs at the base of Charlotte Dome west of the crest along Bubbs Creek in Kings Canyon National Park. Further exploration revealed ample sign (Figure 10). These sheep are likely descendants from a subpopulation of the Mount Baxter herd using Kearsarge Peak, last documented in 1995. A continuous ridge system from Kearsarge Peak to Mount Gardiner probably served as the migration corridor allowing this colonization event. The new population, the Bubbs Creek herd, has persisted. Recent data from satellite-linked GPS collars on Bubbs Creek rams

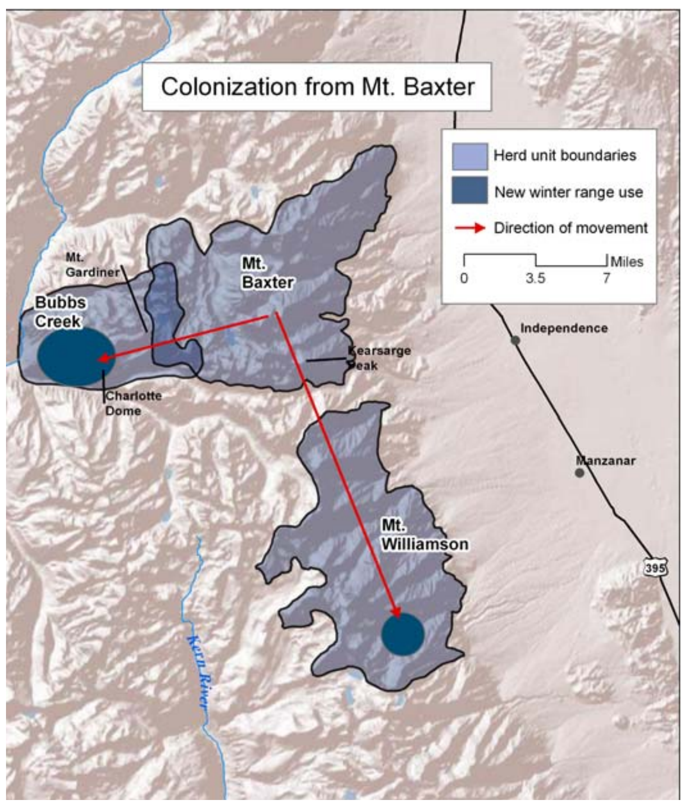

Figure 10. Colonization and range expansions from Mount Baxter.

during the rut suggest that these bighorn contribute to a large metapopulation including the Mount Baxter and Sawmill Canyon herds.

A large movement by 2 VHF-collared ewes from the Mount Baxter herd last winter demonstrates the mechanism by which ewes can colonize adjacent habitat. Genetic analyses confirmed that 2 groups from Mount Baxter containing at least 5 bighorn moved 18 miles south from Mount Baxter to winter in the Mount Williamson herd unit in 2010–2011 (Figure 10). At least 1 of the ewes appears to have returned to Mount Baxter. The outcome of such long-distance explorations likely depends on a number of factors including the vacancy and quality of the new habitat. Historically, long migratory routes may have existed across the Sierra; however, these learned behaviors are not present in populations established by recent translocations. The Mount Baxter herd is 1 of 3 original herds, and it is possible these sheep are again using the range as their ancestors once did.

Evidence of range expansion of bighorn in the Sawmill Canyon herd has also been documented. In 2009 on multiple occasions, 1 collared ewe moved north over Taboose Pass into the Taboose Creek herd unit. Because no ground observations were made, it is unclear how many bighorn were in the group that made these excursions.

Further north, bighorn from the Wheeler Ridge herd have also been exploring. In July 2007, a GPS-collared ewe revealed use of an area at 12,500 feet called Granite Park (Figure 11). This area is adjacent to an area of prior use, but our observations suggest that this movement reflects a range expansion. The Granite Park ewes often remain at high elevation throughout the winter using patches of wind-blown, snow-free habitat, a behavioral strategy previously undocumented in a herd that is known for its use of high-quality, low-elevation winter range. Unfortunately, this subpopulation of the Wheeler Ridge herd may have perished in a large avalanche in Morgan Creek during last year's heavy winter. Whether this behavioral strategy will persist in the Wheeler Ridge herd remains to be seen.

In August 2009, fecal pellets and fresh tracks were observed near Mount Stanford north of Wheeler Ridge in the Convict Creek herd unit, an area then thought to be unoccupied. Genetic analysis of these fecal samples indicated use by 3 bighorn ewes. In January 2011, backcountry skiers reported a group of 7 bighorn on Esha Peak in the Convict Creek herd unit. Photos revealed that the group contained 3 adult ewes, 3 lambs, and a yearling ram. The same group

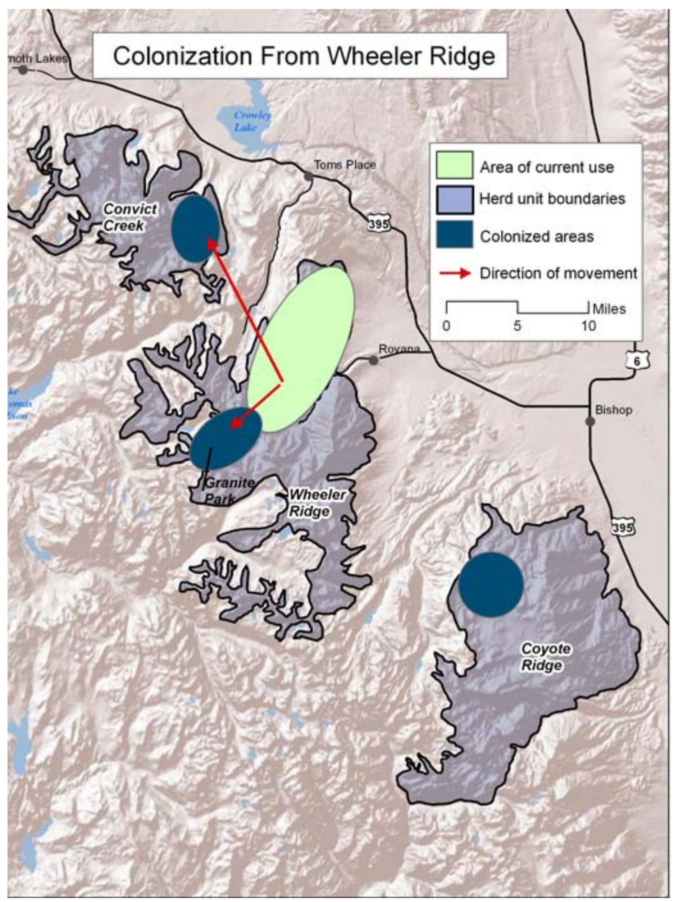

Figure 11. Colonization and range expansions from Wheeler Ridge.

was observed again in June with 2 newborn lambs, and fecal samples were collected. Genetic analysis will determine whether these are the same 3 ewes observed 2 years prior near Mount Stanford. These sheep are likely immigrants from Wheeler Ridge, where population growth may have slowed in part due to these dispersal events (Figure 11).

In July 2009, 2 ewes were photographed on Coyote Ridge. Subsequent surveys of the area have not revealed evidence of use. Either our attempts to find these bighorn have been unsuccessful or this was a failed colonization attempt by bighorn from Wheeler Ridge or from Sawmill Canyon, 26 miles south. Future surveys will continue to search for evidence of colonization of this herd unit.

The most northern herd unit, Mount Warren, was established by a translocation to Lee Vining Canyon in 1986. Despite fluctuations in size, the herd has moved north in a series of range expansions. Bighorn were first observed using the north side of Lundy Canyon and Dunderberg Peak in 2003. These range expansions suggest that bighorn in the Mount Warren herd are optimizing their habitat use as they discover surrounding areas. Unfortunately, their movements north are bringing them closer to domestic sheep grazing allotments. If bighorn in the Mount Warren herd continue to move north, the risk of disease transmission will increase.

Temporary expansions and long-term colonizations are signs of functional metapopulations. As connectivity increases between herds in the Sierra, there is greater potential for the spread of a disease that would devastate Sierra Nevada bighorn sheep increases. To protect this unique subspecies from such a threat, we are planning translocations to reintroduce Sierra Nevada bighorn to 2 herd units in the remote Great Western Divide within Sequoia and Kings Canyon National Parks.

These range expansions and colonizations have helped to expand our understanding of Sierra Nevada bighorn behavior and habitat, demonstrating that multiple types of winter habitat can be used successfully. High-elevation windswept ridges in Mount Warren and Convict Creek, relatively forested mid-elevation slopes at Bubbs Creek, and the more traditional low-elevation slopes along the eastern Sierra at Mount Baxter and Wheeler Ridge are utilized by Sierra bighorn as winter range. As additional suitable habitat is identified both by bighorn and by our habitat models, the distribution of bighorn throughout the Sierra will expand.

Mountain Lion Ecology and Management

The predator monitoring effort associated with the Recovery Program is designed to understand the relationship among Sierra bighorn and predators in the recovery area. The Recovery Plan (USFWS 2007) identifies mountain lions as a primary threat to recovery, and the California Fish and Game Code authorizes the removal of mountain lions that pose an imminent threat to bighorn sheep. The Recovery Plan recommends discontinuing predator management during a monitoring period once downlisting goals are met.

The Recovery Program has implemented an adaptive management strategy with regard to mountain lion predation. During the first 2 years of the program, when bighorn numbers were dangerously low, a lion considered to be a threat was removed before the lion was known to kill bighorn.

Three lions were killed during this time. As bighorn populations increased in size, we attempted to prevent lion predation by intervening before a lion killed a bighorn. In the SRU in spring 2002, we started harassing collared lions near bighorn in an attempt to move the lions away from bighorn. As there was no known predation in the Southern Recovery Unit (SRU) from 1999 to 2003, we studied bighorn/lion interactions in a relatively unperturbed system. As bighorn populations further increased, bighorn/lion interactions also increased and lion predation was detected. In 2003, active lion management became necessary in the Central Recovery Unit (CRU). In February 2006 in the SRU, we readopted the strategy of removing lions that posed an imminent predation threat in order to support bighorn recovery.

In all 3 occupied recovery units, we monitored mountain lions in and adjacent to bighorn habitat to identify individuals that posed an imminent threat. Mountain lions were monitored by experienced trackers who located, collared, and tracked individuals using hounds. Since 2000, 91 individual mountain lions have been handled in or adjacent to the 3 occupied recovery units. Most were captured and collared, but some were kittens too small to collar, and some were killed immediately and never marked because they posed an imminent threat to bighorn. The number of individual adult mountain lions being tracked on bighorn winter ranges fluctuated but generally increased throughout the last decade and peaked in 2008-2009.

We estimated the minimum number of adult, subadult, and dispersing mountain lions in and adjacent to the 3 occupied bighorn recovery units. We determined a minimum count (Figure 13) based on the number of unique lions that were identified within 3 geographic polygons that include occupied herd units in the 3 recovery units (Figure 12). Using physical evidence (McBride et al. 2008), 71 different adult,

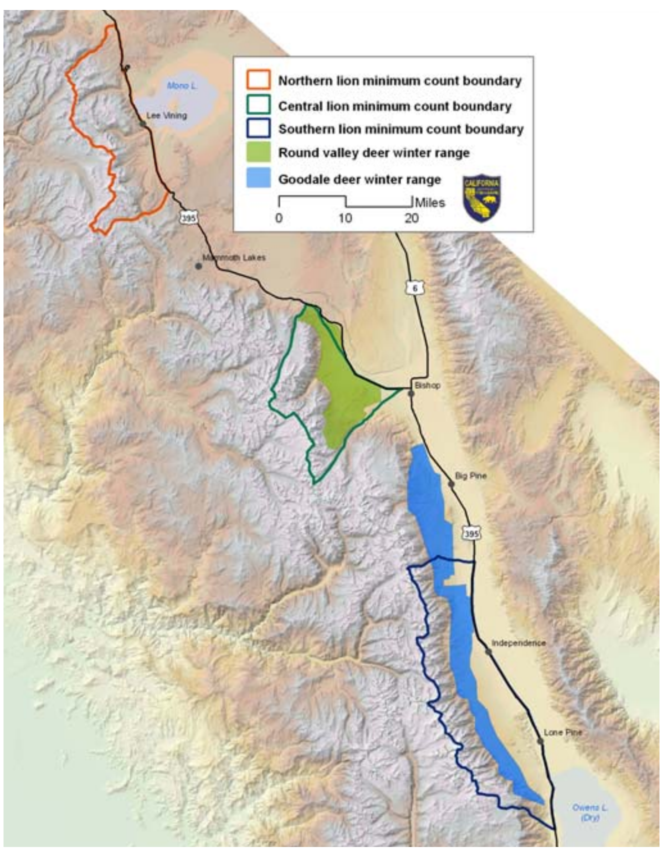

Figure 12. Polygons used to determine minimum counts for mountain lions in the eastern Sierra Nevada during 1999-2011. Mule deer winter ranges represent the primary prey base for mountain lions.

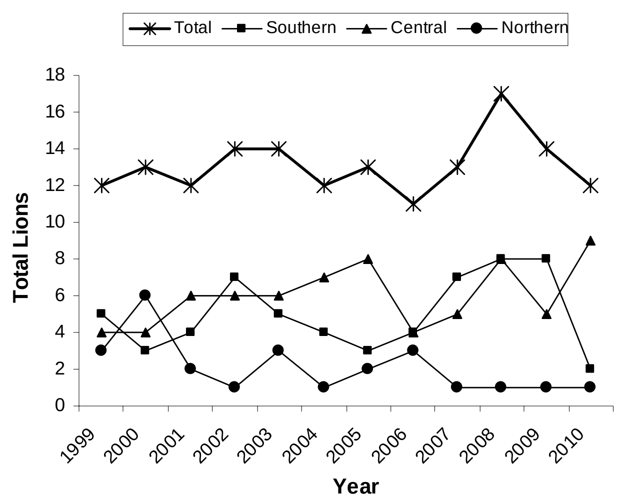

Figure 13. Mountain lion annual minimum counts (July 1 to June 30) in Owens Valley adjacent to Sierra Nevada bighorn sheep low elevation winter range during 1999-2011.

sub-adult, and dispersing lions were included in the minimum count. Kittens were not included. Sixty-seven lions were handled, 3 additional sub-adults were included based on tracks documented early in the program, and 1 adult male has not yet been collared. Eight of these lions used more than 1 recovery unit in the same year; these lions are counted only in the recovery unit they used most in a given year.

The minimum count was developed by continually attempting to capture and collar every lion within each area. This effort entailed tracking with hounds and identifying all lions within each recovery unit. When we encountered tracks of unmarked lions, we pursued them until they were captured or until they left the area (dispersers).

The minimum count of mountain lions was greatest in 2008-2009 when it reached a maximum of 17 (Figure 13) in the polygons defined in Figure 12. Minimum lion counts ranged from 1 to 9 adult, sub-adult, and disperser individuals per year in proximity to each recovery unit.

In addition to the minimum count of lions per Recovery Unit, we documented the number of collared adult mountain lions that traveled within the bighorn herd units. Using polygons of the herd units (Figure 2), we plotted location data from collared lions for the months of November through April. A sum of the number of adult mountain lions that registered at least one location on any winter range was calculated. For the Mount Warren and Mount Gibbs ranges, summer locations were also included. Uncollared lions that were killed or had a confirmed location within a polygon were also included (Figure 14). The level of mountain lion use of herd units was consistent with the incidence of predation on bighorn sheep. For example, abundant lion use of herd units in 2008 coincided with heavy predation, particularly in the SRU.

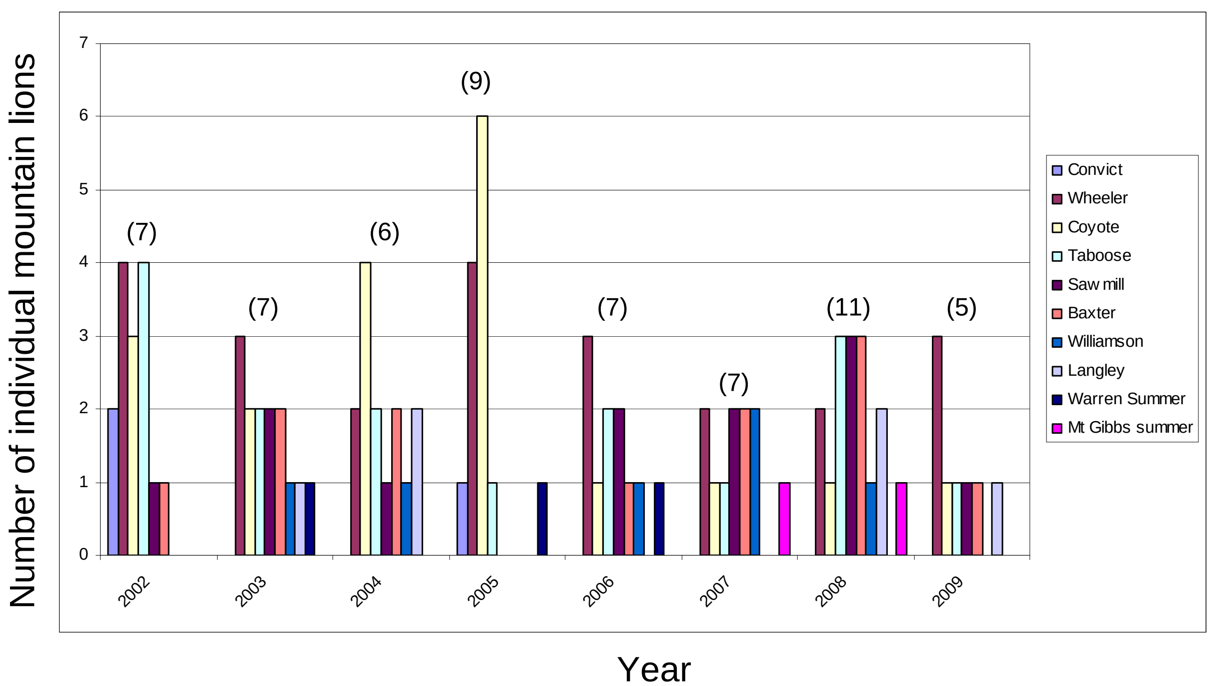

Figure 14. Number of individual adult lions using bighorn sheep ranges from November through April and all months for Mt. Warren and Mt. Gibbs ranges, in each year. The same lion could be counted on different ranges in the same year. Total number of different mountain lions for each year in parentheses.

In general, mountain lions occupied suitable habitat in the majority of the eastern Sierra Nevada and the Owens Valley in proximity to the recovery area for Sierra bighorn. The Round Valley and Goodale mule deer winter ranges supported higher lion populations near the CRU and SRU, respectively. In contrast, the Northern Recovery Unit was not immediately adjacent to the winter range for the Mono Basin mule deer herd that winters at lower elevations in Nevada. Areas of higher lion use tended to be concentrated around mule deer winter ranges (Johnson 2010a). Male home ranges were larger than those of females. Some lions used 2 recovery units in the same year (Figure 15). Figure 15 illustrates the variation in annual range use by mountain lions that wore GPS collars from July 2008 to June 2009. The figure does not represent all lions because not all lions wore GPS collars, but it provides an idea of mountain lion behavior, habitat use, and range use overlap with bighorn sheep and other lions.

Sierra bighorn herd units in the Central and Southern Recovery Units that overlapped with mule deer winter ranges tended to experience higher lion use and heavier predation by mountain lions (Figure 13 and Figure 6A). We observed the heaviest predation on bighorn sheep by mountain lions in the Wheeler Ridge and Mount Baxter herd units, herds that are adjacent to the large Round Valley and Goodale deer winter ranges, respectively. Of mountain lions that were documented to use occupied bighorn habitat repeatedly during 2000-2010, 43% were associated with predation on bighorn sheep. This is likely a conservative estimate of predation rates for mountain lions living in bighorn sheep range because GPS collars were not consistently deployed in all herds until recent years.

In the SRU, VHF collars were replaced with GPS collars on some lions known to kill bighorn starting in 2005. Lions that were not removed after they killed a bighorn were documented to kill additional bighorn. An extreme example of this is lion 95. Lion 95 killed 1 bighorn in March 2007. We replaced his VHF with a GPS collar a few days later. Lion 95 killed a minimum of 5 additional bighorn between February and June 2008. From fall 2006 through spring 2010 in the SRU, 75% of the known resident adult lions were clearly linked to bighorn kills; the other 25% (2) of lions were not directly associated with bighorn kills, but did use bighorn winter range.

Sixty-two bighorn mortalities were identified as probable or certain mountain lions kills in the last 11 years. Bighorn preyed upon by mountain lions were located

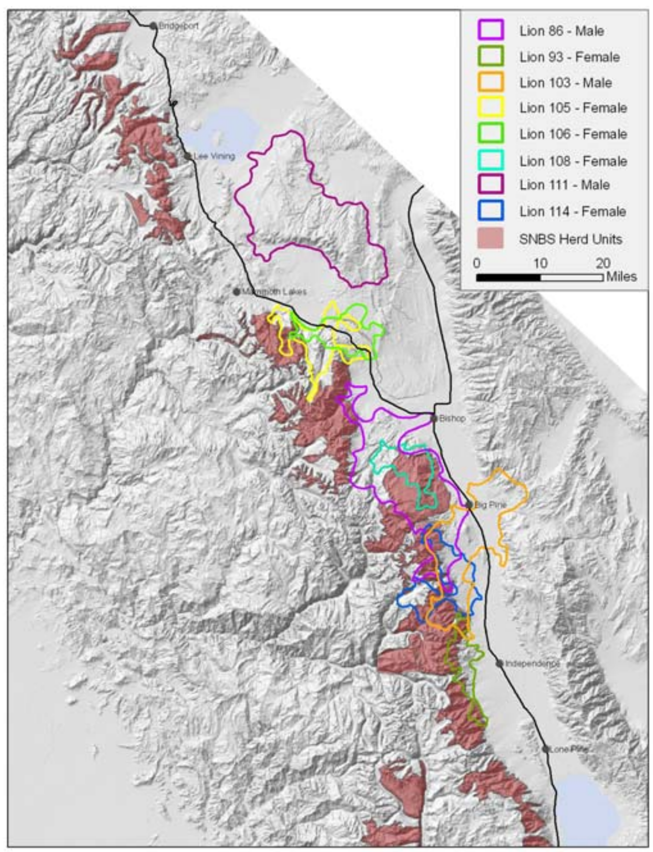

Figure 15. Mountain lion activity areas adjacent to Sierra Nevada bighorn sheep low elevation winter range identified by GPS collar data during July 2008 to June 2009.

by following lion tracks with the use of hounds, by investigating clusters from GPS collars on mountain lions, by investigating mortality signals from sheep collars, and by discovering bighorn mortalities during bighorn population surveys. Since bighorn were listed in 1999, 22 mountains lions were killed to protect them; 18 had preyed upon bighorn. Four were killed because their location data indicated a significant threat to bighorn. Of these, 3 were males removed early in the program (1999-2001), and 1 was a female removed in 2010.

Following heavy predation in the SRU in 2007 and 2008, all lions that demonstrated a threat to bighorn sheep were eventually removed. Nine lions had killed bighorn, and 1 was deemed a threat because of proximity to bighorn. Most removals occurred in 2009. The following year, 2 lions were detected in the SRU, and no lion-killed bighorn mortalities were identified.

The number of known lion deaths per year, including those removed for recovery and those that died of natural causes, road kills, etc., varied between 2 and 11 during 1999-2010 (Figure 16). In all years except 2009, lions died primarily from a variety of natural and human causes not associated with predator removals for bighorn recovery. Although removals for recovery increased in 2009, the total number of annual mortalities was similar to the long-term annual average of lion deaths when adjusted for population size. Mountain lion removal to protect bighorn sheep accounted for 31% of the known lion deaths. Killing mountain lions to protect bighorn sheep is the greatest single cause of mortality of mountain lions in the recovery area (Figure 17).

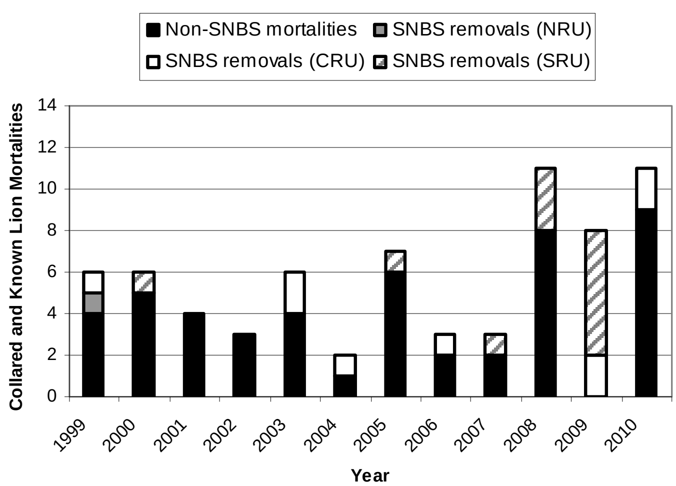

Figure 16. Known mortalities of collared and uncollared lions in the recovery program region by year and cause.

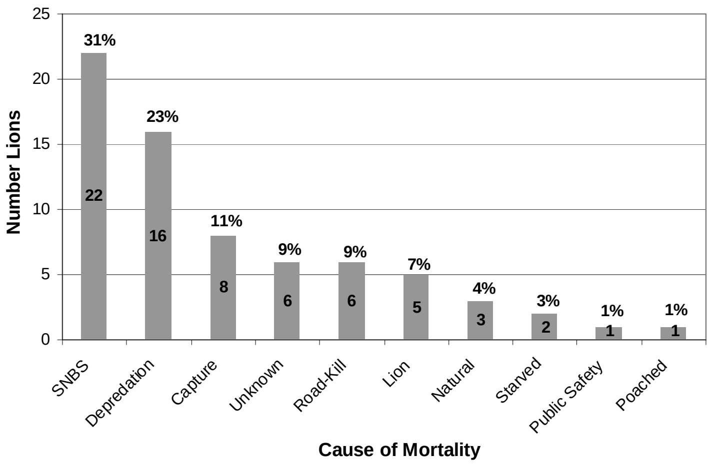

Figure 17. Cause-specific mortality of mountain lions in and adjacent to the recovery area during 1999-2010.

The mountain lion population in California is estimated at 4,000-6,000 animals (Updike 2003). This estimate has a wide range of uncertainty, but illustrates that lions interacting with Sierra bighorn represent a small fraction (<1%) of the overall lion population in the state. The occupied portion of the recovery area for Sierra Nevada bighorn sheep represents about 2% of the habitat for mountain lions in the Sierra Nevada. Although predator management influences the number of mountain lions in localized areas, the effects are not expected to have a negative influence on the larger lion population given the size of the population statewide.

Disease Risk

There is a long history of bighorn sheep die-offs following contact with domestic sheep, and a great deal of research under controlled conditions in captivity has repeatedly found the same result (Lawrence et al. 2010, Wehausen et al. 2011). This evidence was the basis of concern in the Recovery Plan about domestic sheep grazing near bighorn sheep herd units, and a major reason for listing these bighorn as endangered. At the time of listing there were numerous domestic sheep allotments in proximity to existing bighorn sheep herds, including several in the Mono Basin, 1 near the north end of Wheeler Ridge, and a driveway up the Owens Valley through which 6,000 domestic sheep in groups of 1,000 were driven north during springs with good forage growth. In the quarter century prior to endangered listing, stray domestic sheep had been found in bighorn sheep habitat ranging from the Mount Baxter herd north of Independence to the Mount Gibbs herd unit (in Yosemite National Park) and the Mount Warren herd unit north of Lee Vining Creek.

Following emergency federal endangered listing in 1999, the Inyo National Forest (INF) convened an interdisciplinary team to investigate and make recommendations on domestic sheep allotments near Sierra Nevada bighorn herds

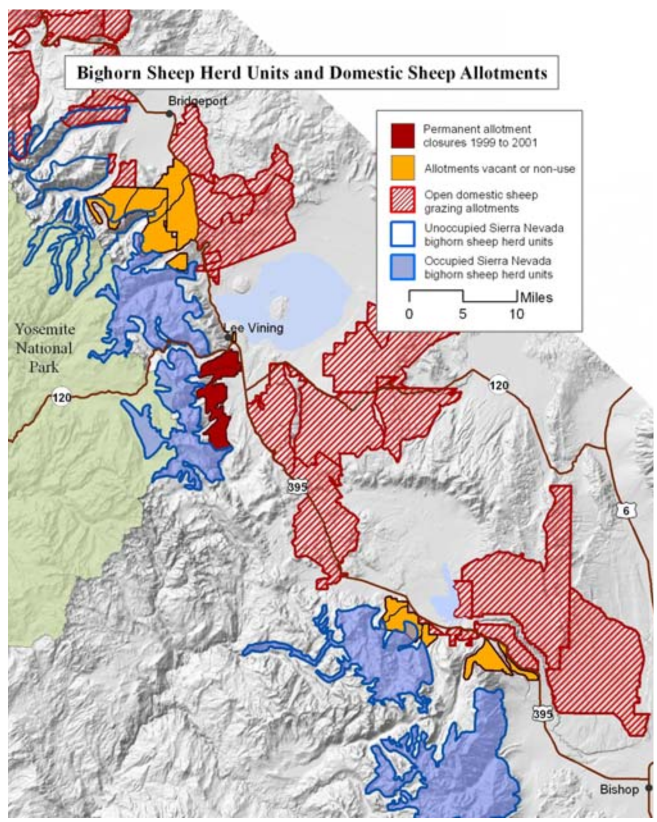

Figure 18. Domestic sheep grazing allotments in proximity to Sierra Nevada bighorn sheep herd units.

on lands administered by INF, Los Angeles Department of Water and Power (LADWP), and other agencies. Those allotments varied greatly in risk from grazing in fenced irrigated pastures in the Mono Basin to allotments in which sheep were moved through higher vegetation with poor visibility in relatively steep terrain on slopes immediately below bighorn ranges. Two such allotments in the Mono Basin were considered a very high risk with no mitigation options. Mitigation measures such as extra fencing and regular counts were proposed for other allotments. LADWP instead chose to terminate all domestic sheep grazing permits on their lands considered in that review, and INF closed the 2 allotments in the Mono Basin that could not be mitigated. This ended the Owens Valley driveway and most domestic sheep grazing in the Mono Basin west of Highway 395.

As part of the 1999 domestic sheep grazing review, allotments further north on lands administered by the Humboldt-Toiyabe National Forest were investigated. Because at that time no bighorn sheep were known to use habitat north of Mill Creek in Lundy Canyon, an agreement was made that an allotment near Lundy Canyon would be closed if bighorn sheep expanded their range across Lundy Canyon. Such an expansion was documented in 2003 and has led to a protracted review process and to multiple agencies vacating allotments. Through that process it was discovered that an allotment at the mouth of Lundy Canyon exists through a permit with Mono County, and discussions are occurring to address this risk.

Deployment of standard VHF and GPS collars on bighorn sheep males by the Recovery Program documented some long distance movements (>53 km) that raised concerns about the risks posed by more distant domestic sheep allotments to the north. The Recovery Program has been very active in dealing with this issue, developing a formal risk assessment relative to this question and convening a Recovery Team subcommittee to address the topic. The Risk Assessment Team met for 2 years and included individuals from agencies and NGOs, as well as permittees. In 2009 the team released a joint document (Baumer et al. 2009) that identified a process for assessing the risk of contact between bighorn and domestic sheep. Subsequently, an additional interagency document (Croft et al. 2009) was completed that clarified recommendations for grazing management. Federal allotments west of Highway 395 were identified as having the most risk. Many of these have been vacated recently or are not currently in use (Figure 18, in orange). Efforts to quantify the risk associated with grazing domestic sheep adjacent to the Sierra bighorn recovery area predict that outbreaks of respiratory disease would be disastrous to the population and to efforts to reach recovery goals (Clifford et al. 2009, Cahn et al. 2011). Planning efforts to further reduce disease risk to Sierra Nevada bighorn sheep are still ongoing.

Habitat Enhancement

Although habitat for Sierra Nevada bighorn sheep has not suffered from fragmentation, pinyon pine encroachment on some winter ranges has reduced winter habitat suitability. Low elevation winter ranges in the Mount Langley, Mount Williamson, and Mount Warren herd units are more heavily forested than bighorn prefer. In April 2001, we carried out a prescribed burn along Diaz Creek on the Mount Langley winter range; the fire produced excellent habitat conditions and is used heavily by Sierra bighorn. During 2009, six polygons outside of designated Wilderness in those 3 herd units were delineated as being suitable for burning to enhance bighorn habitat. During March 2010, a prescribed burn was attempted in Shepherd Creek on the Mount Williamson winter range but conditions were too wet for the fire to carry. In 2010 the Wilderness boundaries were expanded, and all of the proposed burn sites are now in Wilderness. We are evaluating the feasibility of implementing further prescribed burns.

In an effort to better understand the effects of fire on bighorn habitat in the Sierra Nevada, we have studied natural fires such as the Seven Oaks Fire that burned most of the Mount Baxter winter range during July 2007. Forage responded favorably to that fire and was superior within 2 years post burn (Greene 2010).

Translocations

We implemented translocations to augment existing populations during the first 11 years following listing. In 2001, 1 ram was moved from Wheeler Ridge to the Mount Williamson herd to help track bighorn there, but he quickly moved south to the Mount Langley herd. During 2003, 2 rams from Wheeler Ridge were added to the Mount Warren herd to boost genetic diversity. In 2005, 5 pregnant ewes were translocated from Wheeler Ridge to the Mount Baxter herd to expedite recovery, but 3 moved north to the Sawmill Canyon herd. In March 2009, 6 pregnant ewes were moved to Lundy Canyon from Mount Langley (3) and Wheeler Ridge (3), and 5 of the lambs born survived through the summer and were yearlings in spring 2010.

A great deal of planning occurred prior to the translocations in 2009. We used extensive data on collared individuals from source populations to select bighorn ewes with the greatest potential for success following translocation. In particular, we examined data on body condition, disease status, genetic diversity (heterozygosity), winter habitat selection, and reproductive performance. Five of the 6 ewes translocated during 2009 were previously collared and were selected because of their prior optimal health, reproductive history, and heterozygosity. Although program research indicates that changes in genetic variation are not likely to impact short-term conservation efforts, it is import to prevent further losses of genetic diversity (Johnson et al. 2011).

No bighorn have been translocated to unoccupied herd units since listing. Augmentations were restricted to those listed here because of limited source stock, an outbreak of contagious ecthyma, and logistical constraints. Additional planned translocations were not conducted during 2010 because all DFG helicopter operations throughout the state were halted following a helicopter accident in 2010.

Weather

Snow water content was relatively stable during the winters of 2000–2004 (Figure 19), a period during which herds tended to increase in size. Snow water content represents total snowfall as melted water (see figure legend for further explanation). The winters of 2005, 2006, and 2011 were characterized by significantly higher snow levels, while snow water content was below average in the drought year of 2007. Overall, the Mount Gibbs herd unit experienced the greatest snow levels, although this weather station was located at a higher elevation than the other stations. All other herd units exhibit a pattern of comparatively lower snow levels.

Precipitation has the potential both to positively and negatively influence bighorn sheep dynamics (Johnson et al. 2010c). Abundant precipitation results in improved quantity and quality of forage for bighorn sheep; drought years reduce the nutritional quality of habitat. However, although precipitation may ultimately drive population growth, direct relationships between precipitation and population size are often difficult to detect.

A string of relationships separate demographic parameters from precipitation. The complexities arise because precipitation directly affects forage quantity and quality,

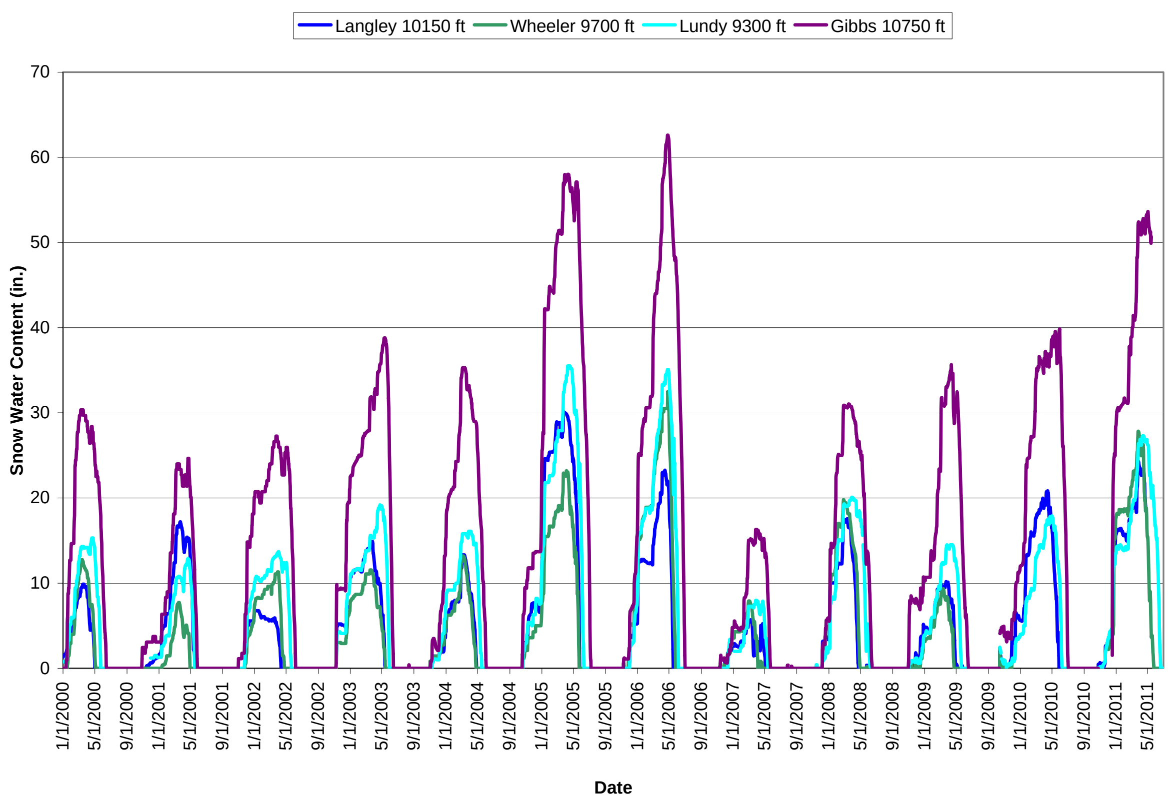

Figure 19. Water content of snow from high elevation weather stations near Sierra Nevada bighorn sheep herd units 2000–2011. Snow depths on an average-weather year can be approximated by multiplying Snow Water Content values reported near the first of the each month by the following factor: January 3.0 and May 2.0. 2010 data is missing for Wheeler; 2004 data is missing for Langley.

which then dictate animal body condition. Population density also affects body condition through competition for forage and its acquisition. Body condition determines survival and reproductive success, which determine recruitment and finally population growth. Further complexities arise from density-independent events, such as predation, avalanches, and disease, that may or may not be influenced by precipitation but that may depress otherwise healthy populations. Many factors interact to determine population size, but on a fundamental level populations will under-perform if precipitation and forage are inadequate.

The average precipitation early in the decade likely benefited body condition of bighorn sheep and is reflected in the overall population growth during that period. Yet the arrival of extreme weather during the middle of the decade appears to coincide with declining population growth rates and recruitment. Specifically, the drought in the winter of 2006-2007 likely had a multiyear influence on bighorn demographics. Several rams in the Mount Warren herd unit died of malnutrition in 2008. In the fall of 2007, bighorn at Wheeler Ridge experienced an outbreak of contagious ecthyma which may have been induced by stress following the drought. At Mount Langley and Wheeler Ridge, declines in fecundity and recruitment were observed in 2008. The severe winter of 2011 also affected bighorn populations. Mortalities of adult bighorn at Wheeler Ridge and Mount Warren due to deep snow and avalanches increased (see Cause Specific Mortality and Survival above). This stochastic weather event may delay recovery of these herds.

Future Actions to Reach Recovery Goals

Downlisting and delisting goals in the Recovery Plan include: (1) at least 305 adult and yearling females in a specified distribution among recovery units, and (2) the occupation of 12 specific herd units. Currently, established herds occupy 7 of those herd units, and at least 1 more is in the early stages of natural colonization. The current total number of females (195) is 64% of the Recovery Plan goal.

Four vacant herd units are required for recovery: Laurel Creek and Big Arroyo in the Kern Recovery Unit and Olancha Peak and Taboose Creek in the Southern Recovery Unit. As few as 3 herd units (Laurel Creek, Big Arroyo, and Olancha Peak) require translocations to achieve herd unit occupancy goals because movement barriers make it unlikely that natural colonizations will occur. Movements of collared bighorn from an adjacent herd indicate that Taboose Creek may be colonized naturally as the adjacent population increases. Each reintroduction will consist of translocations of at least 40 bighorn sheep to maximize genetic diversity and to generate group sizes for optimal survival and reproduction.

The availability of adequate numbers of bighorn sheep for such translocations is dependent on the growth of the Mount Baxter and Sawmill Canyon herds to a size sufficient to serve as a source of translocations, as they did previously for 4 of the currently occupied herd units. Stock for translocations will also come from the Wheeler Ridge and Mount Langley herds, if they maintain a size large enough to allow removals. Other herd units may need augmentations to reach optimal sizes.

Reaching recovery goals will therefore necessitate adaptive management to maximize the demographic health of the potential sources of translocation stock, and removal of sheep from those herds for translocation in a way that optimizes herd productivity while protecting source herds. This will entail continued protection of sources of translocation stock from predation and the use of fire to improve habitat. Efforts to minimize the potential for introduced disease from domestic sheep and goats are also still ongoing, and are essential to protect existing herds.

Continued cooperation among agencies is essential given that Sierra Nevada bighorn sheep reside almost entirely in multiple National Parks and National Forests, and herd units are adjacent to land with many other public and private owners (Figure 20).

Recovery goals may be approached within a decade if commitment is maintained to fully implement primary recovery actions. Because habitat and connectivity are fully intact, there is high potential to reestablish a fully functioning metapopulation in the Sierra Nevada. A unique opportunity exists to restore this native ungulate to the Sierra Nevada ecosystem.

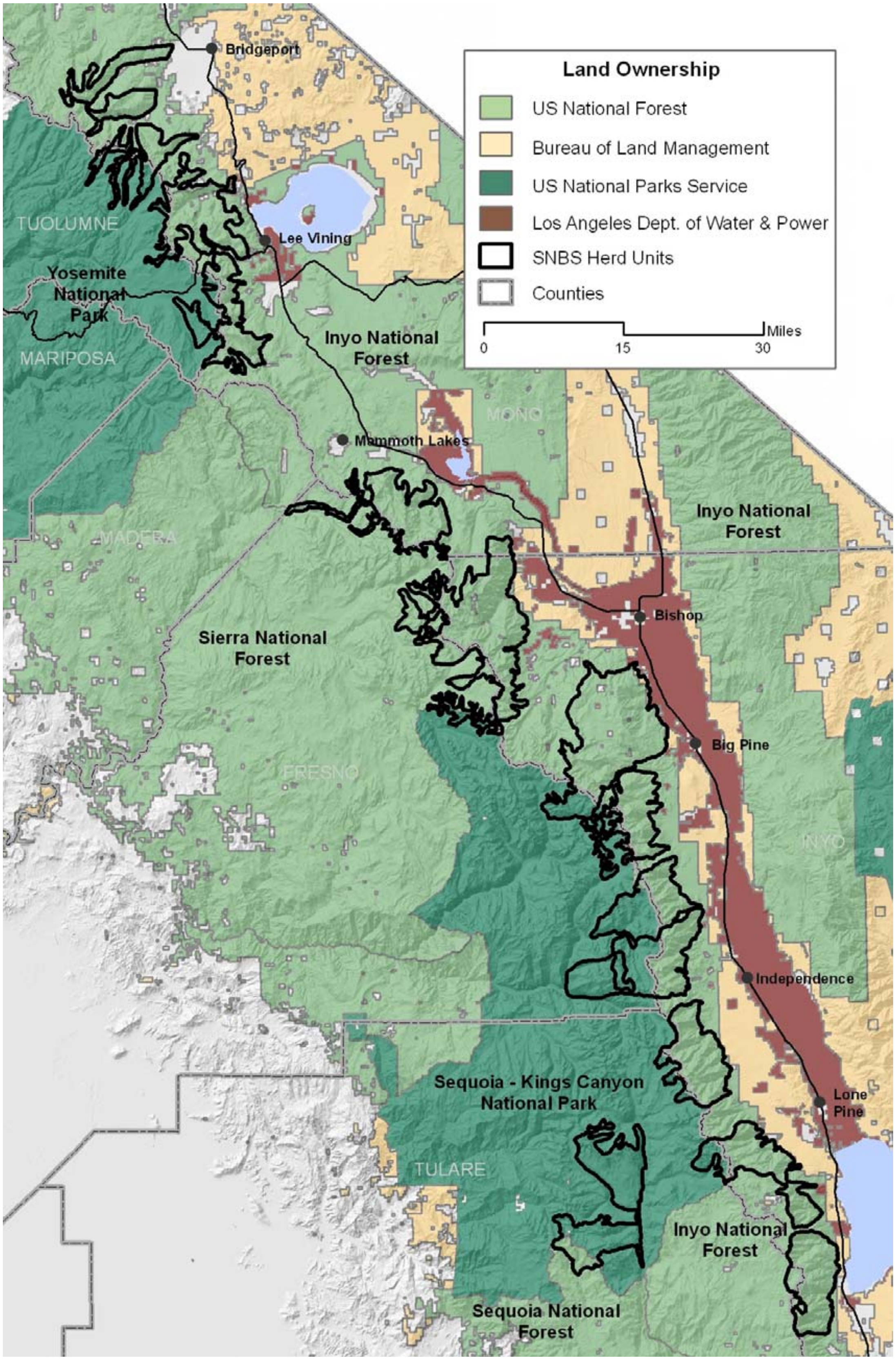

Figure 20. Land ownership of Sierra Nevada bighorn sheep herd units and neighboring areas.

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Appendix A.

Demographic history of Sierra Nevada bighorn sheep during 2006 – 2011.

Herd Unit	Year	Adult Ewes	Yrlg Ewes	Min. Total Ewes	Est. Total Ewes	Lambs	Adult Rams	Yrlg Rams	Min. Total Rams	Est. Total Rams	Min. Total	Total With Ests.
Langley	06-07	34	11	45	38 (35-47)	18	21	7	28		91	
	07-08	34	10	44	47 (38-60)	17	16	6	22		83	86
	08-09	35	3	38	46 (33-65)	8	19	5	24		70	76
	09-10	29	4	37[1]	48 (32-71)	15	15	4	19		71	67
	10-11	36	6	42	41 (30-56)	11	32	7	39		92	
Williamson	07-08	10	3	13		7	7	1	8		28	
	08-09	11	3	14		4	8	2	10		28	
	09-10	8	0	8		2	6	0	6		16	
	10-11	9	1	11[1]		3	-	1	1		15	
Bubbs	06-07	-	-	-		-	-	-	-		-	
	07-08	13	1	14		6	6	1	7		27	
	08-09	14	3	17		1	4	1	5		23	
	09-10	-	-	-		-	-	-	-		-	
	10-11	6	3	9		2	11	1	12		23	
Baxter	07-08	26	3	29		10	9	4	13		53	
	08-09	29	5	34	27 (18-40)	13	12	5	17		64	
	09-10	24	6	30	28 (27-36)	20	21	1	22		72	
	10-11	27	5	32	28 (27-36)	13	26	8	34		79	
Sawmill	07-08	11	1	12	22[1]	4	3	2	5		18	28
	08-09	22	1	23	29[1]	9	8	3	11		43	49
	09-10	29	1	30	33[1]	10	13	2	15		55	
	10-11	33	6	39		16	8	6	14		69	
Wheeler	06-07	34	4	38	49 (37-61)	11	26	4	30	59 (26-92)	79	119
	07-08	36	6	42	55 (43-70)	15	35	4	39		96	109
	08-09	36	2	38	43 (33-56)	14	20	2	22	33 (21-55)	74	90
	09-10	36[1]	3	39[1]	43 (31-59)	12	31	2	33	35 (29-42)	75	90
	10-11	29	5	34	40 (32-51)	21	23	10	33		88	
Gibbs	06-07	3	1	4		2	3	0	3		9	
	07-08	4	1	5		4	3	1	4		13	
	08-09	5	2	7		3	3	2	5		15	
	09-10	8	1	9		2	5	1	6		17	
	10-11	7	0	7		1	6	0	6		14	
Warren	06-07	7	2	9		4	10	0	10		23	

	07-08	7	2	9	11[1]	4	13	0	13		26	28
	08-09	6	2	8	10[1]	5	7	0	7		21	23
	09-10	10 + 6[2]	1	11 + 6[2]	11 + 6[2]	7 + 5[2]	6	2	8		26/37[2]	
	10-11	16	5	21		11	5	3	8		40	
Totals	07-08	141	27	168		67	92	19	111		344	
	08-09	158	21	179		57	81	20	101		338	
	09-10	150	16	170		73	97	12	109		343	
	10-11	163	31	195		78	111	36	147		420	

[1] reconstructed population based on additional ewes documented in later years

[2] translocated ewes and the lambs born to them that survived into summer

Appendix B.
Herd Unit Summaries: Geographic and Demographic Analyses

The information presented in this appendix is intended to summarize all demographic data and significant events for each herd unit since the time of listing as an endangered species or earlier where reliable information is available. Each herd unit summary contains a map describing the location of the herd unit and areas used by bighorn, a timeline containing management actions, immigration/emigration events, known changes in habitat use, and weather events of ecological importance, and where data permit, a series of graphs displaying demographic data over time. The demographic measures presented are the total number of adult and yearling ewes, the rate of change of the total number of ewes (lambda), fecundity (lamb to ewe ratio), recruitment (yearling to ewe ratio), and survival. Methods used to generate demographic data are described below.

Methods

Population Estimates

Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and including mark-resight (MR) estimates with 95% confidence intervals for years when the MR estimate was larger than the minimum count.

For herd units with summer (post-birth pulse) surveys (Mount Langley, Mount Williamson, Bubbs Creek, Mount Gibbs, and Mount Warren); the count data is from July to October of that year. For herd units with winter (pre-birth pulse) surveys (Mount Baxter, Sawmill Canyon, and Wheeler Ridge) the count data were collected from November to April of the following year. For example, most winter surveys typically occur in March; the year associated with those data is typically the prior year such that data collected in March 2010 is recorded for 2009. Data presented in this Appendix are from a consistent season for each herd and may not be consistent with the data in Figure 4 that substitutes summer data for incomplete winter data.

Lambda

Lambda is a measure of population change and was calculated as the current year's population estimate divided by the previous year's population estimate (N_{t+1}/N_t) based on minimum counts for adult and yearling ewes or reconstructed counts and adjusted for translocations and biologically implausible values.

For years in which ewes were removed for translocation, the population estimate the year prior to removal (N_t) was decreased to exclude removed animals. For years in which augmentations occurred, the population estimate of the year of the augmentation (N_{t+1}) was decreased to exclude introduced animals.

Lambda was considered biologically implausible and excluded from analysis if lambda > 1.5 and N > 20 or lambda >

2 and N ≤ 20. These biologically implausible values are likely caused by under counts in year N_t which affects lambda for two years. Thus lambda determined to be biologically implausible by the above rules resulted in censoring that year's lambda and lambda from the preceding year.

Lamb to Ewe and Yearling to Ewe Ratios

Lamb to ewe and yearling to ewe ratios are calculated based on observed animals during one year. No reconstructions are included in these calculations. For winter surveys (pre-birth pulse), adult females are ≥2.7 years old; yearlings are ~1.7-1.9 years old; and lambs are ~0.7-0.9 year old. For summer surveys (post-birth pulse), adult females are ≥2.1 years old; yearlings are ~1.1-1.3 yrs old; and lambs are ~0.1-0.3 years old.

Survival

Kaplan-Meyer survival rates are calculated annually for collared ewes based on sheep birth years (April 15-April 14). We calculated adult female survival of the year (t) as $N_A(t)/(N_A(t-1) + N_Y(t-1))$ where N_A is the number of adult females and N_Y is the number of yearling females. We used a Kaplan Meier estimator treating all adult females as a single age class (Heisey 2006). Staggered entry during a given year was not included. Staggered entry was accounted for only on an annual basis. Survival rates are only plotted for years where populations contained ≥3 collars.

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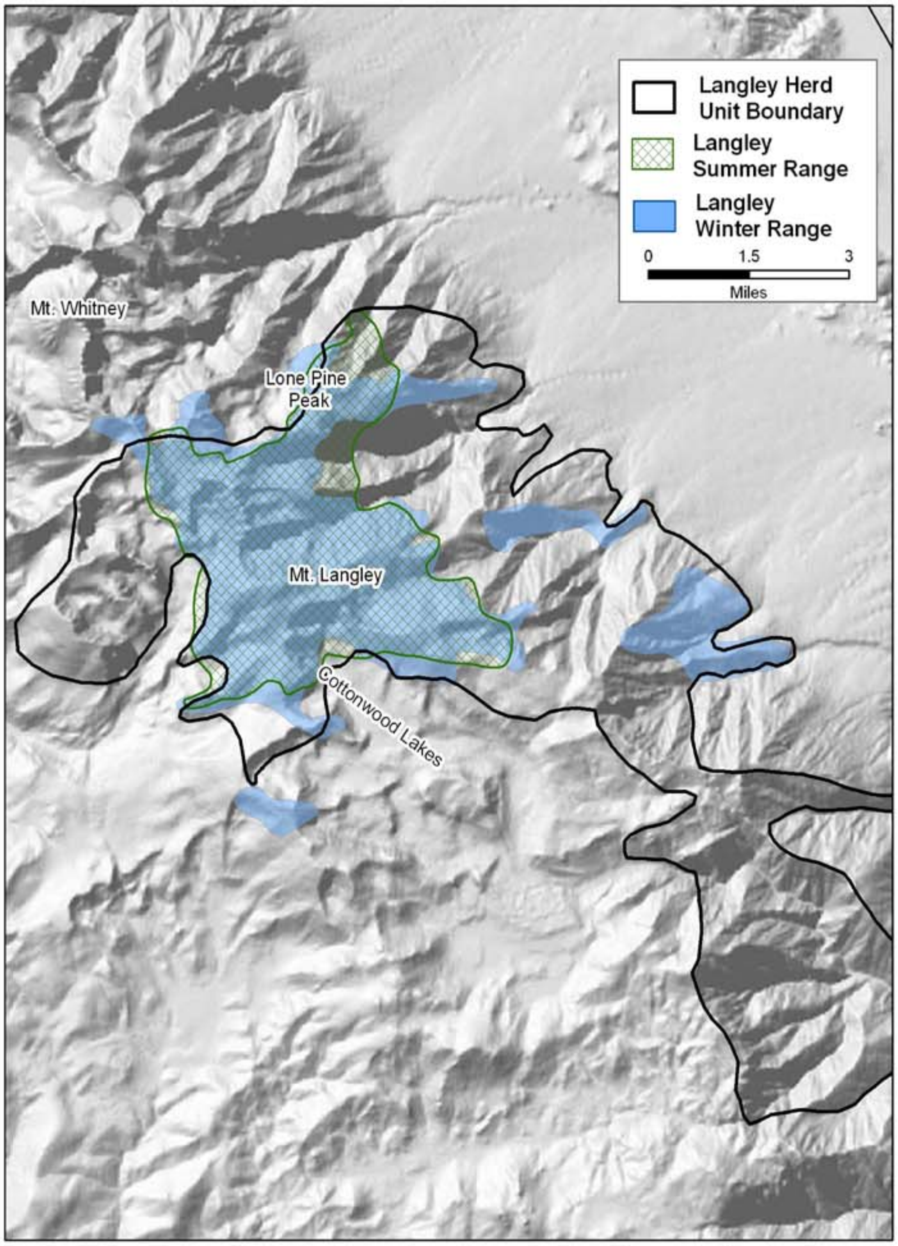
Mount Langley

Herd Unit Description

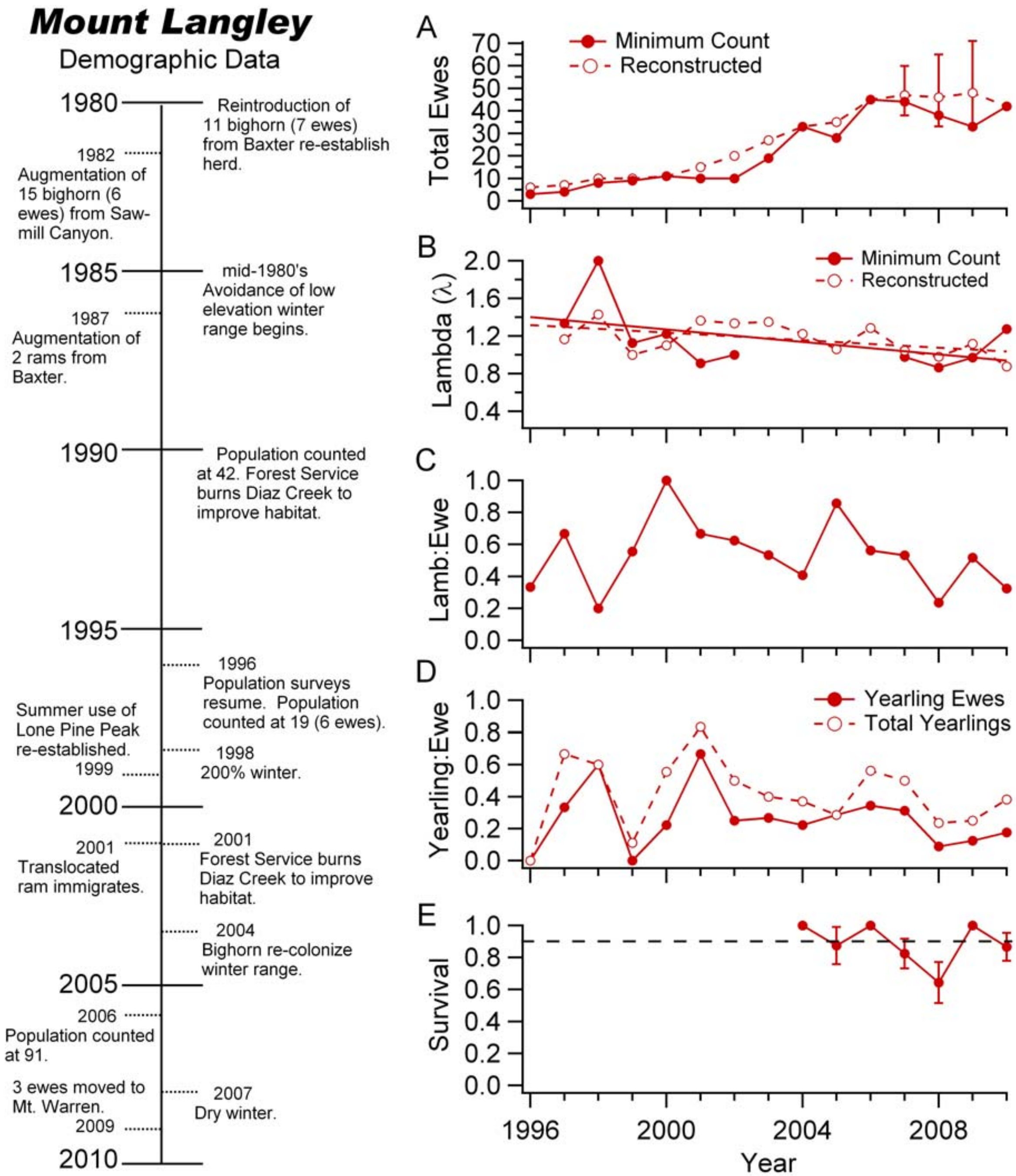


Herd unit area (boundary defined in Recovery Plan): 133 km^2

Combined used summer and winter range area (defined below): 52 km^2 (2D area) or 63 km^2 (3D area)

Lowest Elevation: 1,738 m (5,702 ft)
Highest Elevation: 4,261 m (13,980 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were combined to measure area. Lowest and highest elevations were extracted from this polygon.



This herd unit is surveyed in summer. Count data are collected from July - Oct. and recorded for that year.

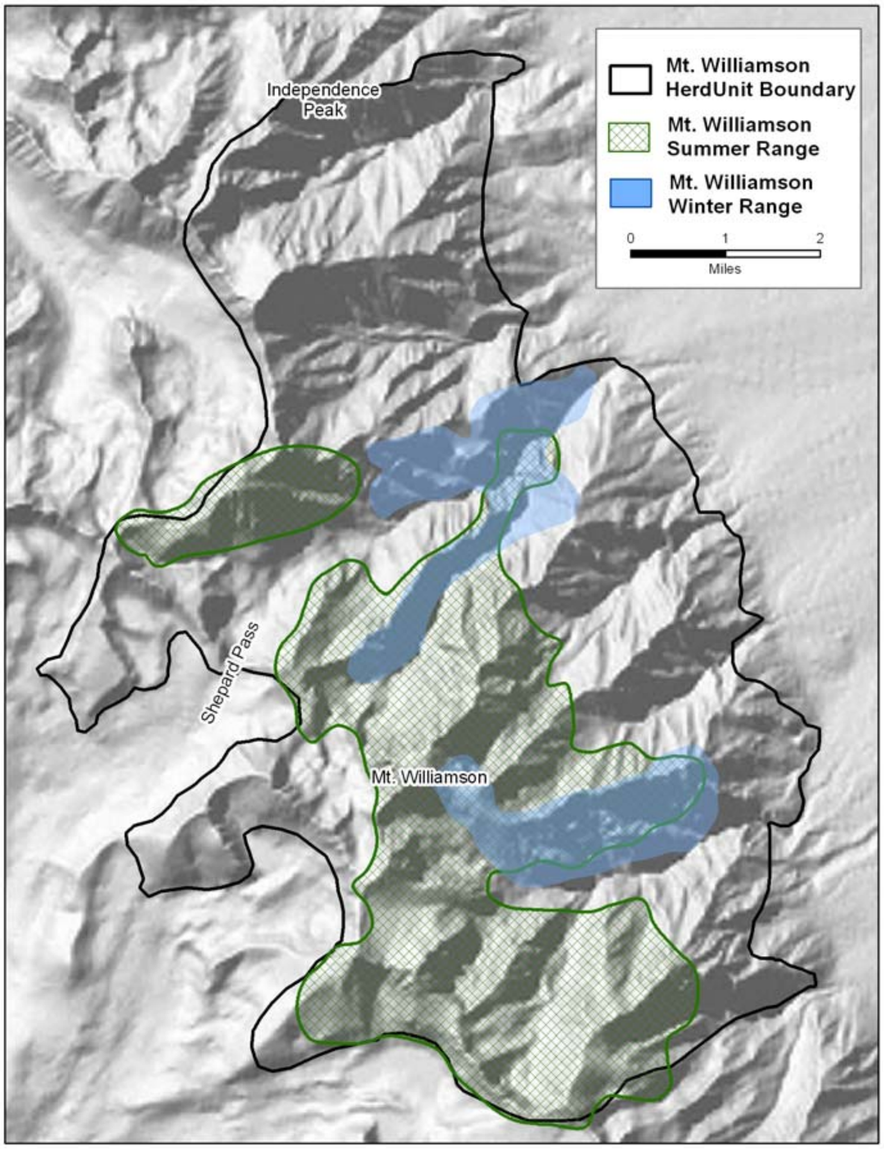
A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and mark-resight estimates with 95% confidence intervals displayed -○-.

B. Lambda (λ) was calculated as N_{t+1}/N_t using population estimates as in A. Lambda was adjusted for translocations and biologically implausible values of lambda were excluded from analysis (see Methods).

C-D. Lamb to adult ewe and yearling to adult ewe ratios are calculated based on observed animals during one year.

E. Kaplan-Meyer survival rates are calculated annually for collared ewes based on sheep birth years (see Methods).

Mount Williamson
Herd Unit Description



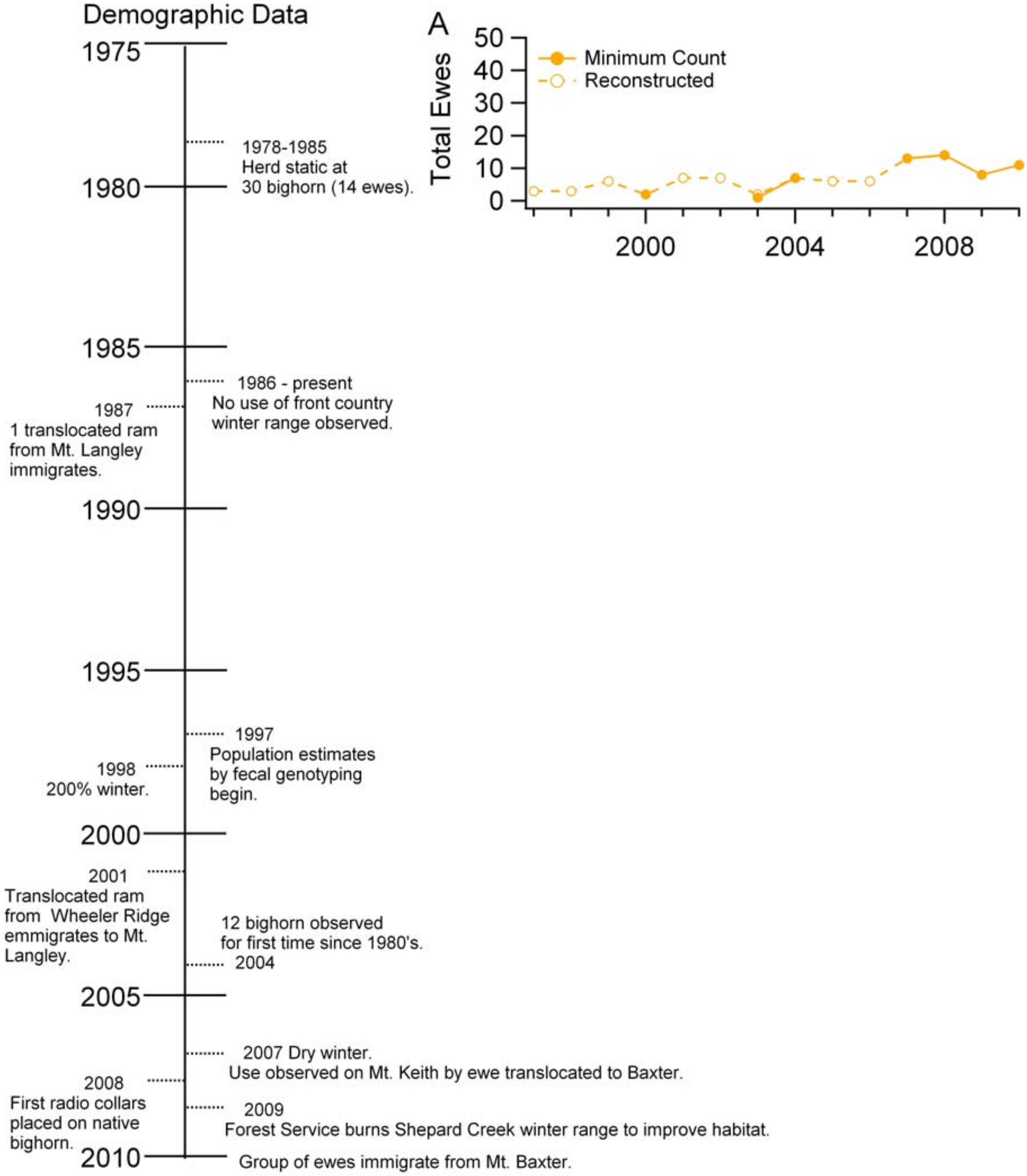
Herd unit area (boundary defined in Recovery Plan): 132 km^2

Combined used summer and winter range area (defined below): 55 km^2 (2D area) or 70 km^2 (3D area)

Lowest Elevation: 1,929 m (6,329 ft)
Highest Elevation: 4,372 m (14,344 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were combined to measure area. Lowest and highest elevations were extracted from this polygon.

Mount Williamson



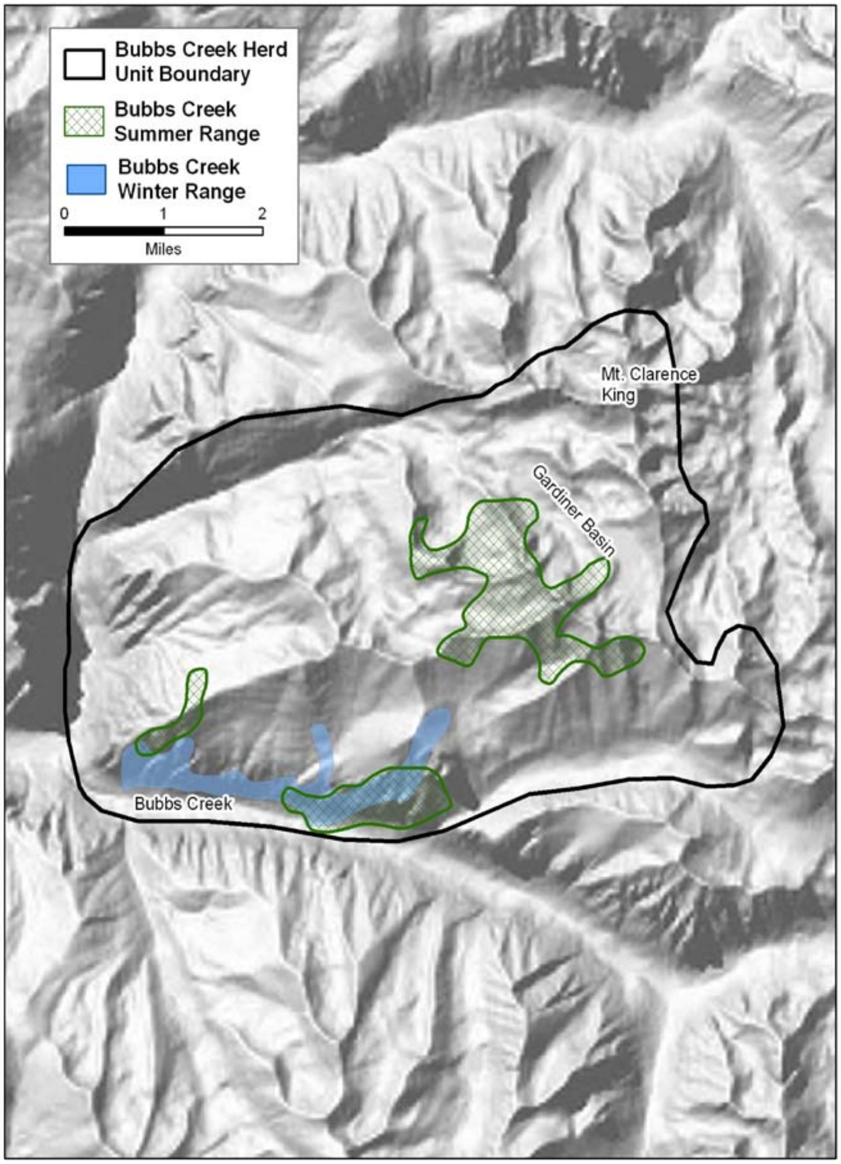
This herd unit has been surveyed in summer and winter.

A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and mark-resight estimates -○-.

Lamb to adult ewe ratios averaged 0.43 based on very small sample sizes. Yearling to adult ewe ratios were calculated based on observed animals during one year. The average yearling ewe to adult ewe ratio was 0.14, and the average total yearling to adult ewe ratio was 0.29 based on very small sample sizes.

Bubbs Creek

Herd Unit Description



Herd unit area (boundary defined in Recovery Plan): 64 km^2

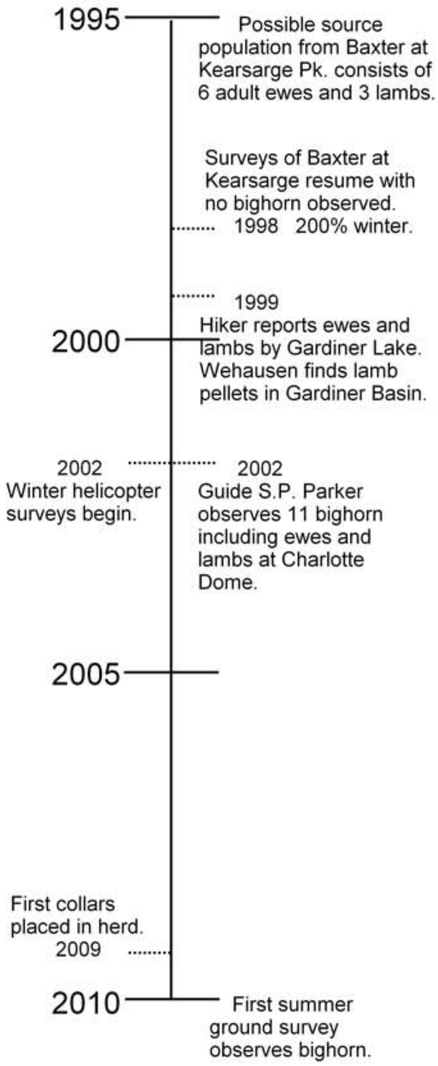
Combined used summer and winter range area (defined below): 7.8 km^2 (2D area) or 10.1 km^2 (3D area)

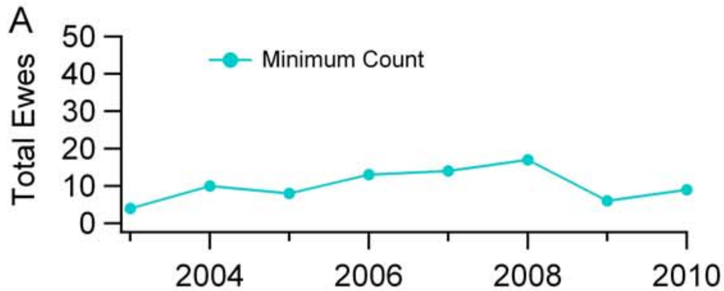
Lowest Elevation: 1,928 m (6,325 ft)
Highest Elevation: 3,927 m (12,884 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were combined to measure area. Lowest and highest elevations were extracted from this polygon.

Bubbs Creek

Demographic Data





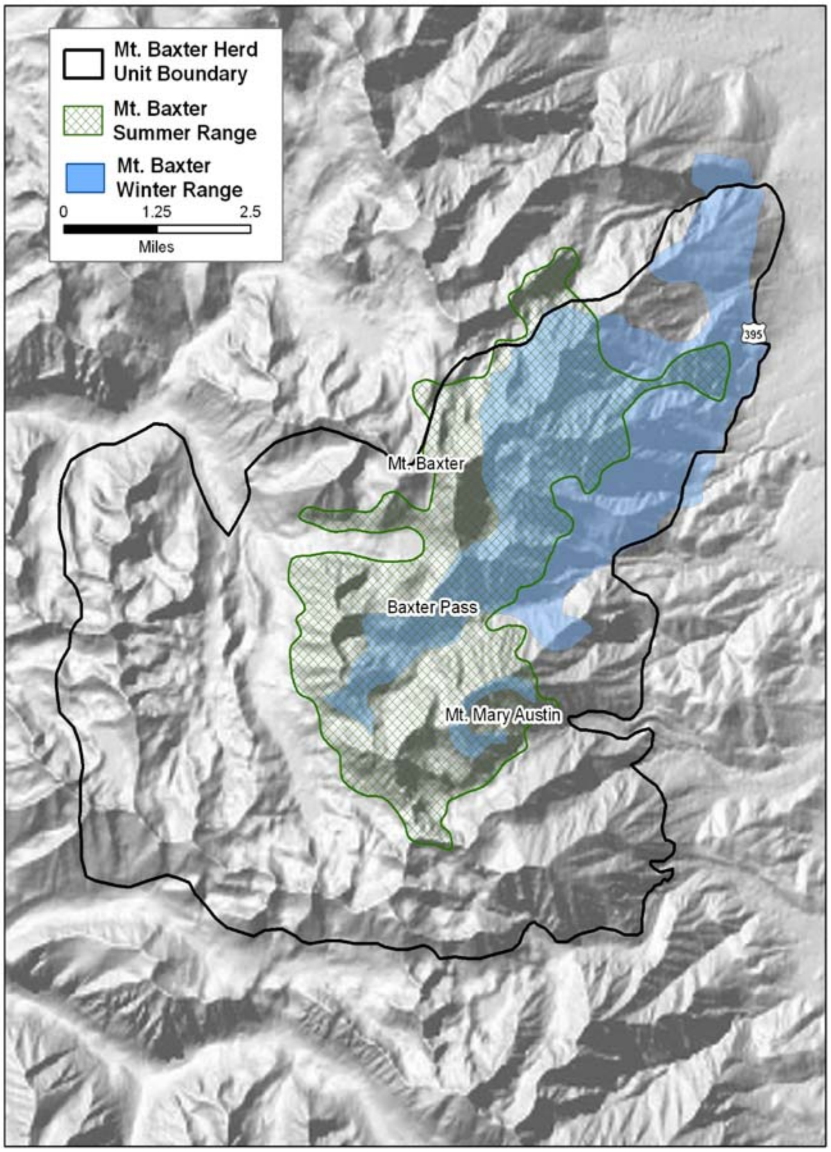
This herd unit has been surveyed in summer and winter.

A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-.

Lamb to adult ewe ratios averaged 0.4 based on very small sample sizes. Yearling to adult ewe ratios were calculated based on observed animals during one year. The average yearling ewe to adult ewe ratio was 0.23, and the average total yearling to adult ewe ratio was 0.4 based on very small sample sizes.

Mount Baxter

Herd Unit Description

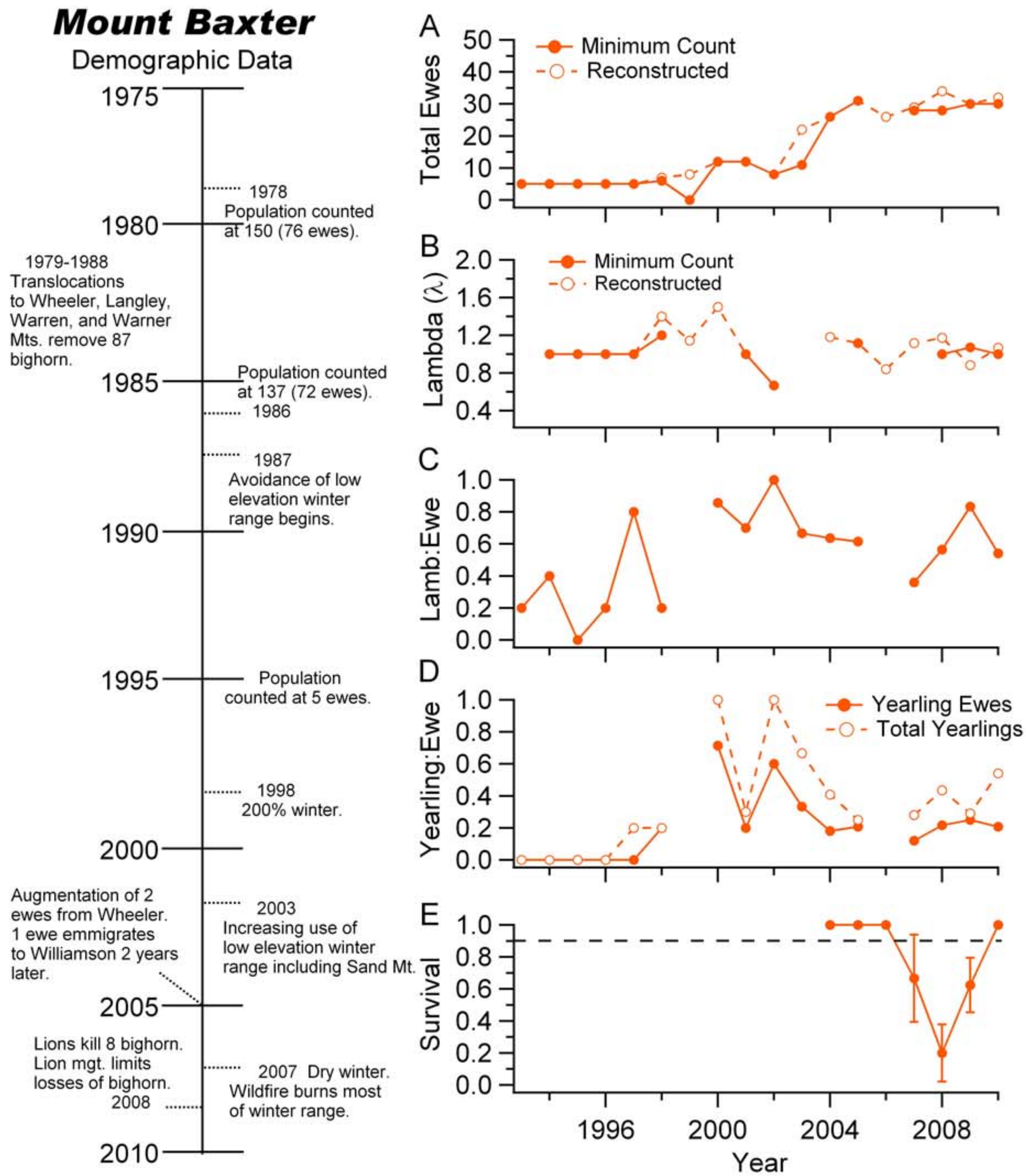


Herd unit area (boundary defined in Recovery Plan): 100 km^2

Combined used summer and winter range area (defined below): 59 km^2 (2D area) or 74 km^2 (3D area)

Lowest Elevation: 1,450 m (4,757 ft)
Highest Elevation: 4,022 m (13,196 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were combined to measure area. Lowest and highest elevations were extracted from this polygon.



This herd unit is surveyed in winter. Count data are collected from Dec. - April and recorded for that year.

A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and mark-resight estimates -○-.

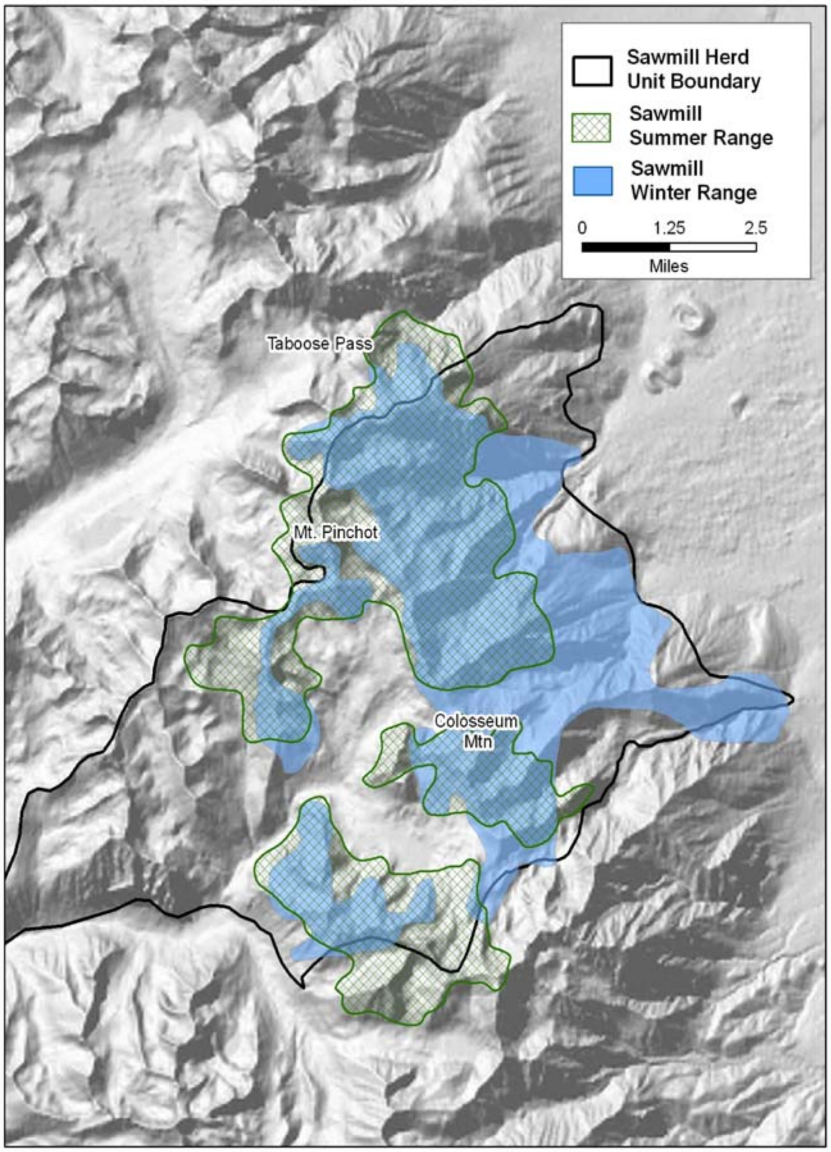
B. Lambda (λ) was calculated as N_{t+1}/N_t using population estimates as in A. Lambda was adjusted for translocations and biologically implausible values of lambda were excluded from analysis (see methods).

C-D. Lamb to adult ewe and yearling to adult ewe ratios are calculated based on observed animals during one year.

E. Kaplan-Meyer survival rates are calculated annually for collared ewes based on sheep birth years (see methods).

Sawmill Canyon

Herd Unit Description

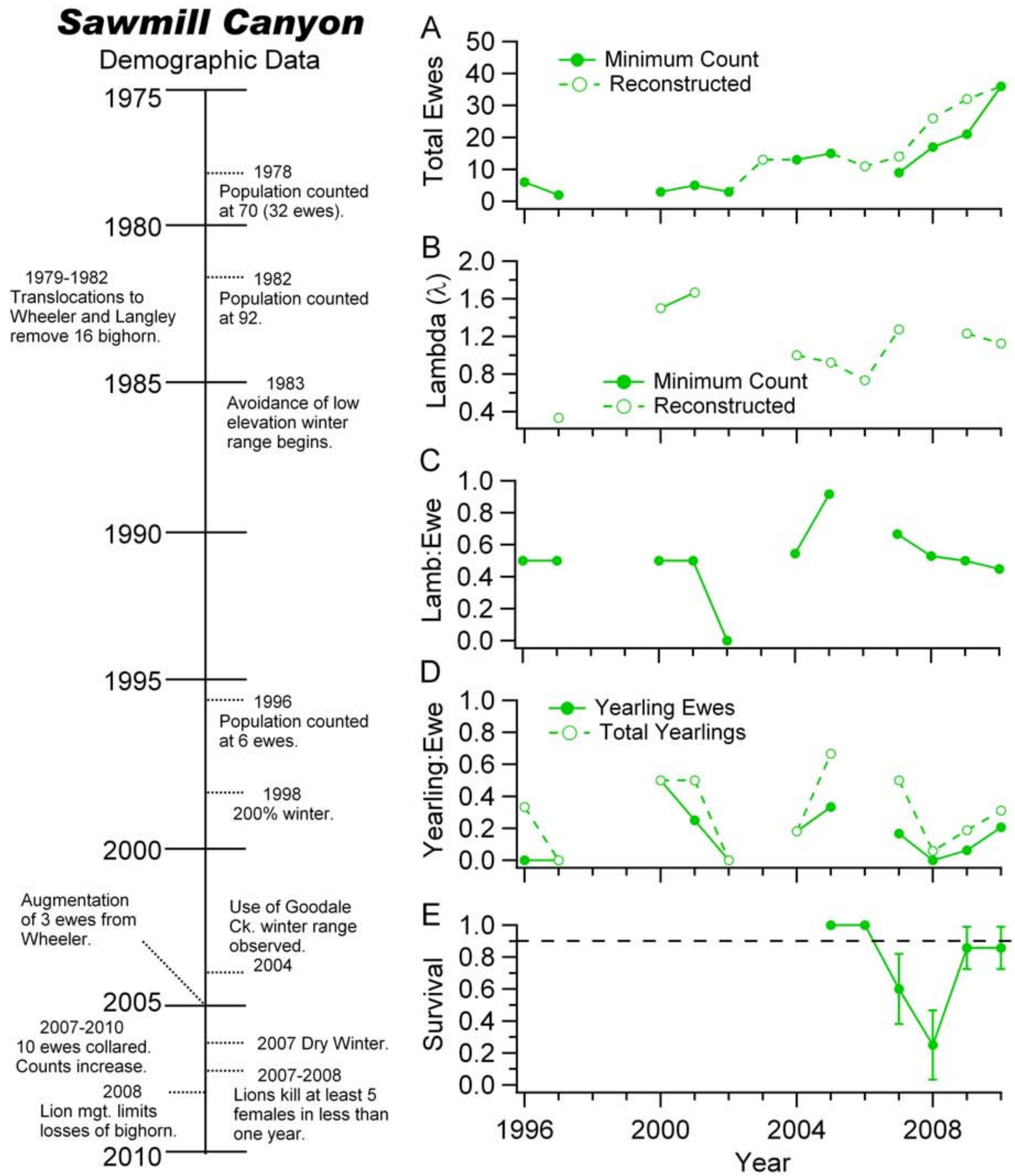


Herd unit area (boundary defined in Recovery Plan): 305 km^2

Combined used summer and winter range area (defined below): 79 km^2 (2D area) or 97 km^2 (3D area)

Lowest Elevation: 1,441 m (4,728 ft)
Highest Elevation: 4,102 m (13,458 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were combined to measure area. Lowest and highest elevations were extracted from this polygon.



This herd unit is surveyed in winter. Count data are collected from Dec. - April and recorded for that year.

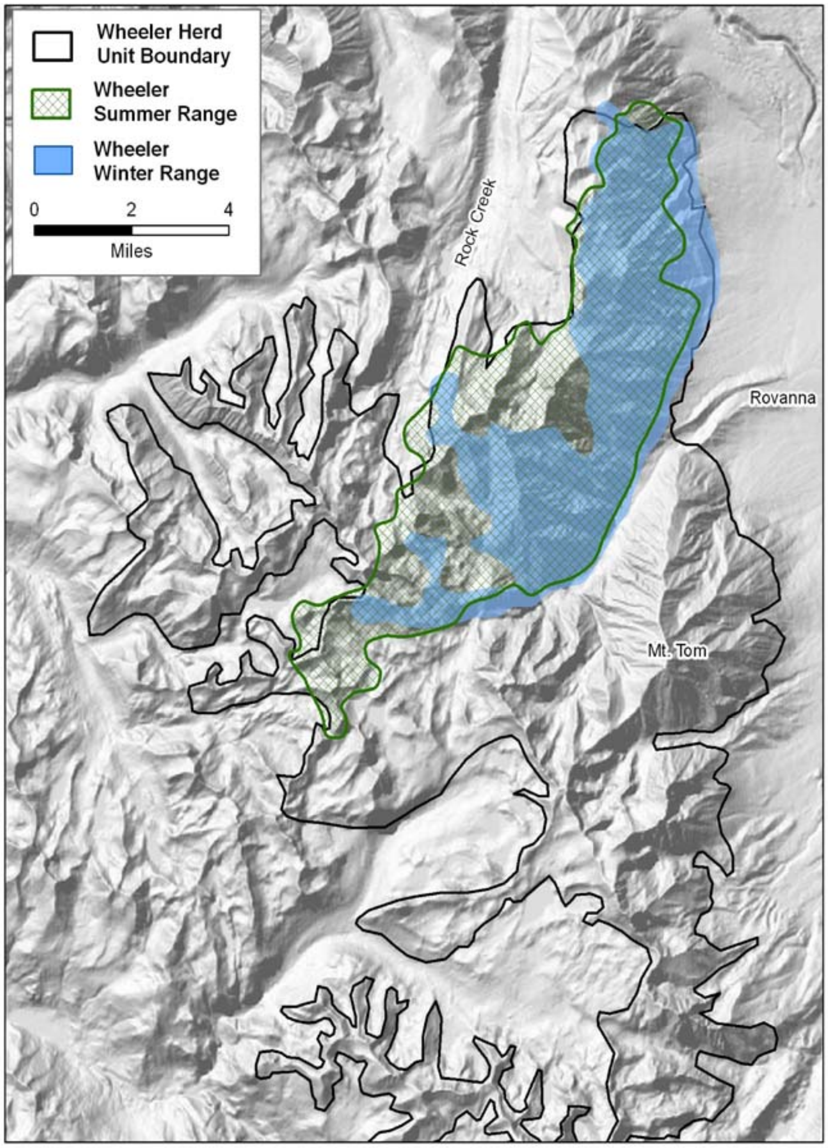
A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and mark-resight estimates -○-.

B. Lambda (λ) was calculated as N_{t+1}/N_t using population estimates as in A. Lambda was adjusted for translocations and biologically implausible values of lambda were excluded from analysis (see methods).

C-D. Lamb to adult ewe and yearling to adult ewe ratios are calculated based on observed animals during one year.

E. Kaplan-Meyer survival rates are calculated annually for collared ewes based on sheep birth years (see methods).

Wheeler Ridge
Herd Unit Description

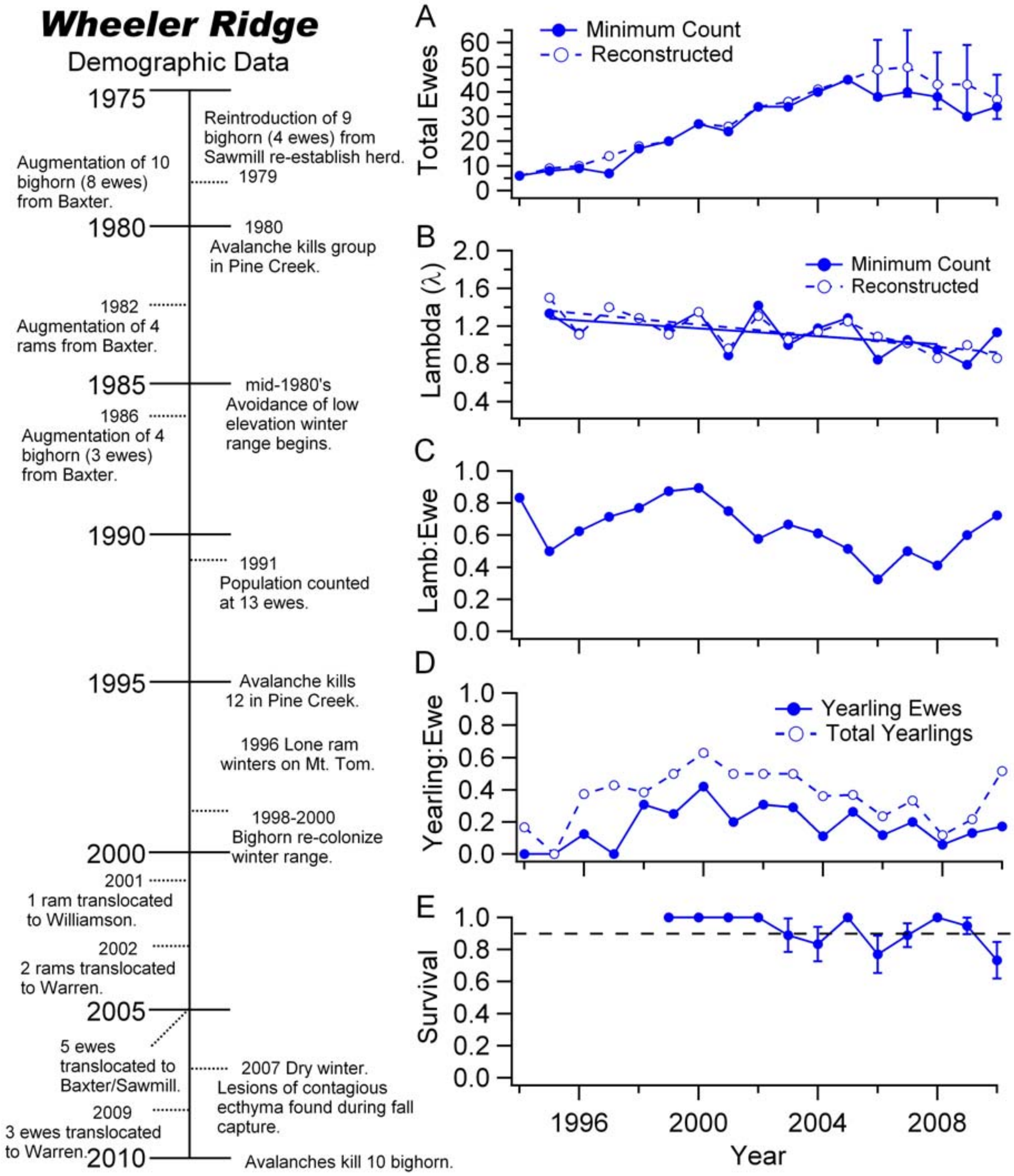


Herd unit area (boundary defined in Recovery Plan): 328 km^2

Combined used summer and winter range area (defined below): 103 km^2 (2D area) or 126 km^2 (3D area)

Lowest Elevation: 1,585 m (5,200 ft)
Highest Elevation: 4,176 m (13,701 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were combined to measure area. Lowest and highest elevations were extracted from this polygon.



This herd unit is surveyed in winter. Count data is collected from Dec. - April and recorded for that year.

A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and mark-resight estimates -○-.

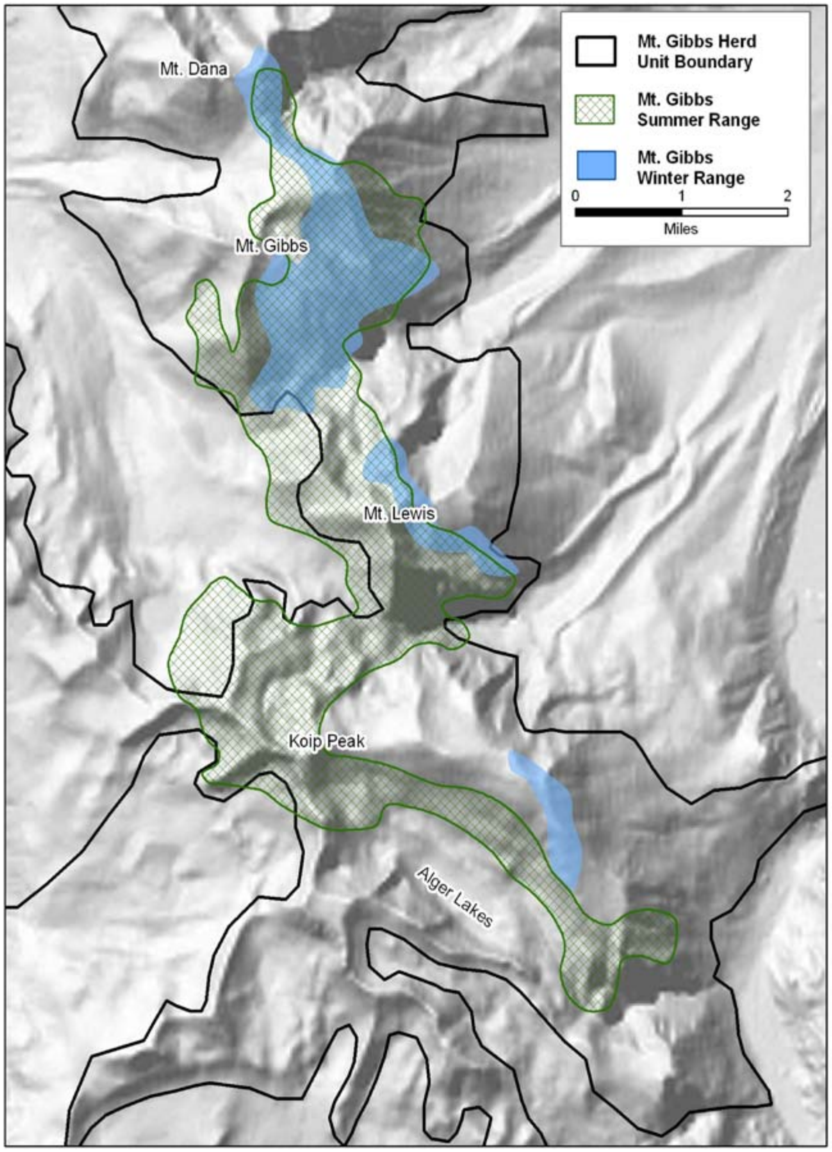
B. Lambda (λ) was calculated as N_{t+1}/N_t using population estimates as in A. Lambda was adjusted for translocations and biologically implausible values of lambda were excluded from analysis (see methods).

C-D. Lamb to adult ewe and yearling to adult ewe ratios are calculated based on observed animals during one year.

E. Kaplan-Meyer survival rates are calculated annually for collared ewes based on sheep birth years (see methods).

Mount Gibbs

Herd Unit Description



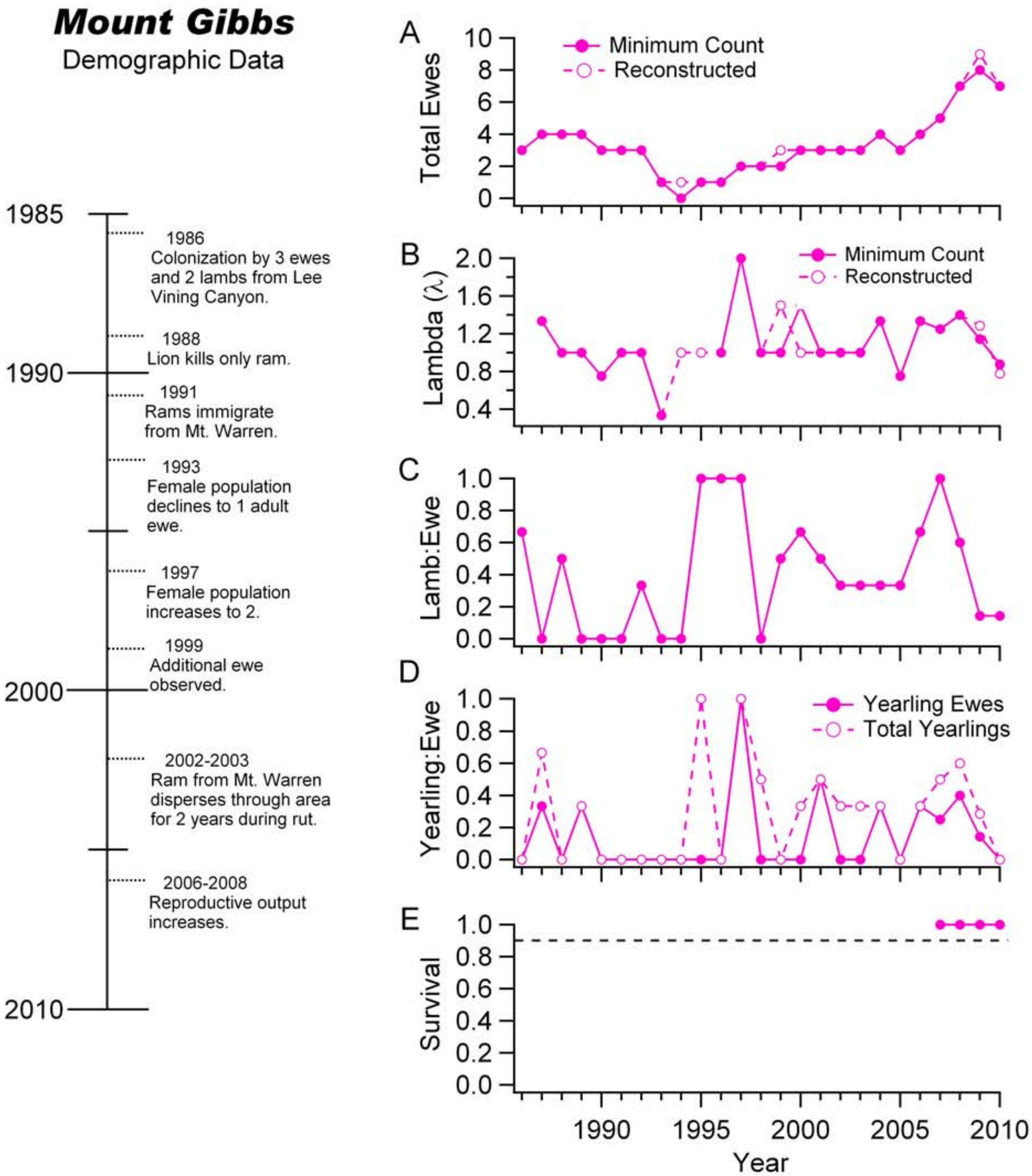
Herd unit area (boundary defined in Recovery Plan): 120 km^2

Combined used summer and winter range area (defined below): 27 km^2 (2D area) or 31 km^2 (3D area)

Lowest Elevation: 2,689 m (8,822 ft)

Highest Elevation: 3,948 m (12,953 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were combined to measure area. Lowest and highest elevations were extracted from this polygon.



This herd unit is surveyed in summer. Count data are collected from July-Oct. and recorded for that year.

A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and mark-resight estimates -○-.

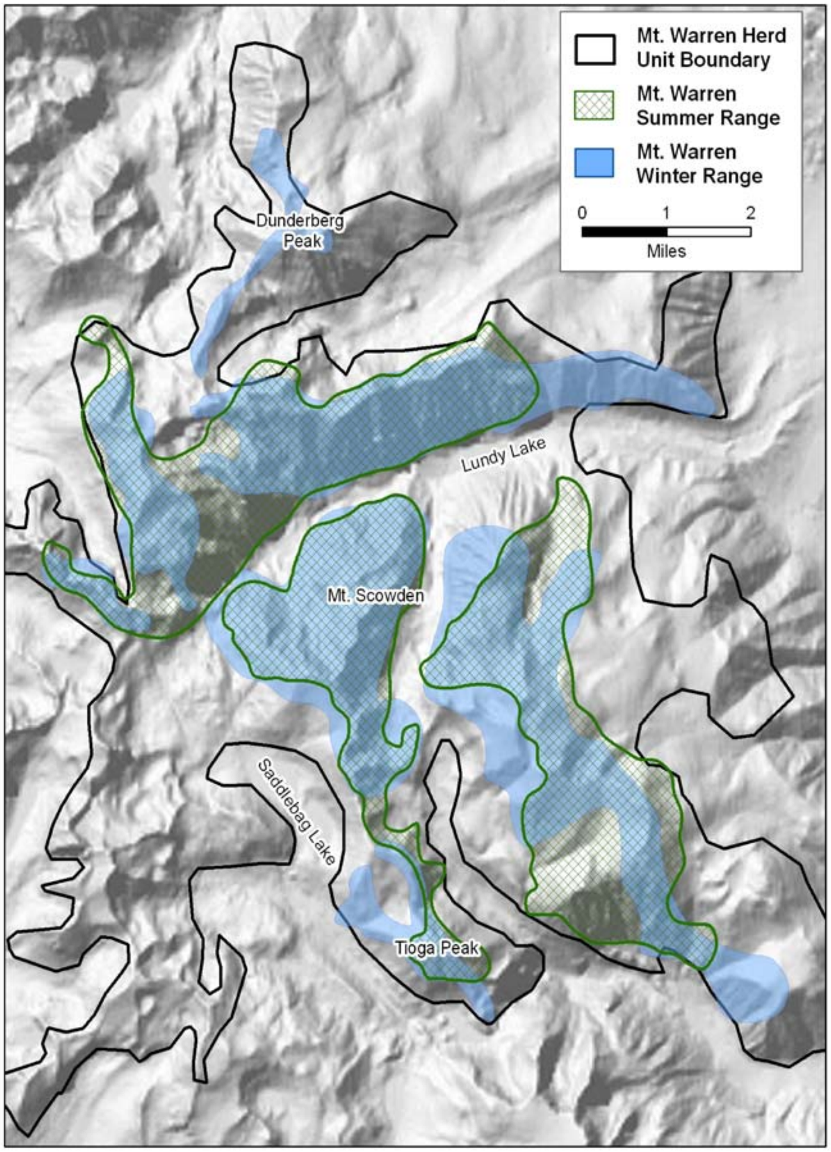
B. Lambda (λ) was calculated as N_{t+1}/N_t using population estimates as in A. Lambda was adjusted for translocations and biologically implausible values of lambda were excluded from analysis (see methods).

C-D. Lamb to adult ewe and yearling to adult ewe ratios are calculated based on observed animals during one year.

E. Kaplan-Meyer survival rates are calculated annually for collared ewes based on sheep birth years (see methods).

Mount Warren

Herd Unit Description

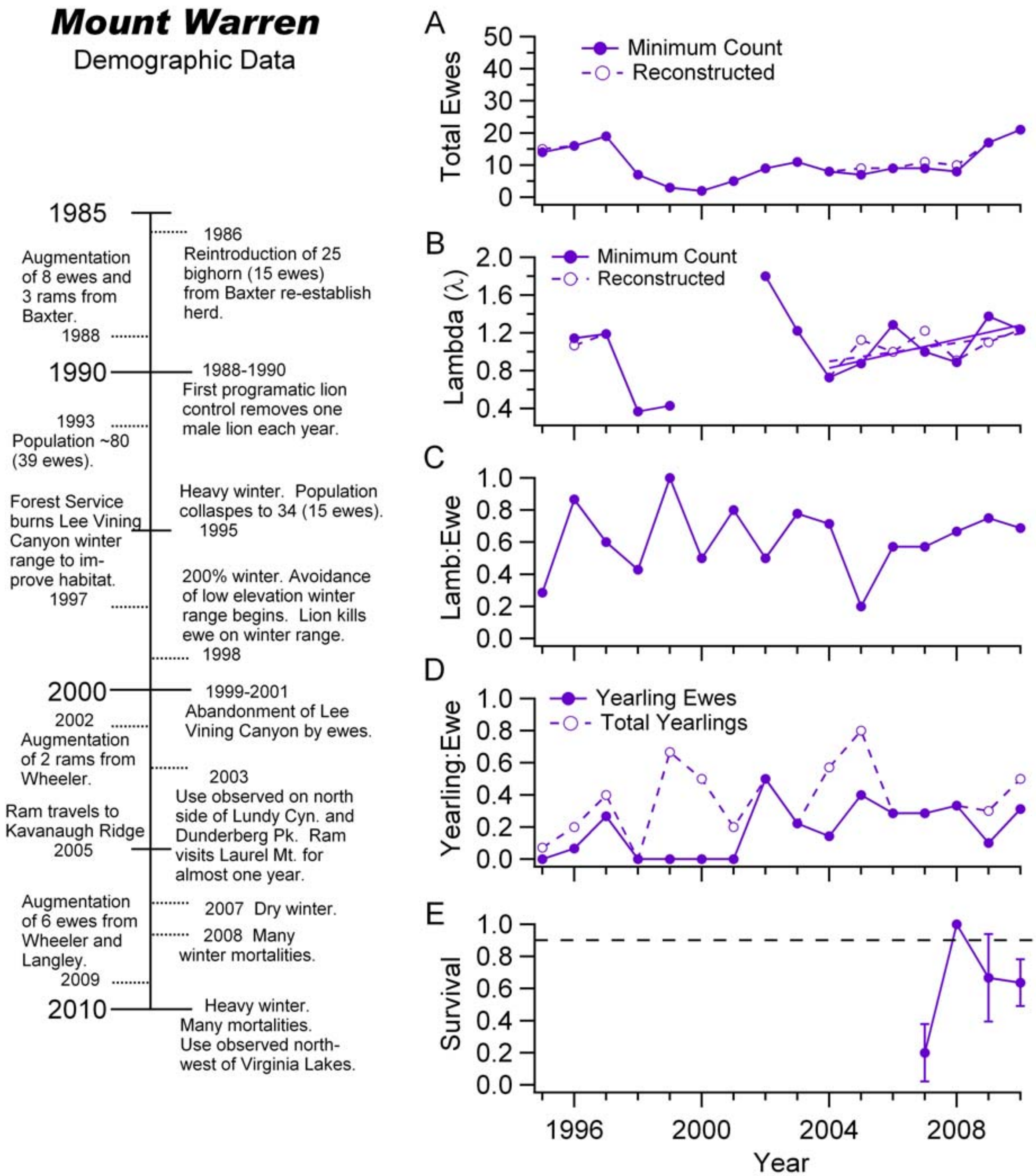


Herd unit area (boundary defined in Recovery Plan): 147 km^2

Combined used summer and winter range area (defined below): 64 km^2 (2D area) or 76 km^2 (3D area)

Lowest Elevation: 2,326 m (7,631 ft)
Highest Elevation: 3,789 m (12,431 ft)

Winter and summer range polygons were created manually using GPS locations of bighorn collected for years 2008 through 2010 for winter (December-March) and summer (June-September). Winter and summer range polygons were used to measure area. Lowest and highest elevations were extracted from this polygon.



This herd unit is surveyed in summer. Count data are collected from July-Oct. and recorded for that year.

A. Minimum count population estimates were generated by counting adult and yearling ewes and adding live collared ewes not observed -●-. Reconstructed counts were generated by adjusting the minimum count upward using data based on fecal genotyping analysis, following years' minimum counts, and mark-resight estimates -○-.

B. Lambda (λ) was calculated as N_{t+1}/N_t using population estimates as in A. Lambda was adjusted for translocations and biologically implausible values of lambda were excluded from analysis (see methods).

C-D. Lamb to adult ewe and yearling to adult ewe ratios are calculated based on observed animals during one year.

E. Kaplan-Meyer survival rates are calculated annually for collared ewes based on sheep birth years (see methods).

Appendix C.
Herd Unit Summaries for 2010-2011

The information presented in this appendix summarizes survey efforts and significant events occurring between July 1, 2010 and June 30, 2011 for each herd unit.

The 2010-2011 winter was a very heavy winter, exceeding 183% of average snowfall in the mountains. However, a large percentage of that snow fell during just 5 days beginning December 18, producing the snowiest December on record. Numerous bighorn sheep were documented to die in avalanches during winter, but other such losses probably went undocumented in some herds.

Mount Langley

In the summer of 2010 it took 3 survey attempts before a sufficiently complete count was achieved in September. That minimum count was 36 adult ewes, 6 yearling ewes, 11 lambs, 7 yearling rams, and 32 adult rams for a total of 92. The mark-resight estimate of 41 adult and yearling ewes (95% CI:30-56) was just under the minimum count of 42. Rams are not the focus of these counts, but this was the highest number of rams ever counted in this herd.

One radio collared ewe died at high elevation during winter. All others successfully descended to winter ranges despite the deep snow in December.

Mount Williamson

A summer survey in 2010 located only a single group of 9 sheep in North Bairs Creek. It contained 6 adult females, 1 yearling female, 1 lamb, and 1 yearling male, thus suggesting the possibility of a low lamb:ewe ratio in the population. During the following winter 17 non-immigrant sheep could accounted for: 8 adult ewes, 2 yearling ewes, 4 lambs, and 3 adult rams. One radio-collared ewe died in spring.

Two radio-collared females from the Mount Baxter herd emigrated to Mount Williamson in 2010 and were located on winter ranges in early April of 2011. These were apparently independent events. One of these ewes (S167) was seen during a summer survey of the Mount Baxter herd in 2010, whereas the other (S166) was not. When found at Mount Williamson they were a considerable distance apart. S166 was located between George Creek and South Bairs Creek in a patch of habitat that was the most favored winter range of the Mount Williamson sheep up to 1985 before they abandoned use of low-elevation winter ranges south of Shepherd Creek. Accompanying S166 was another adult female and a yearling of each sex. Given the absence of Mount Williamson sheep at this location for 25 years, these other sheep were suspected also to be from the Mount Baxter herd. They were genotyped from DNA extracted from droppings and tested for 18 microsatellite loci relative to past samplings of the Mount Williamson herd and the combined Mount Baxter and Sawmill Canyon herds. All 3 showed strong alliance with the Mount Baxter/Sawmill Canyon population; thus this entire group apparently emigrated from the Mount Baxter herd. S167 was located in Shepherd Creek in a group of 12 sheep that included 4 collared females from Mount Williamson. Behavioral interactions (dominance and association) suggested that she was a lone immigrant. These observations indicate the total emigration of 5 Mount Baxter sheep: 3 adult females and a yearling of each sex.

Bubbs Creek

This population was not surveyed by helicopter during the 2010-2011 winter. An attempt was made to count these sheep on the ground in the summer of 2010. The result was 6 adult ewes, 3 yearling ewes, 2 lambs, 1 yearling ram, and 11 adult rams. The adult rams are not necessarily from this herd, and the number of ewes was about one-half that of the last good helicopter count.

Mount Baxter

A coordinated summer count of females and associates was carried out in July of 2010. During that count all collared ewes except S166 (who emigrated to Mount Williamson) were seen. Minimum totals were: 29 adult ewes, 6 yearling ewes, 21 lambs, and 8 yearling rams, for a total of 71 sheep.

Winter range counts began in late December and continued into April. The result was a minimum total count of 77 sheep that included all collars that did not emigrate: 25 adult ewes, 5 yearling ewes, 13 lambs, 8 yearling rams, and 26 adult rams. The sheep that emigrated to Mount Williamson would increase this to 28 adult ewes, 6 yearling ewes, 13 lambs, 9 yearling rams, 26 adult rams, and a total of 82. This suggests a 75% survivorship of the 20 lambs counted the previous year, and 83% survivorship for adult and yearling ewes if no further emigrants existed.

Comparisons with the summer count data suggest losses of at least 3 adult ewes, 1 yearling ewe, and 8 lambs between summer and winter range counts. It is possible that many of these perished after the record December snow fall. One young radio-collared ram from the Mount Baxter herd began emitting a mortality signal at high elevation following that December storm but could not be investigated because of deep snow.

Sawmill Canyon

Counts of this population have been rapidly increasing each year with the development of better summer census approaches made possible by the recent addition of numerous radio collars on females in this herd unit. Known minimum population sizes have increased from 12 total females in the 2007-08 winter to 23 the following summer and 30 in the summer of 2009. That increase continued in 2010 when 37 total females were counted in a coordinated summer count that logged 33 adult ewes, 4 yearling ewes, 16 lambs, 6 yearling rams, and 4 2-year-old rams.

In the first half of January 2011, following the record December snows, a winter range count logged 30 adult ewes, 6 yearling ewes, 13 lambs, 3 yearling rams, and 8 adult rams for a total of 63. Not long before that count John Dittli photographed 10 sheep on the summit plateau of Goodale Mountain, including ewes, lambs, and yearlings. This suggested that the population could be yet larger. The 6 yearling females recorded on the winter range compared with 4 the previous summer also suggested that the summer count was incomplete.

Wheeler Ridge

Deep snow following the record snow storm in December created treacherous conditions for bighorn sheep at Wheeler Ridge given the extreme steepness of the terrain. It took numerous days for surviving sheep to travel through the deep snow in Pine Creek out to front country winter ranges. One old ram in poor body condition broke a leg and died on that journey. Ten sheep including 6 adult females were documented to die in avalanches.

Subsequent winter counts produced minimum totals of 29 adult ewes, 5 yearling ewes, 21 lambs, 10 yearling rams and 23 adult rams, for a total of 88, and a mark-resight estimate of 40 adult and yearling females (95% CI: 32-51). The known early winter deaths would have put the minimum total population in mid-December at 98. The 6 ewes known to die in avalanches constituted 17% of the minimum total ewes counted. In early March a female lamb and a yearling male died from mountain lion predation.

Convict Creek

This fledgling herd is likely a recent natural colonization from the Wheeler Ridge herd unit and lives in habitat immediately south of McGee Canyon. In the summer of 2010 it was known to contain 3 ewes, 3 lambs, and a yearling ram. In late June of 2011 all 7 of these sheep were still alive with the addition of 2 new lambs. The 3 lambs observed in the summer of 2010 appear to be 2 females and 1 male that were observed as yearlings in June 2011.

Mount Gibbs

In the summer of 2009 this herd contained 7 adult females, 1 yearling female, 1 lamb, 1 yearling male, and 5 adult males. In the summer of 2010 the composition was 7 adult females, 1 lamb, and 6 adult males (ages 2-9).

Mount Warren

In the summer of 2009 this herd unit included 3 subgroups of females: 1 on Mount Scowden and 2 on the north side of Lundy Canyon, 1 of which contained ewes recently translocated there. Sheep numbers that summer were 16 adult ewes, 1 yearling ewe, 12 lambs, 2 yearling rams, and 6 adult rams, for a total of 37.

From coordinated group counts in the summer of 2010 the numbers were (1) Mount Scowden: 4 adult females, 1 yearling female, 2 lambs, and 1 yearling male; and (2) Lundy Canyon north side: 13 adult females, 5 yearling females, 10 lambs, 2 yearling rams, 2 2-year-old rams, and 3 older rams; for totals of 17 adult females, 6 yearling ewes, 12 lambs, 3 yearling males, 5 adult males, and 43 total sheep. The 2010 count of the Mount Scowden group was consistent with the 2009 count, given a capture-related death of 1 adult ewe in between those counts. However, on the north side of Lundy Canyon the 2010 count was 1 adult female more than could be accounted for in the 2009 count, and 2 yearling females more than known female lambs from fecal genotyping of 2009 lambs. Consequently, there was some question whether this was a true minimum count or might have involved some double counting of sheep appearing and disappearing in complex terrain.

The 2 functional radio collars on ewes at Mount Scowden both began transmitting mortality signals at the very end of November 2010, but could not be investigated then due to treacherous conditions in the mountains, weeks before being covered with deep snow in December. Three radio-collared sheep on the north side of Lundy Canyon shifted to mortality signals after the December storm. One adult female was an avalanche death. The cause of death could not be determined for a young male, and the second adult female had not yet been found by the end of June 2011. Two other adult females on the north side of Lundy Canyon died in spring at high elevation as a result of efforts to capture and collar them.

Appendix D.

Summary of Monitoring Activities and Mortalities for 2010-2011

Sierra Nevada bighorn sheep and mountain lions in and adjacent to Sierra bighorn herd units were monitored. Monitoring efforts for bighorn focused on maintaining VHF collars on 30-35% of the adult ewe population to collect data on demographic rates. As of June 30, 2011, 29.7% of ewes were collared. Monitoring efforts for mountain lions focused on collaring all lions near bighorn habitat with GPS or VHF collars and investigating potential kill sites (clusters of GPS locations).

Table 1. Bighorn collaring activities and mortalities. (Activities occurred between July 1 and June 30 of the following year.)

	Langley		*Williamson*		*Baxter*		*Sawmill*		*Bubbs*		*Wheeler*		*Gibbs*		*Warren*	
	Ewes	Rams	Ewes	Rams	Ewes	Rams	Ewes	Rams	Ewes	Rams	Ewes	Rams	Ewes	Rams	Ewes	Rams
7/1/2010	**15**	**2**	**5**	**2**	**10**	**2**	**7**	**2**	**2**	**0**	**15**	**10**	**5**	**4**	**11**	**6**
additions	0	0	0	0	0	0	0	0	0	0	1	1	0	1	3	1
re-collarings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	(1)	(1)
translocations	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
mortalities	-2	0	-1	0	0	-1	-2	0	0	0	-4	-2	0	0	-7	-2
censors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/30/2011	**13**	**2**	**4**	**2**	**10**	**1**	**5**	**2**	**2**	**0**	**12**	**9**	**5**	**5**	**7**	**5**

Table 2. Mountain lion collaring activities and mortalities. (Activities occurred between July 1 and June 30 of the following year.) Three additional lions were captured or recaptured in areas adjacent to the recovery units that are not displayed in the table below.

	Southern R.U.	*Central R.U.*	*Northern R.U.*
7/1/2010	**2**	**4**	**1**
additions	2	5	0
immigration	1	6	1
emmigration	-2	-2	0
mortalities	-1	-8	-1
re-collarings	(1)	(6)	(0)
6/30/2011	**2**	**5**	**1**

Appendix E.

New index developed for mountain lion population trends

All or most cougar researchers believe that the most reliable estimates of density (cougar numbers per unit area) are derived from long-term radio-telemetry studies that attempt to mark all animals in the population. Although these estimates have no formal mathematical basis other than simple counting, and lack statistical confidence intervals, they are endorsed as the "gold standard" against which indices or other estimates should be compared (Seidensticker et al. 1973, Hemker et al. 1984, Logan and Sweanor 2001). These methods were used in Round Valley, CA from 1992 to 1999 (Pierce et al. 2000, Bowyer et al. 2005). During this study an index to population trends for the mountain lions in Round Valley was developed (Figure 1). This index was derived from the number of collared lions located within a defined area during each aerial telemetry flight averaged over the winter (November thru April). An index is a number that is monotonically related to population size, N. The best indices are linearly related to N (Cougar Management Guidelines Working Group 2005). Indices based on sign are generally assumed linearly related to N whereas harvest number and catch per unit effort are usually not linearly related to N (Caughley 1977). Intensive monitoring of mountain lions during the study in Round Valley supported the assumption that the index was tracking the trends in the study area in a consistent and linear manner.

In 2000, the need to monitor mountain lions in the Eastern Sierra increased with the listing of the Sierra Nevada bighorn sheep. This change in priorities greatly expanded the area that mountain lions needed to be monitored. The effort to collect data for the Round Valley index continued but that did not provide more specific trend data for other winter ranges. Surveying for mountain lion sign and the capture and radio-collaring of mountain lions were expanded to all areas of interest, but as previously stated, catch per unit effort is not a reliable index, and measuring unit effort for searching for sign is very difficult. Global Positioning System (GPS) units are being used to measure effort, but a large data set is needed to offset the variability created by technical difficulties in measuring actual search effort on a daily basis not to mention the variability in detecting sign. For these reasons, a new method for indexing mountain lion use was tested, using radio collar locations, not just from the air but also from GPS recorded data. The proportion of locations within the Round Valley study area, for each individual lion that ever used the original aerial index area, was calculated for each winter, and then all values were summed. This method was then compared to the previous index for all years available and the result was a correlation of 0.69 for the 15 years available. Values were nearly identical for 7 of 15 years and direction of change was the same for 12 of 15 years. Differences seen from 2004 through 2006 were likely a result of less effort during aerial surveys made for mountain lions. These results suggest that the index used in the Round Valley study was valid. Additionally, these results provide the Sierra Nevada Bighorn Sheep Recovery Program with an alternative method for indexing mountain lion use of any area selected, as long as an intensive effort to radio-collar all lions using an area is made.

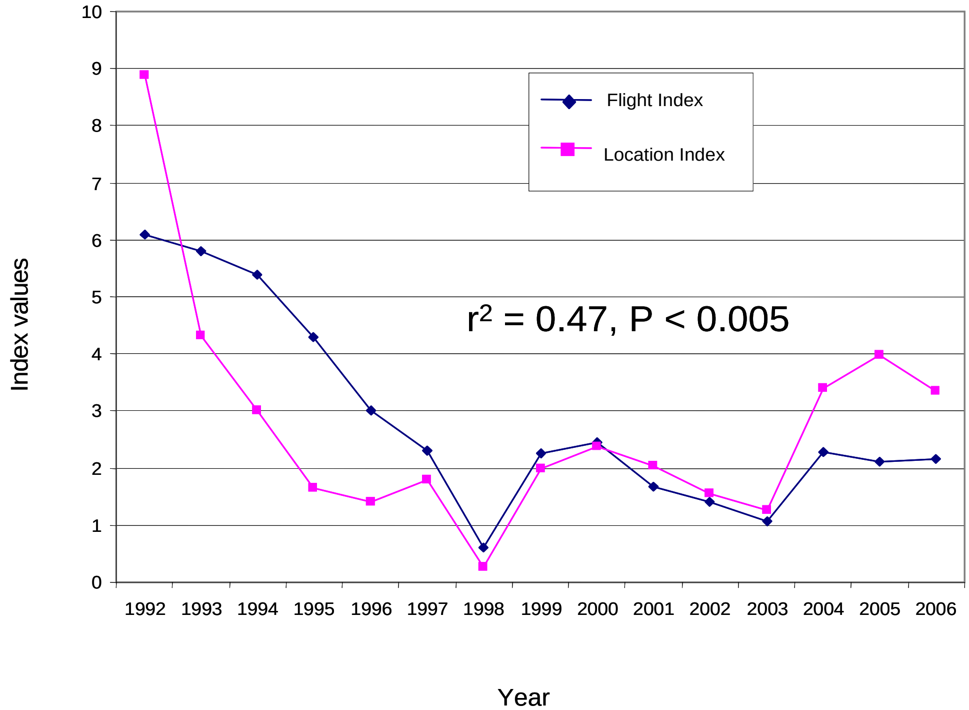


Figure 1. Comparison of mountain lion indices during winter (November – April). Flight Index is based on the average number of individual lions located in Round Valley during weekly flights. Location Index is based on percentage of all location data collected in Round Valley from radio collars.

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