2023-24 Annual Report
Sierra Nevada Bighorn Sheep Recovery Program

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***Figure 1**. A remote wildlife camera revealed the persistence of Sierra bighorn in the Big Arroyo herd: one ram photographed on November 15, 2023.*

Executive Summary

Although Sierra Nevada bighorn sheep faced several challenges in 2023, relatively mild winter conditions provided a welcome reprieve following the substantial losses associated with the severe winter of 2022-23. Overall survival and recruitment were marginally sufficient to support population growth; growth was enabled in part by an extensive mountain lion monitoring and management program. Although adult female survival improved markedly compared to the previous year, the population is growing more slowly (lambda = 1.05) than we would like to see to promote recovery from 2022 and eventual downlisting. Predation by mountain lions accounted for the majority of adult female mortalities; no deaths were attributed to snow-related causes.

In 2023, the population was estimated at 366 individuals, including 175 females. The Baxter and Olancha herds—both southern populations with substantial low elevation winter range—remained the largest. To improve monitoring coverage and data resolution, 17 individuals across eight herds were captured and fitted with GPS collars during fall operations, enhancing future survey and management capacity and adding to our substantial long-term dataset on Sierra bighorn. The Recovery Program supports and directs research using this data to guide adaptive management.

A total of 74 individual mountain lions were documented within the eastern Sierra population, of which 43 were captured and collared. Two adult female lions were translocated from the Southern Recovery Unit due to elevated predation risk to bighorn sheep. These actions, combined with six lion translocations conducted in the previous year, are expected to yield

positive demographic effects. However, predation impacts remained substantial in some areas; for example, the Warren herd lost three of eight adult females to mountain lions. Notably, two of these events occurred at high elevation on Kavanaugh Ridge in early March. Increased detection of high elevation predation—during both mild winters and year-round—likely reflects improved monitoring associated with expanded collaring efforts. The individual responsible for predation in the Warren herd was subsequently translocated after this reporting period.

Finally, a desert bighorn ram infected with *Mycoplasma ovipneumoniae* was documented moving from Death Valley across the Sierra Nevada into Fresno County, where it was lethally removed to mitigate risks to both wildlife and public health. This incident underscores the continued importance of disease surveillance and prevention. Although no major respiratory disease outbreaks have occurred in Sierra bighorn populations to date, such pathogens remain a significant threat across western North America. Potential sources of transmission include nearby domestic goat operations, particularly near the Wheeler herd, as well as contact with dispersing desert bighorn sheep.

Introduction

Science is the foundation of the recovery effort and an ongoing need that makes adaptive management possible. In the 2023 animal year covered in this report (May 1, 2023 through April 30, 2024), the Recovery Program, along with affiliated graduate students, published several articles in peer-reviewed journals. Much of the recent research has been aimed at understanding the risk sensitive trade-offs made by Sierra bighorn in selecting habitat. Sierra bighorn are partially migratory with some animals remaining at high elevations during winter, foraging on wind-swept slopes, and other individuals descending to lower elevations where they gain access to earlier green forage but are also exposed to higher predation risk (map of herd units, Figure 2).

In a classic but complex forage-predation trade-off, migratory decisions in Sierra bighorn rams are linked to individual body condition (Denryter et al. 2024). Individuals with greater fat reserves measured by ultrasound remained at higher elevations throughout the winter, while leaner individuals were more likely to migrate to lower elevations with access to better quality forage, at the risk of higher predation. Thus, migratory behavior is sensitive to physiological state, and the ability of animals to store body fat during summer influences their migratory tactics (Denryter et al. 2024). In addition to enabling large fat reserves, high quality forage in the Sierra alpine also provides the nutrients necessary for large body size. Sierra bighorn have the largest body size when compared with desert and Peninsular bighorn (Massing et al. 2024), which serves as an adaptation to a highly seasonal landscape.

The costs and benefits of using certain habitats related to predation risk, adequate nutrition, and avalanche risk inform Sierra bighorn management decisions. Ultimately, we want to understand where, under what conditions, and at what population sizes different herd units can be supported. Interestingly, nutritional carrying capacity is a function of how many bighorn use the landscape. Bighorn are risk averse to predation and select steep terrain to reduce that risk. However, the more individuals in a herd or group, the more the predation risk is diluted for any one animal. Consequently, group living yields access to more habitat because larger groups move farther from escape terrain and therefore have expanded access to forage resources (Rankins et al. 2024).

In addition to forage biomass, the timing of forage green-up influences nutrients available on winter and summer range. Snowmelt timing was a strong predictor of green-up (John et al. 2024). Migratory Sierra bighorn tended to follow the green wave, selecting destinations at their peak annual biomass, but specifically, precipitation events were a key component forcing Sierra bighorn down to lower elevations, and relatively high temperatures drove them up in elevation (John et al. 2024).

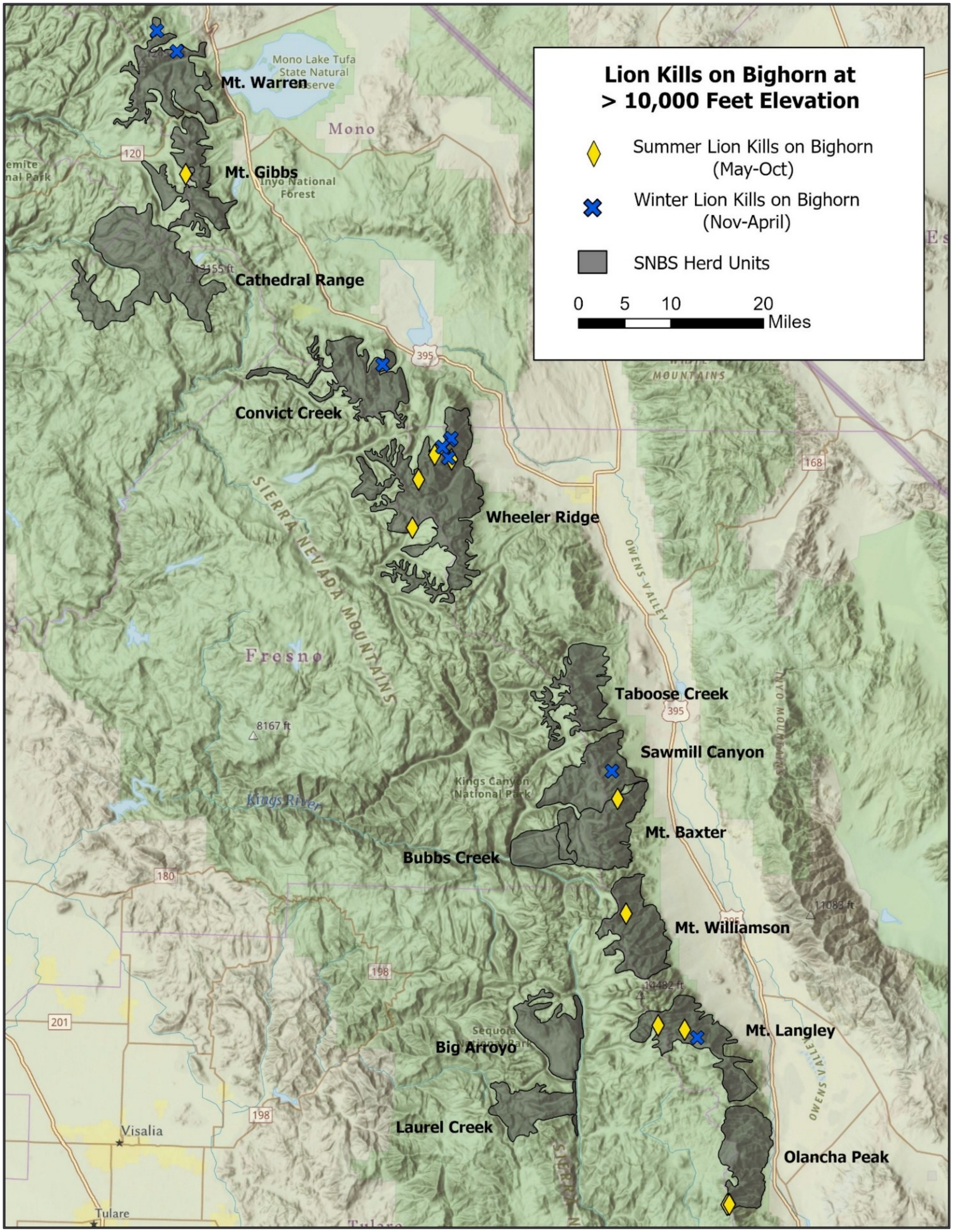

Figure 2. Map of Sierra bighorn herd units, including locations of all known Sierra bighorn lion kills that occurred 2003- 2024 at elevations above 10,000 feet.

During winter, high elevation habitat selection is constrained by snow cover and human disturbance. Sierra bighorn generally avoid popular backcountry ski zones, but this avoidance lessens during winters with more extensive snow cover, when their options for selecting snow-free habitat are more limited (Kolek et al. 2025).

Extensive longitudinal data collection continues to be essential for research efforts that support adaptive management within the Recovery Program. Our monitoring goals continue to focus on collecting demographic and behavioral data along with covariates that inform those population metrics.

Population Monitoring and Recovery Goals

In 2023, we estimated there were 366 Sierra bighorn including 175 females, 65 lambs, and 126 males (based on males observed, Table 1). Typically, we estimate that there are 2 males for every 3 females (Appendix B), but this year we observed a higher proportion of males, so we report our observed count. Baxter continues to be the largest herd, with 48 females, followed by Olancha with 35 females (Figures 3 and 4).

Monitoring efforts during the 2023 animal year were directed toward understanding the impacts of the severe 2022-23 winter. Many mortality investigations were conducted in summer 2023, as receding snowpack allowed access to higher elevations. Survey efforts were complicated by a limited number—or complete absence—of collared individuals in several herd units. As a result, minimum count surveys were often difficult, requiring repeated visits to detect even a single animal within extensive talus habitats. Without radio-collared animals to guide search efforts, confidence in survey results is reduced, and we know that some individuals were not detected. To assist survey efforts, we set up a few cameras in key locations targeting specific areas associated with losses from 2023. The cameras added animals not observed during ground counts, such as at least one ram in the Big Arroyo herd (Figure 1).

Several notable observations occurred during the 2023 animal year as well as after the reporting period. On April 1, 2024, we were excited to observe a single adult female at Convict, where all collared females had died. The following year at Convict, we found a group of 6 that included 3 adult females, 1 yearling female, 1 lamb, and 1 adult male. Given the challenges of detecting small numbers of bighorn in herds without collars, the Convict ewes observed in the 2024 animal year may have been there but were previously undetected, or they may have emigrated from Wheeler; they were therefore not included in the 2023 count. In Taboose, where all collared females had died and it was unknown if any sheep remained, an adult and yearling female were captured in October 2024. It is possible that these animals emigrated from Sawmill, but they were included in the final 2023 count (Table 1).

The Recovery Plan (U.S. Fish and Wildlife Service 2007) specifies minimum counts are used to evaluate progress toward downlisting goals, requiring at least 305 females with specific geographic targets in four Recovery Units. Our 2023 count set recovery back to 2007 numbers and eliminated the Kern Recovery Unit (Figure 5). Each Recovery Unit consists of 2-7 herd units. Based on this year's minimum counts, we are currently below recovery goals in all Recovery Units (Figure 6). Additionally, due to the loss of animals in the Kern Recovery Unit (Big Arroyo and Laurel herd units), we have females distributed in 10 of the 12 essential herd units identified in the Recovery Plan (Criteria B2, SNBS Recovery Plan 2007). We recognize that our counts represent a minimum number of bighorn and the true number and distribution may be higher and broader than our current estimate.

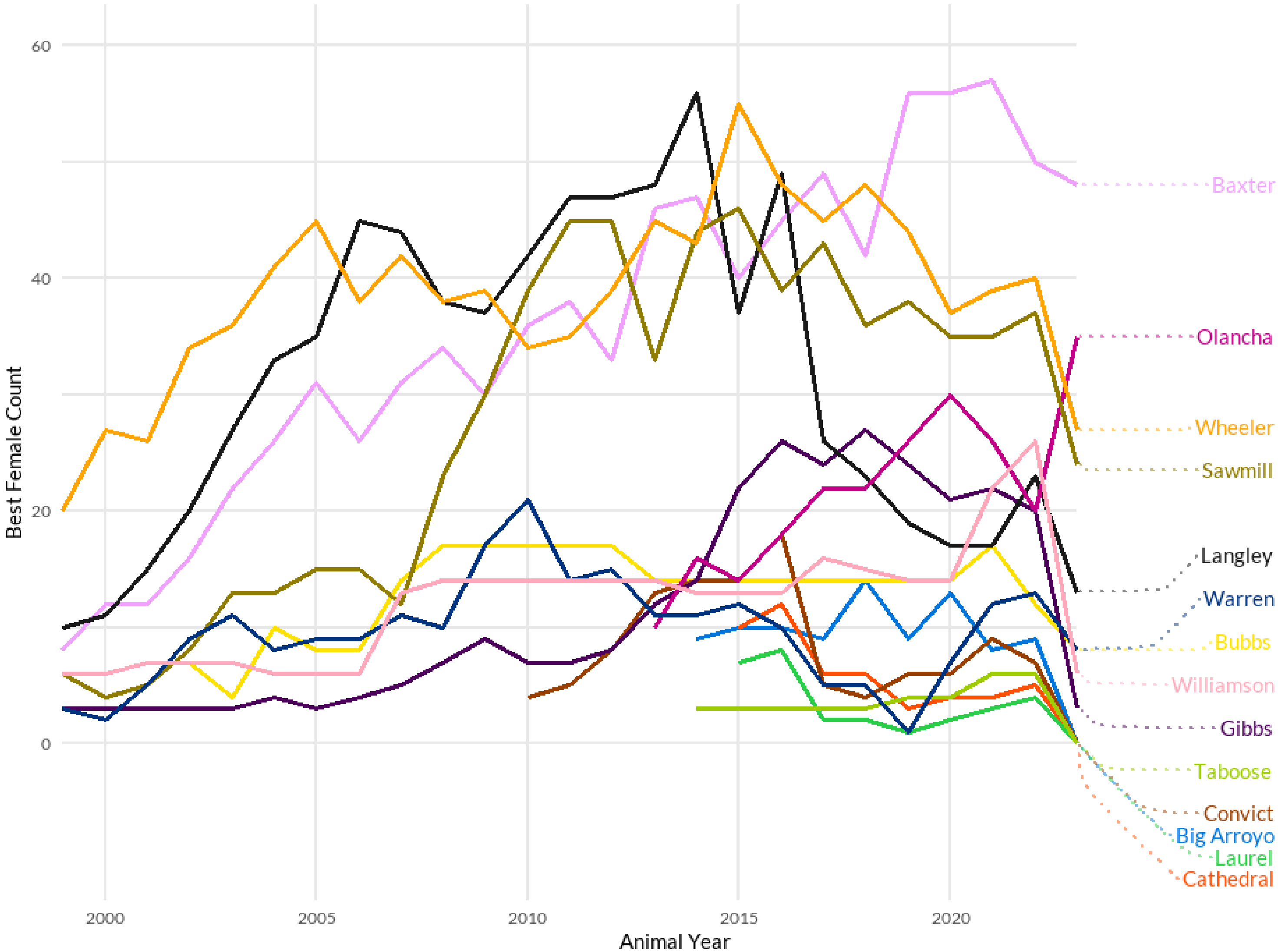

Figure 3. *Minimum counts for female Sierra bighorn 1999-2023. The 2023 summer counts include losses from the extreme winter in which the only herd to increase was Olancha. These data include the best count for each herd and animal year.*

Table 1. *Reconstructed minimum counts (MC) of Sierra bighorn during the 2023 animal year: May 1, 2023 – April 30, 2024. Lambs are not identified by sex. Female and lamb estimates are likely more accurate than male estimates because there is a higher proportion of marked females and survey routes are designed to detect females. Year-end population is reduced by all known mortality that occurred after the survey. Counts are from summer surveys, except where indicated. C = data combined from winter and summer surveys.*

Herd	Female Adult	Female Yrlng	Female Total	Lambs	Male Adult	Male Yrlng	Male Total	MC	Year-End Females	Mortality post survey	Notes
Olancha	27	7	**35 ***	14	19	4	23	**72**	34	S494F	* Includes 1 female unknown age
Laurel	0	0	**0**	0	0	0	0	**0**	0	NA	All adults were collared and confirmed dead from snow in 2022
Big Arroyo	0	0	**0**	0	1	0	1	**1**	0	0	Male on camera in Chagoopa Bowl (Fig. 1)
Langley	11	2	**13**	5	10	2	12	**30**	12	S661F	
Williamson[C]	6	0	**6**	4	4	0	4	**15 ***	6	S492M	* Includes 1 unclassified animal. Combined observations from summer and winter but did not classify yearlings in case of misclassification.
Baxter[C]	44	4	**48**	22	40	2	42	**112**	48	0	Females from summer, males from winter
Sawmill	20	5	**25**	4	4	1	5	**34**	23	S643F, S645F	Known to be poor count. 11 lambs seen in winter 2024
Bubbs	7	1	**8**	2	1	1	2	**12**	8	0	S631F presumed dead during count
Taboose	1**	0	**1****	1**	0	0	0	**0**	1**	0	** Not seen during survey but 1 AF, 1 YF captured in October 2024. These could have moved over from Sawmill
Wheeler	22	5	**27**	9	16	0	16	**53**	25	S625F, M263F, S624M	Added 1 unclassified animal. 1 unidentified male seen, possibly S410M (last seen in 2016)
Convict	1	0	**1**	0	5	0	5	**6**	1	0	1 AF found in April 2024. 3 AF, 1 YF, and 1 lamb seen in Feb 2025 but unknown if they were Convict animals or emigrants from Wheeler
Cathedral	0	0	**0**	0	4	0	4	**4**	0	0	1 unclassified animal seen on camera 2024
Gibbs	2	1	**3**	1	9	0	9	**13**	3	0	Believed to be census. No evidence that Blacktop deme persists
Warren	8	0	**8**	3	3	0	3	**14**	4	S534F, S532F, S622F, S659F	
Totals	**149**	**25**	**175**	**65**	**116**	**10**	**126**	**366**	**165**		

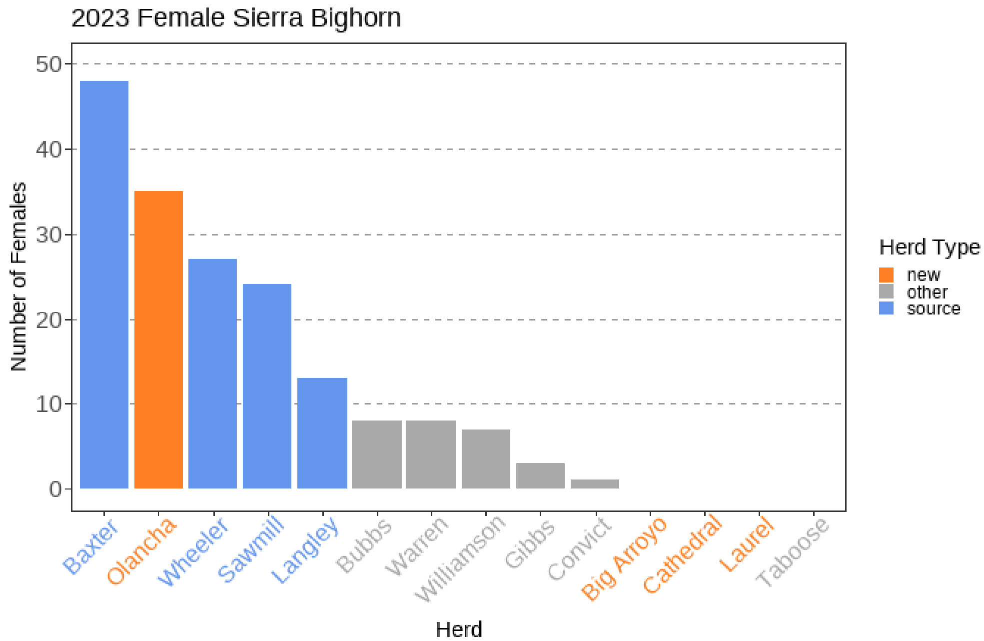

Figure 4. *Reconstructed minimum counts of female Sierra bighorn in 2023. "New" herds were created through translocations by the Recovery Program beginning in 2013, "source" herds have been used for translocating to and augmenting existing herds, and "other" herds are all of the remaining herds.*

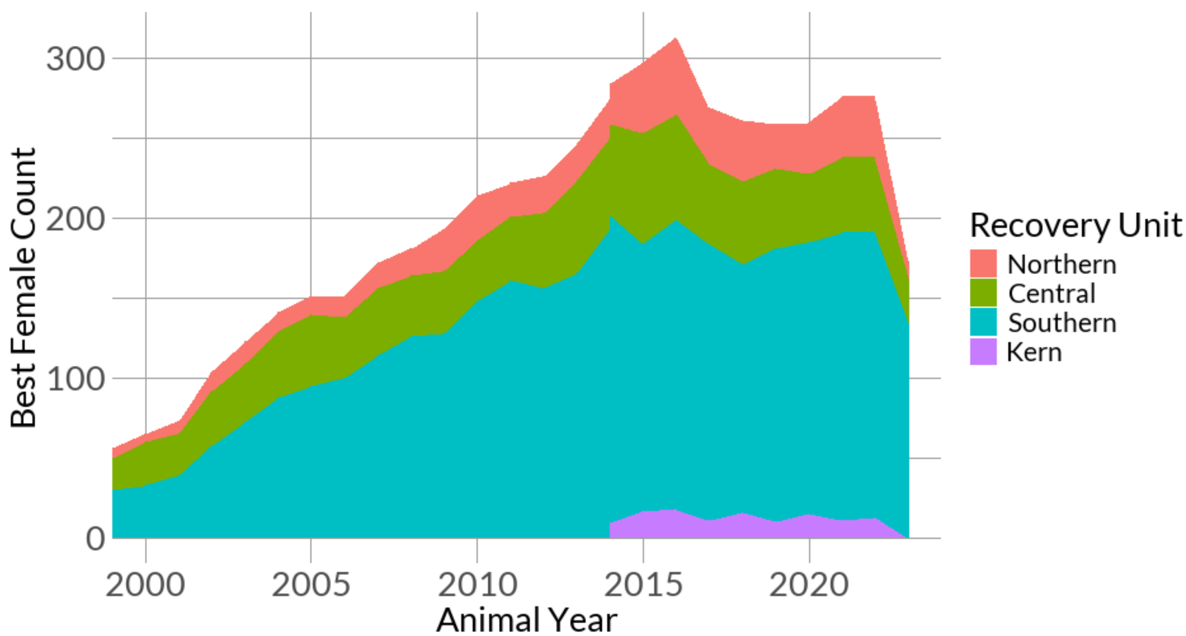

Figure 5. *Range-wide female Sierra bighorn population abundance 1999-2023. Range-wide numbers are calculated using annual herd values based on reconstructed minimum counts and Mark-Resight estimates, as well as the most recent survey results for herds not surveyed annually. Herd counts are combined across the animal year (May 1 – April 30). Because some herds are counted before winter in summer and others are counted during or after winter in the spring, the complete impacts of a given winter are not shown on this graph.*

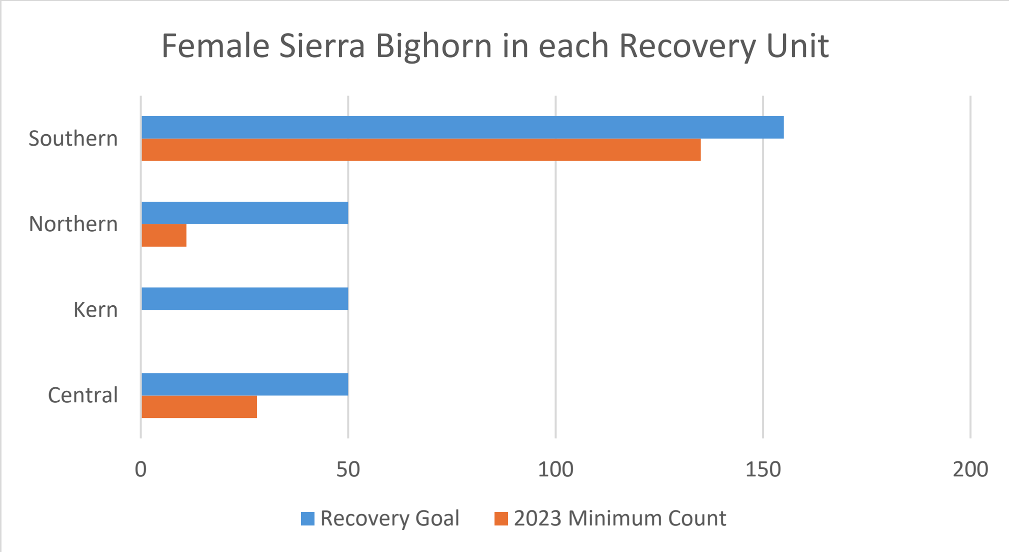

Figure 6. Abundance and distribution of female Sierra bighorn in the 2023 animal year across Recovery Units compared to downlisting goals.

Demographic Rates

The remarkably average snowfall of 2023-24 provided adequate moisture for forage production without reducing survival. Tropical storm Hilary doused the region after a hot summer, but this was followed by a mild fall and a slow start to snowfall, with limited accumulation until January. February was the snowiest month, and in the high-country April snow water equivalent was slightly above average (Hittle 2025). We did not document a single snow-related bighorn mortality. During these relatively calm conditions, the Sierra bighorn population began to rebound with a positive growth rate (lambda, λ = 1.05, Figure 9; see Appendix B for methods), after a decline associated with the severe winter of 2022-23 (λ = 0.63).

Growth rate, or λ, is driven by a combination of female survival and lamb production (recruitment). Generally, λ is more sensitive to survival rates (Johnson et al. 2010), but it is a combination of both factors that determine whether a population is increasing or decreasing. After the low survival rates during 2022-23, survival of adult females rebounded to 0.83, which is inadequate for population growth, along with lamb survival at 0.75, which is equivalent to the long-term average (Figure 9). Lamb:ewe ratios tend to drop below average in the year following a big winter and this year was no exception. Because the younger age classes tend to be more sensitive to winter conditions, the lamb and yearling to female ratios are lower than average. The lamb:ewe ratio of 0.42 was below the long-term average of 0.55, and the yearling:ewe ratio of 0.28 was below the long-term average of 0.37 (Figure 8). Despite metrics that are lower than long-term averages, the population is growing; both the demographic-based λ calculated from eigenvalues as well as λ calculated from minimum counts indicate an increasing population with $\lambda > 1$ (Figure 9; see Appendix B for methods).

While survival tended to be close to average in most herds, Warren females suffered from especially low survival (Figure 7). Lamb survival was also low at Warren, Williamson, and Baxter (Figure 7), but the method we use to calculate lamb survival (Appendix B), may not be representative when applied to small populations. Female survival was high in Baxter and Williamson where we did not detect any collared female mortalities (100%, Figure 7).

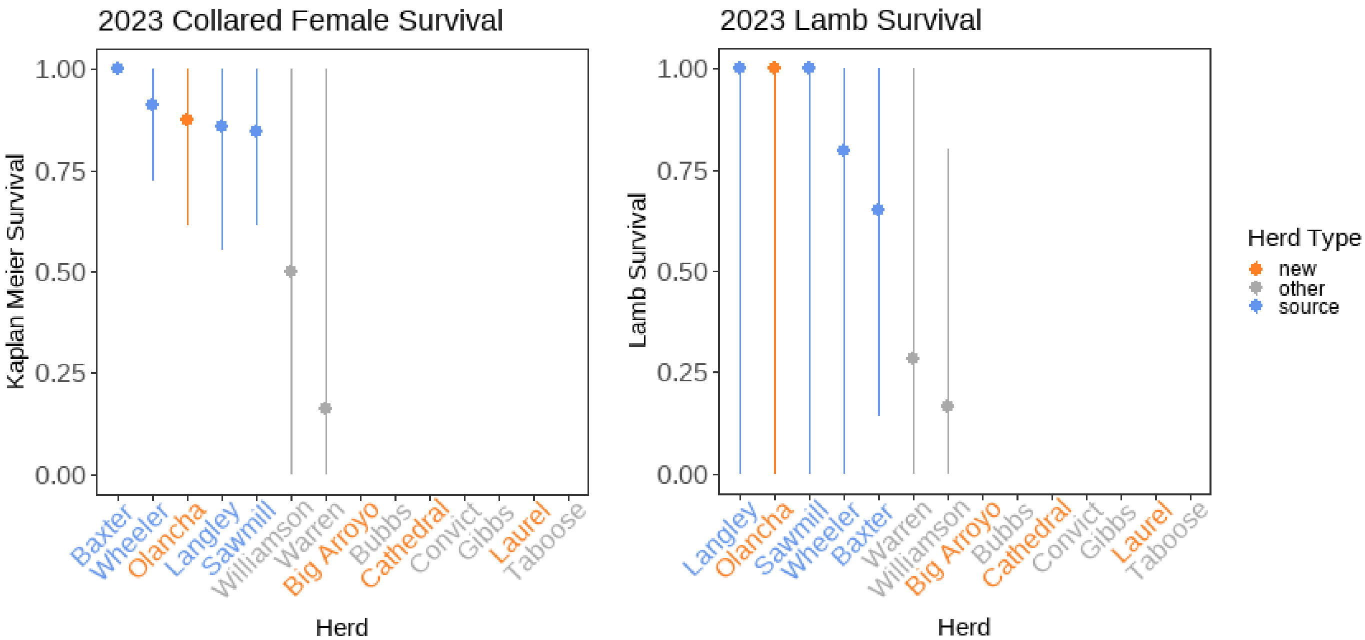

Figure 7*. Sierra bighorn collared female and lamb survival with 95% confidence intervals, for herds with at least 3 collared females in 2023. Female survival was estimated using Kaplan Meier, and lamb survival was estimated using age ratios. Herds are arranged from largest to smallest value in each graph. "New" herds were created through translocations by the Recovery Program beginning in 2013, "source" herds have been used for translocating to and augmenting existing herds, and "other" herds are all of the remaining herds.*

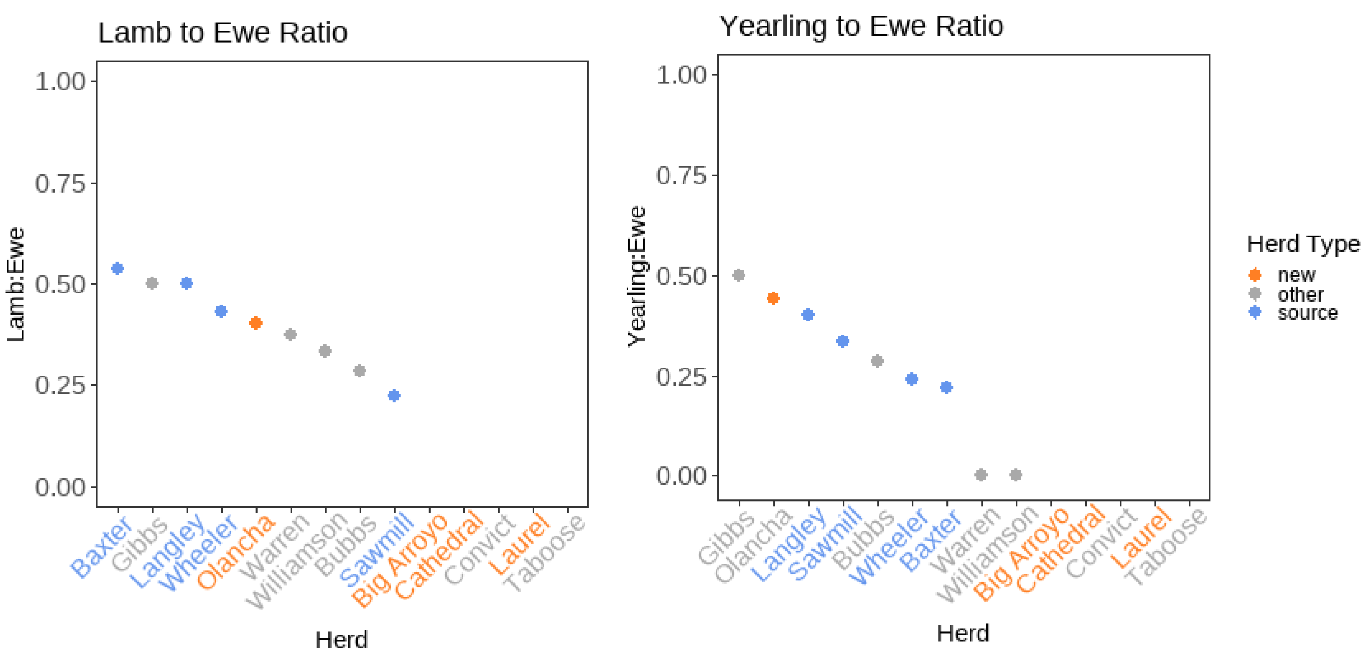

Figure 8. *Observed ratios of Sierra bighorn lambs and yearlings (males and females combined) to adult females by herd in 2023. Herds are arranged from largest to smallest value in each graph. "New" herds were created through translocations by the Recovery Program beginning in 2013, "source" herds have been used for translocating to and augmenting existing herds, and "other" herds are all of the remaining herds.*

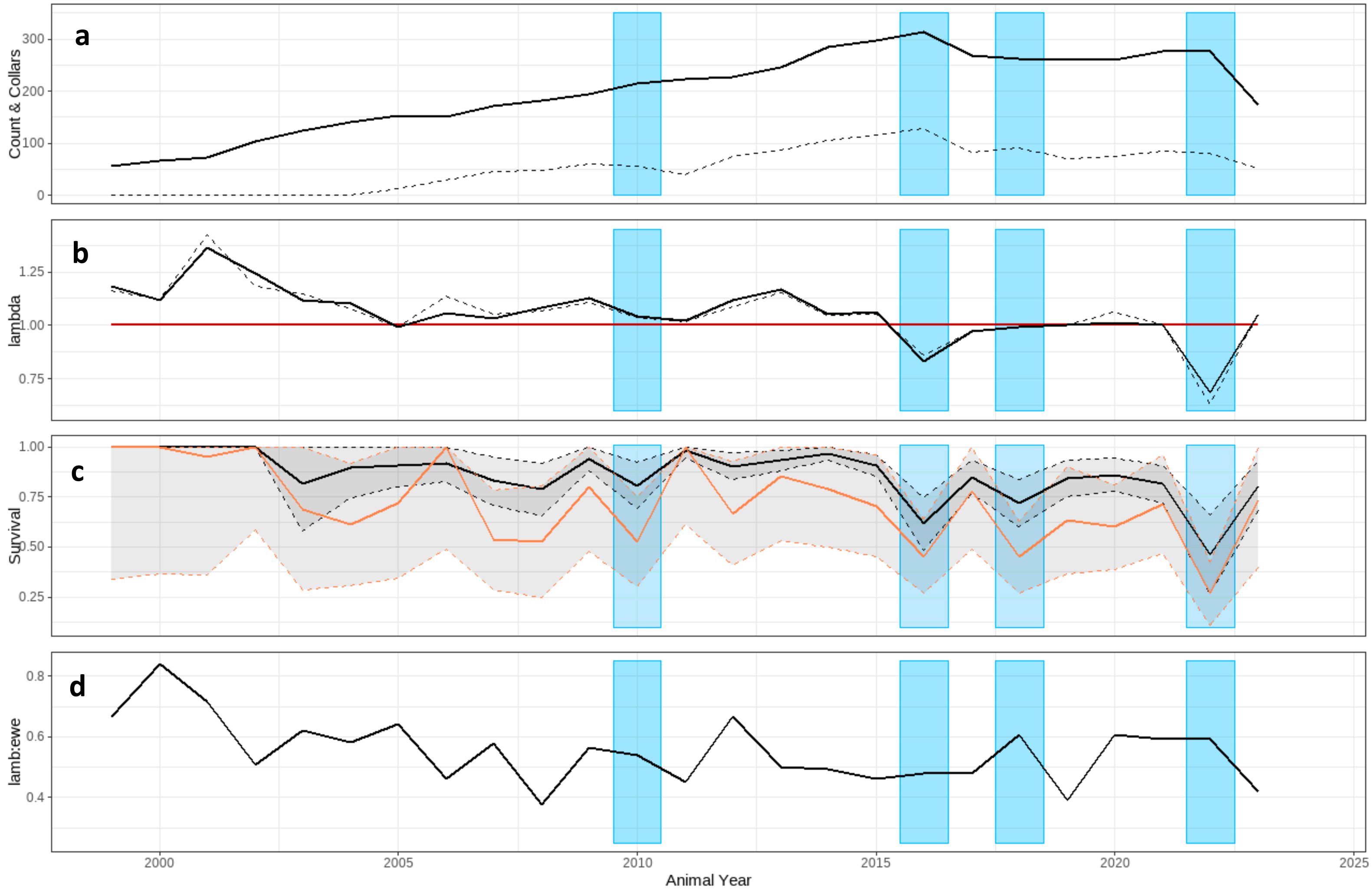

***Figure 9**. Long-term and range-wide female Sierra bighorn population estimates and vital rates, 1999-2023; winters with >150% average snow are highlighted in blue.*

- *a) Total female population estimate (solid black line) and collared females (dashed black line).*
- *b) Lambda (λ) calculated from eigenvalues derived from vital rates (solid black line) and lambda from minimum counts (dashed black line). Red line at 1 differentiates growing vs. declining population.*
- *c) Adult female survival (black line) and lamb to yearling survival (orange line) with 95% confidence intervals.*
- *d) Lamb:ewe ratios as a measure of fecundity.*

Range-wide Cause-specific Mortality

In general, Sierra bighorn tend to die in the winter from either predation or snow-related causes (Figure 10). This year mortality was geographically widespread and largely predation driven. We documented 21 bighorn mortalities (males and females; 16 collared) within 8 herds (Bubbs, Baxter, Langley, Warren, Williamson, Olancha, Sawmill, and Wheeler). There were 11 collared female mortalities: 6 died from lion predation, and 5 from unknown cause (Figure 10). Collared females are our strongest dataset because captures are designed to target 30% of females in each herd, therefore collared female mortalities represent a higher proportion and distribution throughout the Sierra. At Warren, 3 out of 5 collared female mortalities were from lion predation, including two at high elevation on Kavanaugh ridge in March.

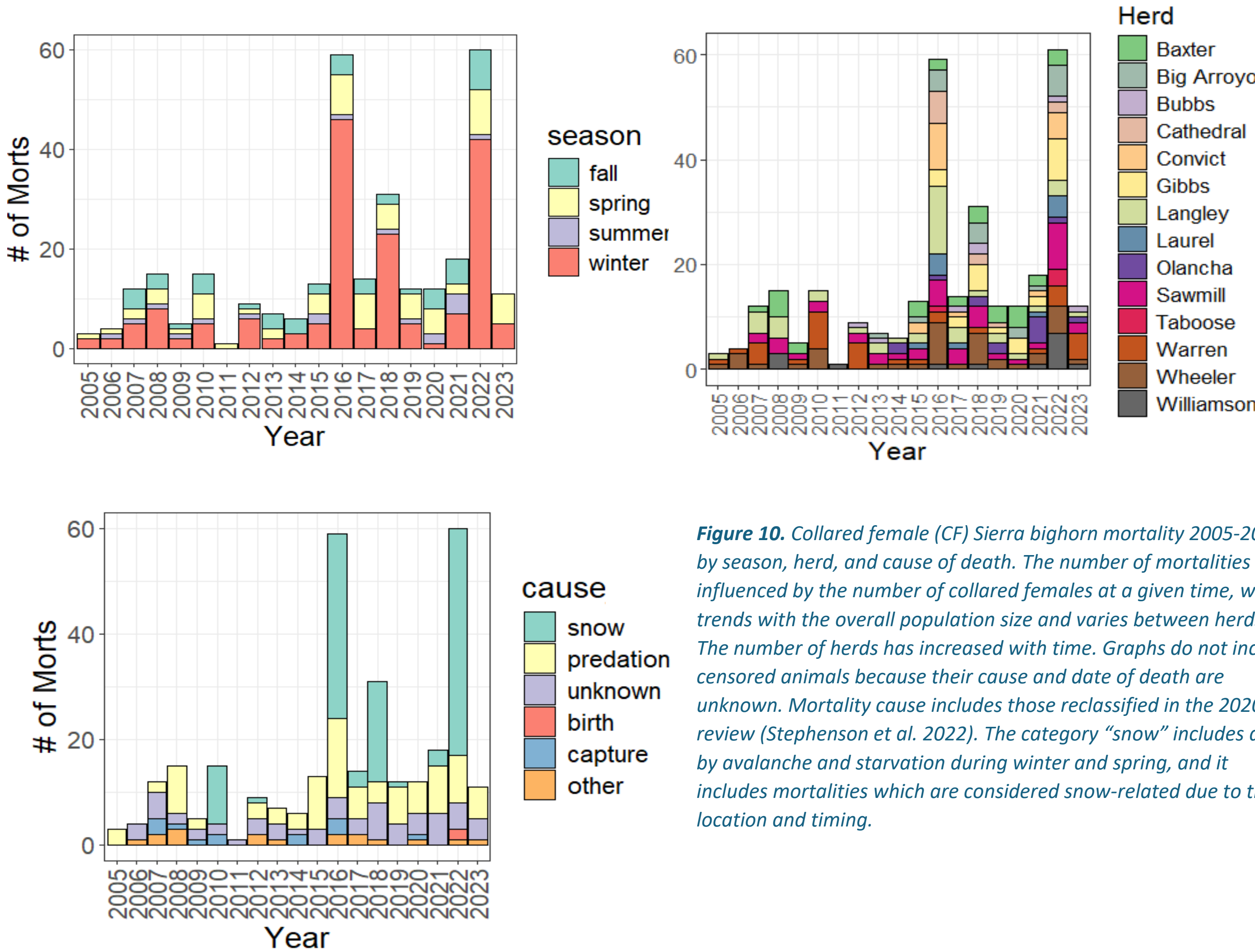

__Figure 10.__ Collared female (CF) Sierra bighorn mortality 2005-2023 by season, herd, and cause of death. The number of mortalities is influenced by the number of collared females at a given time, which trends with the overall population size and varies between herds. The number of herds has increased with time. Graphs do not include censored animals because their cause and date of death are unknown. Mortality cause includes those reclassified in the 2020 review (Stephenson et al. 2022). The category "snow" includes death by avalanche and starvation during winter and spring, and it includes mortalities which are considered snow-related due to their location and timing.

Capture, Collaring, and Translocation

During October 27-31, 2023, we captured 18 animals (8 females, 10 males) across eight herds: 2 at Bubbs, 1 at Cathedral, 1 at Gibbs, 1 at Convict, 6 at Langley, 2 at Warren, 3 at Williamson, and 2 at Wheeler. There were no spring capture activities and no capture mortalities. All captures were performed with a net gun fired from a helicopter by Leading Edge Aviation. All animals were released within the herd captured and most (17/18) were equipped with both a VHF and GPS collar, while one had a VHF collar only. Younger animals often receive only one collar to allow for neck girth growth. Increasing the number and distribution of GPS-collared animals should greatly improve our ability to track and monitor these herds.

Sierra Bighorn Movements

The number of GPS-collared animals was lower this year due to the losses in 2022. Despite this, we were able to detect some interesting movements, particularly of rams during the fall and winter. Ram S608M took a rambling journey beyond the Cathedral herd unit, initially traveling north as far as the north side of Medlicott Dome, but also visiting Matthes Crest and Emeric Creek (Figure 11). He also trekked south outside of the herd unit during the rut to visit Iron Mountain and the upper San Joaquin River, all between October 15, 2023 and January 15, 2024. The Middle Fork of the San Joaquin was originally identified as potential low elevation winter habitat by an interagency group (Sierra Nevada Bighorn Sheep Interagency Advisory Group 1984) and again recently using remotely-sensed fractional snow cover to assess snow conditions (Rittger et al. 2021). We are interested to see where he explores in future winters.

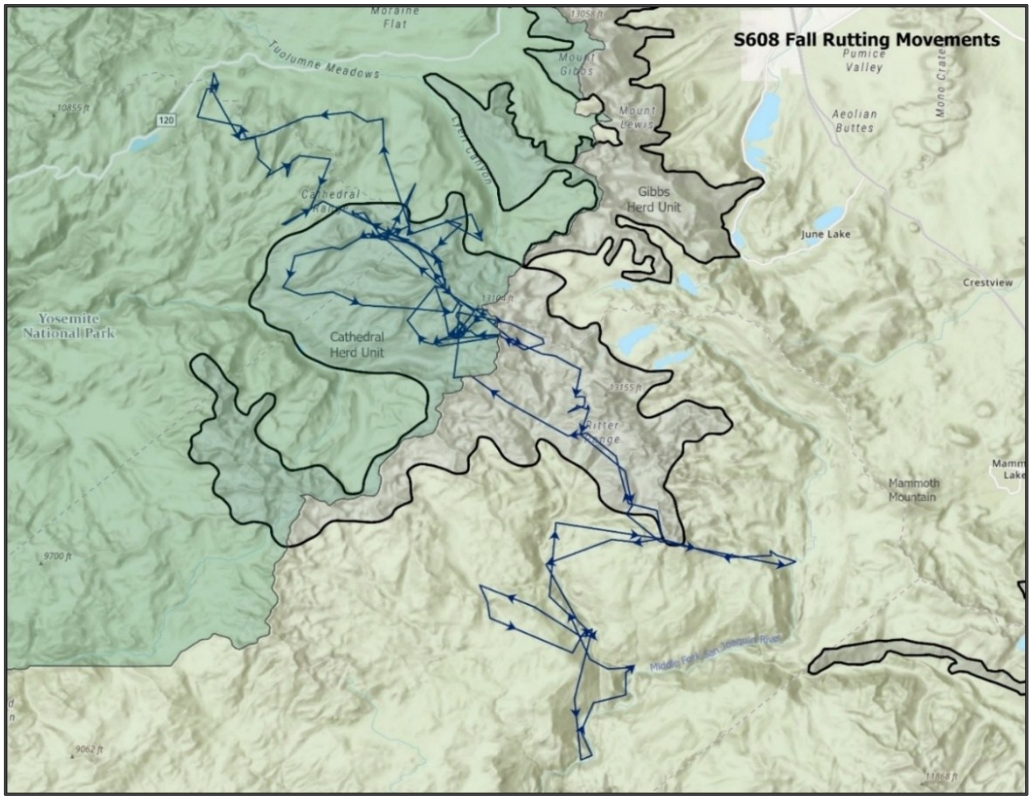

__Figure 11__. Fall movements of Sierra bighorn Cathedral ram S608M, October 30 through December 31, 2023.

Convict ram S657M made a large foray from traditional Convict habitat south to visit the Wheeler herd unit (Figure 12). Based on the density of animals at Wheeler, it is likely he overlapped with several Wheeler bighorn. With the exception of augmentations, we generally think Convict animals originated from Wheeler; use of the Convict herd unit by female bighorn was first confirmed in 2009 in the vicinity of Mt. Stanford (based on fecal pellet analysis). S657M also forayed north near Duck Lake to just south of the town of Mammoth Lakes.

Sawmill herd rams S653M and S652M traversed four herd units during June through December 2023, and visited the Palisade Lakes Basin, using more terrain in that area than we had previously documented (Figure 13). These rams were frequently together but also made solo forays.

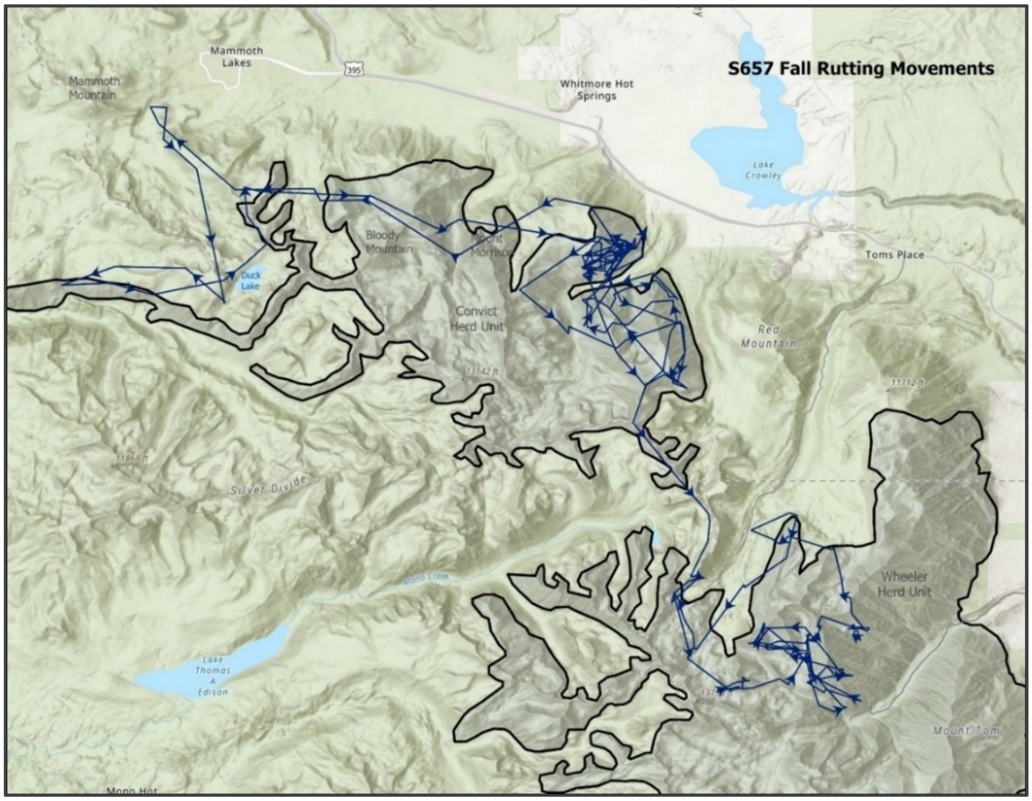

Figure 12. *Fall movements of Sierra bighorn Convict ram S657M, October 30 through December 31, 2023.*

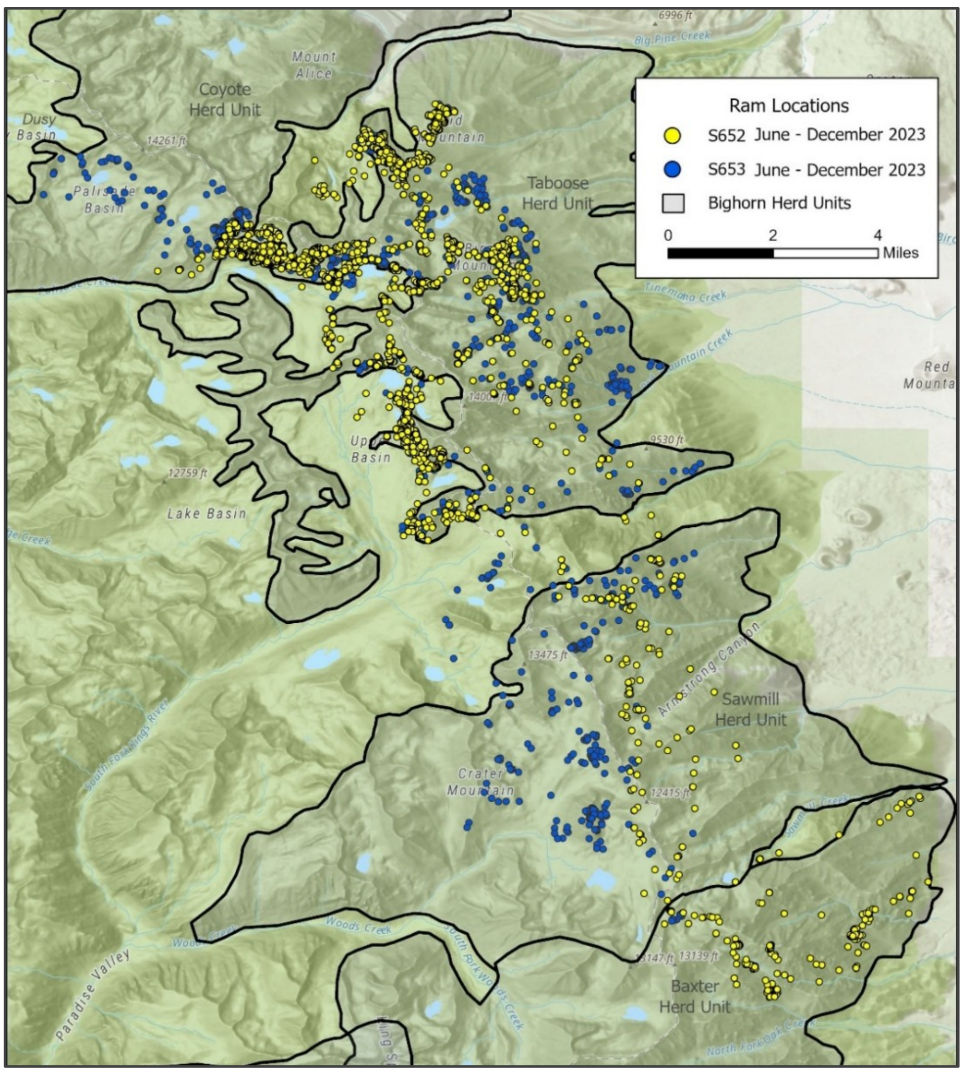

Figure 13. *Movements of Sierra bighorn Sawmill rams S652M and S653M during June through December 2023.*

Mountain Lion Monitoring and Management

Lion Minimum Counts

In the 2023 count year we documented 74 mountain lions in the eastern Sierra population: 26 adult females, 18 adult males, 28 subadults, and 2 lions whose sex and age class could not be determined. The adult population appears stable (in 2022 we detected 84 total lions: 27 adult females, 16 adult males, and 41 subadults), but less effort was put into juvenile monitoring in 2023, hence the juvenile count was lower.

In the Northern Recovery Unit we detected 13 lions: 5 adult females, 4 adult males, and 4 subadults (Figure 14). In the Central Recovery Unit we detected 26 lions: 8 adult females, 7 adult males, 10 subadults, and 1 of unknown sex and age. In the Southern Recovery Unit we detected 17 lions: 5 adult females, 4 adult males, 7 subadults, and 1 of unknown sex and age. In the Olancha Recovery Unit we detected 10 lions: 2 adult females, 2 adult males, and 7 subadults (Figure 14). Outside of the designated Sierra bighorn Recovery Units we detected an additional 17 lions: 8 adult females, 6 adult males, and 3 subadults, mostly in the Long Valley Caldera and Mono Basin. See Figure App. 1 (Appendix B) for a map of lion count zones.

Individual lions that are detected in multiple Recovery Units are counted in the total for each Recovery Unit but are only counted once for the total population estimate of 74 individuals. Fifty of these 74 individuals were monitored with GPS collars for at least part of the year. The 23 uncollared individuals detected in the population were mostly dependent juveniles whose fates are unknown, but also included 4 adult females, 3 adult males, and 2 animals whose sex and age could not be determined. These uncollared individuals were identified by physical evidence such as unique scars and marking, age of dependent subadults, non-functional collars, eartags, and unique track features (Appendix B).

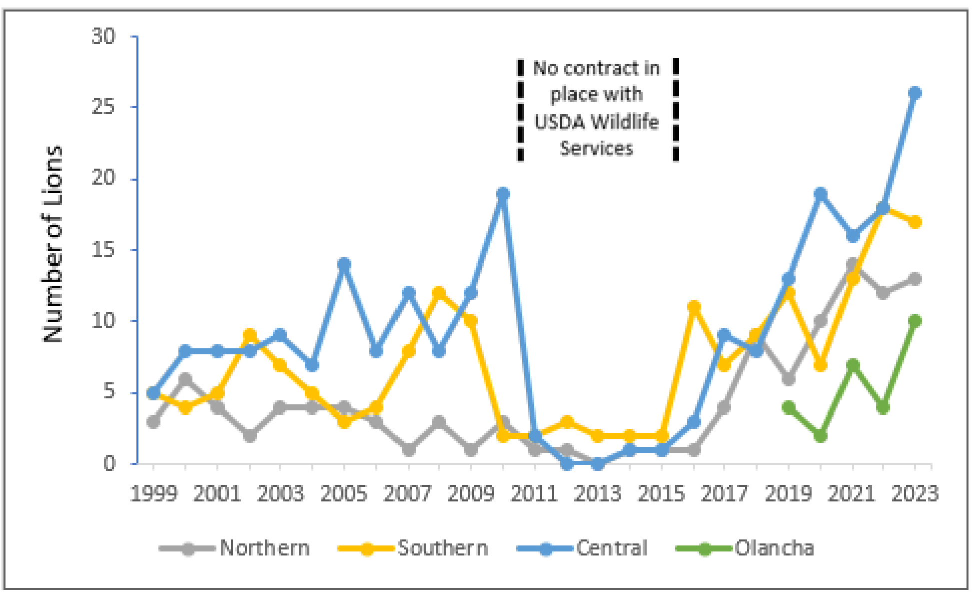

Figure 14. *Mountain lion minimum counts during 1999-2023 in the eastern Sierra. Lion monitoring effort was not consistent during this time period, and the Olancha count zone was added in 2019.*

Lion Captures

We captured 43 individual lions (19 recaptures and 24 new captures) including 19 adult females, 10 adult males, and 14 subadults. This is a significant increase from last year's total of 32 lions captured, largely due to increased detection probability with improved camera placement, particularly in the Central and Northern Recovery Units.

Predation on Sierra Bighorn

We documented 13 Sierra bighorn killed by mountain lions in 2023, distributed across 7 herds in the Northern, Central, Southern, and Olancha Recovery Units (Figures 15-16). Lions killed 2 adult ewes in the Baxter herd, 1 adult ewe in the Langley herd, 3 adult ewes in the Warren herd, 1 adult ram in the Williamson herd, 1 adult male and 1 unknown age/sex individual in the Olancha herd, 2 adult ewes in the Sawmill herd, and 1 adult ewe and 1 adult ram in the Wheeler herd.

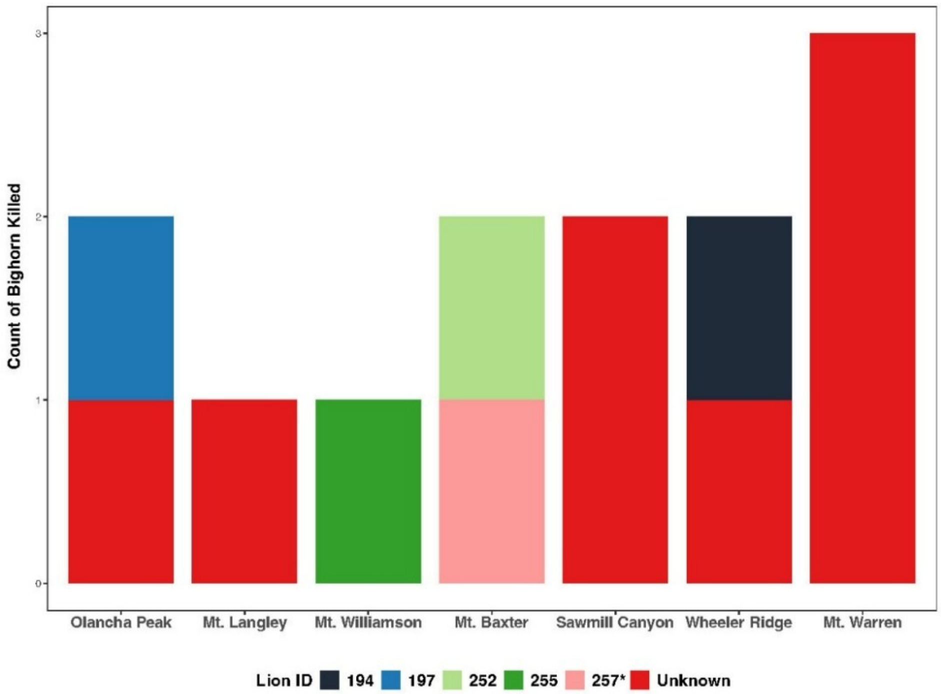

***Figure 15**. Lion predation on Sierra bighorn in the 2023 animal year by herd unit and individual lion. Lions denoted with an asterisk were translocated out of Sierra bighorn Recovery Units for Sierra bighorn protection during this time period.*

The Warren herd was hit particularly hard by the loss of 3 adult ewes to lions, out of 8 ewes documented in the entire herd. Two of these predation events occurred at high elevation on Kavanaugh Ridge in early March when the landscape was largely snowbound, travel routes were restricted, and primary prey populations of mule deer had vacated to their eastern winter ranges.

It is particularly concerning to document predation on high elevation winter ranges in the Northern Recovery Unit, where herds are currently small and vulnerable. Typically, Sierra bighorn that winter at high elevations are relatively safe from predation because they are unlikely to be discovered by lions who seldom venture into these areas during winter, but once discovered these bighorn are likely particularly vulnerable to predation as snow restricts their movements. A single lion that learns to target these alpine resident bighorn in the Northern Recovery Unit can have a devastating impact, illustrated by the loss of 37.5% of the Warren herd's ewe population in less than two months. The lion suspected to be responsible for these predation events was captured and translocated at the end of 2024 and will be discussed in the next report. These losses at Warren illustrate the significant impact lions can have on sheep wintering at high elevation when lions choose not to follow migratory deer to low elevation winter ranges.

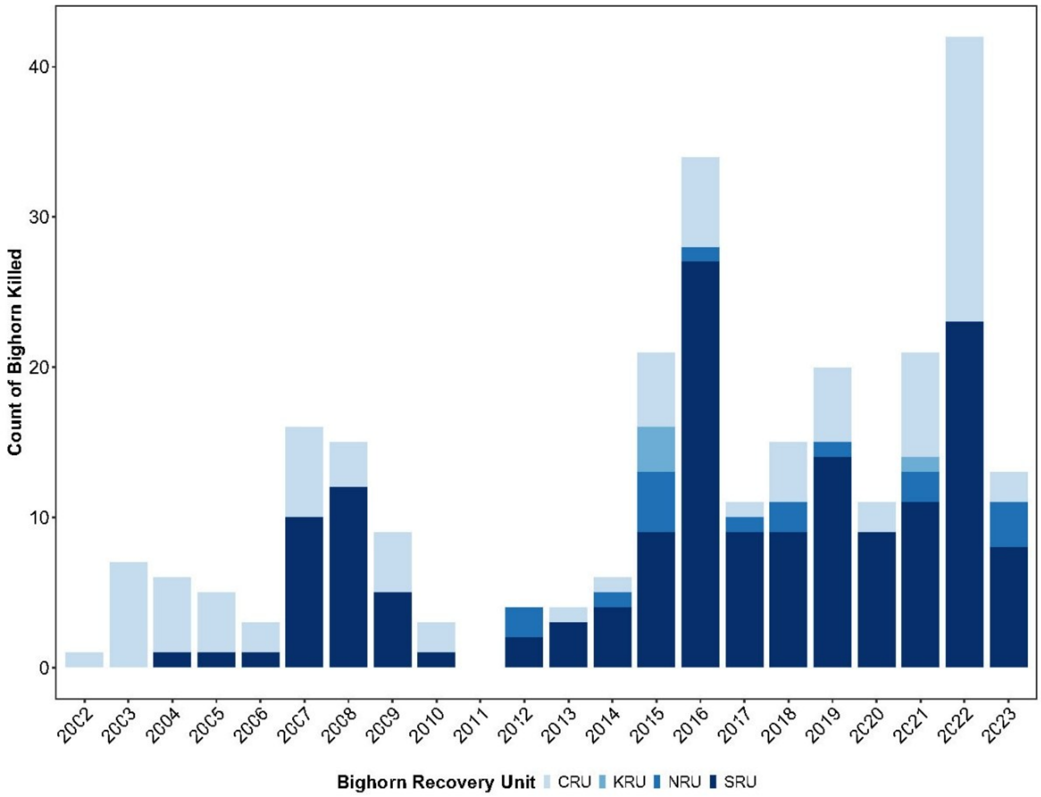

Figure 16*. Lion predation on Sierra bighorn by Recovery Unit from 2002-2023. Lion monitoring effort and Sierra bighorn population sizes were not consistent across this time period.*

Mountain lion GPS data allows us to quantify predation on Sierra bighorn by lions once they are collared, but many Sierra bighorn-predating lions were collared as mature adults later in life (Figure 17). There is little evidence suggesting that lions change their home-ranges and diet strategies in the middle of their lives, and it is likely that collared Sierra bighorn-predating lions have been impacting Sierra bighorn herds throughout their lives, prior to their collaring. As lion GPS data is an important method of detecting predation on Sierra bighorn, predation on Sierra bighorn by those lions would have been undetected or underestimated prior to the collaring of those lions, even with a proportion of bighorn collared in each herd. Therefore, reported lion predation in this and prior reports should be considered minimum estimates because we typically do not extrapolate total mortality from the proportion of collared bighorn.

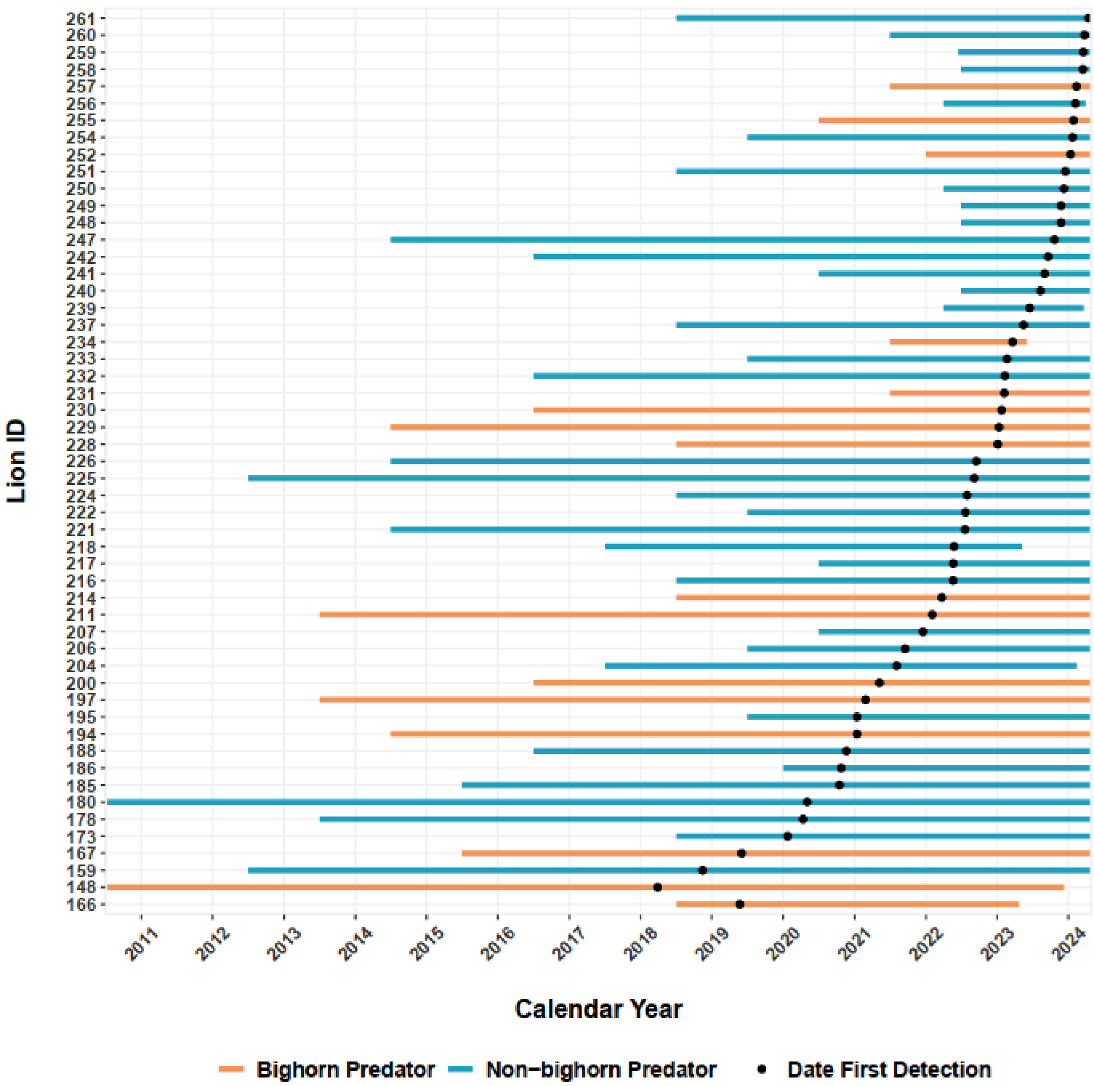

Figure 17. Temporal presence of collared lions in the eastern Sierra and their known status as Sierra bighorn predators. Birth year is based on estimated age from gum recession and tooth wear at first capture date (detection). The graph includes all collared lions that were alive during the 2023 animal year. We assume that individual lions maintain the same predatory preferences before and after capture, once they have established a home range.

Predation Management – Lion Translocations

The severe winter of 2022-23 and the associated spike in lion predation prompted the translocation of 6 lions that year, and the translocation of these individuals undoubtedly continued to benefit Sierra bighorn into the 2023 count year (Figure 16). In 2023, we translocated 2 lions, one adult female (L207F) and one subadult female (L257F), both from the Southern Recovery Unit (Figure 15). L207F was a 4-year-old female who was threatening Sierra bighorn in the Southern Recovery Unit, and L257F was a dispersing 2-year-old female who was captured at Black Canyon on the Baxter winter range after she killed an uncollared Sierra bighorn ewe.

As of April 30, 2024 we have monitored 15 translocated lions with a total annual survival probability of 0.733 (95% CI: 0.540–0.995), which is similar to the survival of non-translocated lions. After refining our translocation strategy and improving release site selection in 2022, survival of translocated lions improved further and was estimated at 0.889 (n=9; 95% CI: 0.706-1) for the 2022 and 2023 animal years combined.

Lion Survival and Mortality

Total lion survival in the 2023 animal year across all age and sex classes was 0.776 (95% CI: 0.650-0.928). Survival across age and sex classes were consistent with prior years with adult females at 0.878 (95% CI: 0.734-1), adult males at 0.735 (95% CI: 0.517-1), and subadults at 0.727 (95% CI: 0.506-1). We documented 13 lion mortalities in the eastern Sierra lion population due to depredation (n=4), anthropogenic poison (n=1), intraspecific aggression (n=1), public safety removal (n=1), abandonment (n=1), and unknown causes (n=6).

Lion Reproduction

We confirmed that 14 of the 26 adult female lions had at least 1 offspring. In total we detected 19 juveniles whose fates are unknown.

Management Considerations

Predation

Predation by lions on Sierra bighorn has been difficult to predict among years. Throughout much of the recovery effort, lion predation was expected to be relatively rare in alpine habitats, which were therefore considered comparatively secure from lion predation. Studies have suggested that Sierra bighorn trade nutritional opportunities on lower elevation ranges for reduced predation risk in alpine environments during winter (Spitz et al. 2020, Denryter et al. 2024). However, continued monitoring of Sierra bighorn predation indicates that predation at higher elevations may occur more often and be more consequential than previously suspected.

Predation on Sierra bighorn at elevations above 10,000 feet has now been documented in 9 of 14 herds (Figure 2). Of particular concern, the Northern Recovery Unit has experienced multiple instances of alpine predation. In 2019, a wildlife biologist of Yosemite National Park observed an uncollared lion killing a lamb at Mono Pass in the Gibbs herd (elevation 10,795 feet). During 2023, two GPS-collared ewes in alpine habitat within the Warren herd were killed by lions. The losses in the Warren herd in 2023 were particularly unfortunate because those females had survived the severe winter of 2022-23. The Recovery Program is pleased with the recent successes of translocating lions to reduce predation at all elevations, and protection of bighorn is essential for reaching recovery.

One possibility for the continued persistence of Sierra bighorn is an ecosystem shift in predator-prey dynamics. Berger and Wehausen (1991) described a predator-prey disequilibrium in the Great Basin, a concept that extends to many human-altered landscapes, including California. Changes in the abundance and composition of herbivore and carnivore communities in California have undoubtedly altered predator-prey dynamics. The Central Valley once supported as many as 500,000 tule elk (McCullough 1969), which likely sustained a substantial population of wolves across the landscape. Given their high rates of long-distance dispersal, wolves would have expanded into the Sierra Nevada and beyond. In addition, abundant salmon, elk calves, and acorns in the Central Valley would have supported a large population of grizzly bears. Together, wolves and bears likely constrained mule deer populations and exerted both direct and indirect effects on mountain lion abundance. These conditions, reduced mule deer availability and the presence of coursing predators (i.e., wolves), may have benefited Sierra bighorn.

Now consider the present: wolves dispersed from Oregon into California in 2011, and in 2021 a lone wolf spent several weeks in Mono County. In 2022, a pack—the Yowlumni Pack—was documented on the west side of the southern Sierra, marking the first confirmed pack south of Interstate 80 (CDFW 2025). Depending on the extent to which humans are able to coexist with wolves, the species may become established across additional portions of the southern Sierra. Mule deer are currently abundant throughout the Sierra and would provide sufficient prey to support wolves near the Sierra bighorn recovery area. If wolves become established in the southern and central Sierra, they are expected to alter native ungulate populations as they have in the Greater Yellowstone Ecosystem (Elbroch et al. 2020). Over time, wolves would likely depress deer abundance, followed by a subsequent decline in mountain lion numbers. Such a wolf-initiated trophic cascade could benefit Sierra bighorn, potentially leading to population increases. Wolves are typically not effective predators in steep terrain and are rarely an important source of mortality for mountain sheep (Sawyer and Lindzey 2002, Gasaway et al. 1983). The presence of wolves could shift ungulate abundance such that Sierra bighorn become the predominant ungulate in the Sierra Nevada as may have been the case in the past. The effect of wolves on lions will be influenced by the degree to which lions are able to use mountainous terrain as refugia and rely on prey such as bighorn. Understanding this evolving ecosystem will require monitoring all four large mammals: mule deer, lions, wolves, and Sierra bighorn.

Disease Risk to Sierra Bighorn

During September 2023, we received reports of a bighorn ram occupying forested habitat on the west slope of the Sierra Nevada, east of Shaver Lake. Over a period of approximately 10 days, the ram traveled south and west, ultimately entering a residential neighborhood in Clovis, where it was euthanized for public safety and animal welfare concerns. Subsequent laboratory testing confirmed that the ram was positive for *Mycoplasma ovipneumoniae*. Genetic analysis indicated that the animal was a desert bighorn sheep originating from the vicinity of Hunter Mountain in Death Valley. While we cannot be sure it was the same ram, an environmental scientist with the Department observed a bighorn ram on the east side of U.S. Highway 395 on September 7 (12 days before it was observed on the west slope of the Sierra Nevada), apparently attempting to cross from east to west.

Had this ram come into contact with Sierra bighorn, the consequences could have been catastrophic for the subspecies and may have jeopardized ongoing recovery efforts. Although Sierra bighorn populations can experience significant losses due to severe winters and lion predation, they have demonstrated notable resilience and the capacity for relatively rapid recovery. In contrast, disease outbreaks in bighorn sheep often result in long-term population impacts, sometimes persisting for decades, as pathogens continue to circulate within affected herds. Chronic poor lamb recruitment is common, as infected ewes repeatedly transmit *Mycoplasma ovipneumoniae* to their lambs (Cassirer and Sinclair 2007, Cassirer et al. 2013, Manlove et al. 2016). The appearance of a bighorn infected with a respiratory pathogen underscores the importance of continued disease surveillance and highlights the critical need for rapid response to any detected or emerging disease threats.

Sierra bighorn have not experienced a documented respiratory disease outbreak since intensive population monitoring began in the 1970s. This absence of disease is likely attributable to two primary factors. First, the population was small and spatially restricted during the 1970s, thereby limiting opportunities for contact with domestic sheep and goats. Second, interagency cooperation reduced domestic sheep grazing within and adjacent to occupied bighorn habitat when restoration efforts were initiated, beginning in the 1980s.

Domestic goats are known reservoirs and vectors of pathogens capable of infecting bighorn sheep, and they continue to represent a potential source of pathogen transmission to Sierra bighorn. In Arizona, domestic goats were implicated in the transmission of infectious keratoconjunctivitis, resulting in an average duration of blindness of 34 days in a desert bighorn sheep population (Jansen et al. 2006). On March 20, 2024, a free-ranging domestic goat was reported in lower Rock Creek Canyon, immediately north of the Paradise neighborhood in the eastern Sierra Nevada. Agency staff conducted multiple surveys over several days, ultimately locating and removing the animal. Public reporting of free-ranging livestock was critical for disease risk mitigation, as Rock Creek Canyon is in close proximity to the Wheeler bighorn herd. Domestic goats have also previously escaped onto Pine Creek Road near Round Valley School, and reports indicate that multiple feral goats have been observed in recent years north of the Swall Meadows neighborhood, also near the Wheeler herd.

Literature Cited

Berger, J. and J. D. Wehausen. 1991. Consequences of a mammalian predator-prey disequilibrium in the Great Basin

Desert. Conservation Biology 5:244-248.

California Department of Fish and Wildlife (CDFW). 2025. Ten Years of Gray Wolf Conservation and Management in California: 2015-2024. California Gray Wolf Conservation and Management 20152024 Multiyear Report. 31 pp. California Department of Fish and Wildlife, West Sacramento, CA, 95605.

Cassirer, E.F., R. K. Plowright, K. R. Manlove. 2013. Spatio-temporal dynamics of pneumonia in bighorn sheep. Journal of Animal Ecology 82:518 – 528.

Cassirer, E. F., and A. R. E. Sinclair. 2007. Dynamics of pneumonia in a bighorn sheep metapopulation. Journal of Wildlife Management 71:1080–1088.

Denryter, K., T. R. Stephenson, and K. Monteith. 2024. Migratory behaviours are risk-sensitive to physiological state in an elevational migrant. Conservation Physiology 12:1-12.

Elbroch, M., J. M. Ferguson, H. Quiqley, D. Craighead, D. J. Thompson, H. U. Wittmer. 2020. Reintroduced wolves and hunting limit the abundance of a subordinate apex predator in a multi-use landscape. Proceedings of the Royal Society B. 287(1938): 20202202.

Gasaway, W. C., R. O. Stephenson, J. L. Davis, P. E. K. Shepherd, and O. E. Burris. 1983. Interrelationships of wolves, prey, and man in interior Alaska. Wildlife Monograph 84.

Greene, L. E., P. Johnston, C. P. Massing, D. W. German, E. A. Siemion, K. Anderson, and T. R. Stephenson. 2023. Sierra Nevada Bighorn Sheep Recovery Program Annual Report 2022-23.

Hittle, M. 2025. Water Year 2024 Summary: An unusually average water year. California Nevada River Forecast Center. https://storymaps.arcgis.com/stories/0500f390954a448fbc27ae2140d0ba13.

Jansen, B. D., J. R. Heffelfinger, T. H. Noon, P. R. Krausman, and J. C. deVos Jr. 2006. Infectious keratoconjuctivitis in bighorn sheep, Silver Bell Mountains, Arizona, USA. Journal of Wildlife Diseases 42:407-411.

John, C., T. Avgar, K. Rittger, J. A. Smith, L. W. Stephenson, T. R. Stephenson, and E. Post. 2024. Pursuit and escape drive fine-scale movement variation during migration in a temperate alpine ungulate. Scientific Reports Nature Portfolio 14:1-11.

Johnson, H. E., L. S. Mills, T. R. Stephenson, and J. D. Wehausen. 2010. Population-specific vital rate contributions influence management of an endangered ungulate. Ecological Applications 20:1753-1765.

Kolek, J. T, T. R. Stephenson, K. Rittger, and K. L. Monteith. 2025. With great powder comes great responsibility: winter severity modulates antipredator responses of wildlife to recreation. Biological Conservation 310 https://doi.org/10.1016/j.biocon.2025.111374.

Manlove, K. R., E. F. Cassirer, P. C. Cross, R. K. Plowright, P. J. Hudson. 2016. Disease introduction is associate with a phase transition in bighorn sheep demographics. Ecology pp. 1 – 10.

Massing, C. P., D. W. German, and T. R. Stephenson. 2024. Morphologic differences in bighorn populations of California. Southwestern Naturalist 67:263-273.

McCullough, D. R. 1969. The tule elk: its history, behavior, and ecology. University of California Publications in Zoology 88. Berkeley, California.

Rankins, S. T., T. R. Stephenson, and K. L. Monteith. 2024. Sociality modulates nutritional carrying capacity of an endangered species. Frontiers in Ecology and Evolution.

Rittger, K., M. Krock, W. Kleiber, E. H. Bair, M. J. Brodzik, T. R. Stephenson, B. Rajagopalan, K. J. Bormann, T. H. Painter. 2021. Multi-sensor fusion using random forests for daily fractional snow cover at 30m. Remote Sensing of Environment 264:112608.

Sawyer, H. and F. Lindzey. 2002. A review of predation on bighorn sheep (Ovis canadensis). Wyoming Cooperative Fish and Wildlife Research Unit.

Sierra Nevada Bighorn Sheep Interagency Advisory Group. 1984. Sierra Nevada Recovery and Conservation Plan. 22 pp.

Spitz, D. B., M. Hebblewhite, and T. R. Stephenson. 2020. Habitat predicts local prevalence of migratory behavior in an alpine ungulate. Journal of Animal Ecology 89:1032-1044.

Stephenson, T. R., P. Johnston, C. P. Massing, D. W. German, K. Anderson, and L. E. Greene. 2022. Sierra Nevada Bighorn Sheep Recovery Program Annual Report 2021-22.

U.S. Fish and Wildlife Service. 2007. Recovery Plan for the Sierra Nevada Bighorn Sheep. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=27634 215.

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Appendix A: 2023 Herd Unit Summaries

Olancha

Olancha was the only herd that grew during the 2022 animal year, which had the wettest winter on record. Olancha was surveyed in the summer, September 12-13, 2023, and in the winter on March 7. By combining these counts, we had the highest count recorded at Olancha including 72 animals: 27 adult females, 7 yearling females, 1 female unknown age, 14 lambs, 4 yearling males, and 19 adult males. Some collars were missed during each survey indicating this is likely an underestimate. In September L197M killed a bighorn of unknown sex on the south plateau. This was the fourth lion kill documented on the south plateau, but despite their close proximity these kills involved at least two different lions (3 by L197M, and 1 by L211F). In October, an uncollared lion killed S638M low in a canyon north of Olancha Canyon. Also in October, a hiker reported seeing a bighorn at low elevation between Sage Flat Road and Walker creek at ~5,600 ft. Although atypical, one ewe was seen in this area in 2013. No captures occurred in Olancha this year.

Laurel

All known adults in the Laurel herd had been translocated there on March 23, 2022, so they were all wearing collars. All of these collared animals, and presumably any offspring they had, subsequently died during the winter of 2022-23, so it is assumed this herd has been extirpated within the herd unit boundaries. All mortalities have been investigated and collars retrieved. Effort was made to determine if there might be any surviving bighorn remaining from the initial introduction in 2015. The last observation of these animals was in June 2021, when there was still a functional VHF collar (S382F), and they were found on the east side of the Kern River in a group of four (2 adult females, 1 unknown aged female, and 1 adult male). Unfortunately, S382F died in September 2021 (on the east side of the Kern River) and none of the bighorn previously seen with her have definitively been observed since (but see below because they may have moved to the Boreal plateau). Surveyors traveled from Funston Lake to the Kern station through some of this area east of the Kern River, but no bighorn sign was observed. This is a vast and convoluted area, however, and will continue to be surveyed occasionally for survivors.

Two groups of bighorn were observed outside of the Laurel herd unit to the east—a group of 2 females and 1 male just west of Funston Lake and a group of 5 rams on the Boreal plateau. Bighorn have sporadically been observed in this area, including two rams photographed on Mt. Anna Mills in 2017. In November 2011, Langley S188M traveled through the Boreal plateau, and additionally 3 GPS-collared Laurel rams visited the area in March 2015 after being translocated into Laurel. The 2023 observations are currently being counted as Langley animals, due to historical use. However, it is possible these are remnant Laurel animals from the initial Laurel introduction in 2015. Pellets have been collected, and genetic analysis may be able to differentiate the origin of these animals. Future monitoring and surveys should target this region.

Big Arroyo

All collared Big Arroyo animals died from snow-related causes in the winter of 2022-23 but were not able to be investigated until the summer due to deep snow. When these 7 collared mortalities were investigated in August, an additional 4 uncollared mortalities were found (see Greene et al. 2023 for details). Areas typically occupied by Big Arroyo bighorn, including the Chagoopa bowl, Chagoopa switches, and the rocky area above upper Funston meadow, were all surveyed for sheep. No fresh sign was observed. Game cameras were placed in Chagoopa bowl and in the rocks above upper Funston meadow. A single ram was photographed in Chagoopa Bowl in November and January; it is possible these were two different individuals (Figure 1). Additionally, a hiker claimed to have seen a single bighorn (unclassified sex and age) near upper Funston meadow in August.

Langley

Our best count at Langley included observations from June through September for a total of 30 animals: 11 adult females, 2 yearling females, 5 lambs, 10 adult males, and 2 yearling males. Both collared males were observed and 2/3 of the collared females were observed. This includes the 8 animals observed on the Boreal plateau (2 females, 6 males) which may be remnant Laurel or Big Arroyo animals (genetics tests pending). This is a ~50% decline from the 2022 count of 23 females. Particularly with so few collars at Langley, we are unsure if we missed animals, or if we lost 50% of the population, which would match range-wide losses associated with the severe winter of 2022-23.

S612M died from rockfall in August and was subsequently excluded from the count, and S661F was killed by a lion in April 2024. In October, we captured and collared 6 previously uncollared individuals (4 females and 2 males). No novel or notable movements were observed.

Williamson

Summer and spring counts yielded different results at Williamson, but at a minimum we can account for 15 animals, including 6 females, 4 lambs, 4 males, and 1 unknown animal. In early August we accounted for 12 total sheep: 6 adult females, 2 lambs, and 4 adult males. This included groups from both the Barnard deme (4 adult females, 2 lambs) and the Williamson deme (2 adult females). The only collared female (S589F) was seen, and the one collared male (S492M) was not seen. During the survey, the tracks of an adult (presumed female) and lamb were observed with the 2 adult females in the Williamson deme, but these animals were never encountered. Therefore, we assume this minimum count is missing some animals and not a census. In April, ground counts identified 4 adult females, 2 yearling females, 4 lambs, 3 adult males, 1 yearling male, and 1 unknown that was either a yearling female or a large lamb. When combining counts, we concluded that yearlings and adults could potentially have been misclassified, so we only included definitively distinct additional animals.

In the spring, L255M killed S492M in North Bairs Creek. S632F is also believed to have died of unknown causes in the summer, but we were unable to locate her carcass or collar. In the fall, three animals were captured including one recaptured female and two new captures (1 male and 1 female). Prior to capture, there was only a single GPS-collared female in Williamson and her collar worked intermittently.

Baxter

This year we accounted for 112 animals: 44 adult females, 4 yearling females, 22 lambs, 40 adult males, and 2 yearling males. As often occurs at Baxter, our highest count of females and lambs occurred in the summer, and our highest count of males occurred during the winter. The summer count included animals from two different demes: Mt. Baxter and Mary Austin. There were 14 animals in the Mary Austin deme: 8 adult females, 1 yearling female, 4 lambs, and 1 adult male, and the rest were from Mt. Baxter.

This year we documented 4 bighorn mortalities and censored 1 animal that wasn't detected for 2 years. One ram died of unknown cause on Sand Mountain in June, and a second ram died of unknown cause in December at the top of the Sand Mountain bench. In February, L257F killed adult female M260F low in Black Canyon Creek and was translocated. In April, a different lion, L252M, killed M262F between Thibaut and the north fork of Oak Creek. Mary Austin deme S223F was censored after not being detected for 2 years. No captures occurred within Baxter this year.

Sawmill

The summer count at Sawmill accounted for only 34 animals: 20 adult females, 5 yearling females, 4 lambs, 4 adult males, and 1 yearling male. Even with the large known losses at Sawmill, we believe this may be an undercount. During the April 10, 2023 fieldtrip, we observed 22 adult females, 3 yearling females, and 10 lambs. Additionally, 11 lambs were seen in winter 2023-24. The minimum count only includes direct observations, but many animals were caught on wildlife cameras at Colosseum Pass and Crater Mountain. However, no additional animals could be added to the count from these cameras because they were potential double-counts. The minimum count includes animals in the core and Goodale demes, but no animals were found in the Acrodectes deme. The Acrodectes deme can overlap during the summer with the Baxter deme.

Unusually, S646F was seen with only a GPS collar and seems to have dropped her VHF collar. There were 2 mortalities detected at Sawmill, S643F and S645F, who were both killed by unknown lions.

Bubbs

On August 26, a group of 12 animals was seen: 7 adult females, 1 yearling female, 2 lambs, 1 adult male, and 1 yearling male. This included the only collared animal in Bubbs, S630F. We assume that the female S631F, who had been intermittently on mort since April 2023, is dead. In May and June, 2 animals died of unknown causes (S629F and S628M).

In the fall, on October 27, two unmarked males were captured and collared. GPS collars detected no unusual movements.

Taboose

With limited staff and no collars in Taboose, there were no observations, captures, or mortalities detected here in 2023. S543F has traveled between the Goodale deme of Sawmill and Taboose in the past, but this year she stayed south of Cardinal Peak, generally within the Sawmill herd unit.

Wheeler

In the fall we accounted for 53 animals at Wheeler: 22 adult females, 5 yearling females, 9 lambs, 16 adult males, and 1 unclassified animal. This included a somewhat mysterious ram that was seen with a black VHF collar. Our best guess is that this is S410M who was last seen in 2016. We are hoping to confirm this ID with an eartag observation. We detected three mortalities: L194F killed an uncollared female (M263F) in Hellcat Canyon, an unknown lion killed S624M near Dorothy Lake, and S625F died from unknown cause in March; the carcass and collar were never found.

In the fall we recaptured 1 female and captured 1 previously naked male to increase collars in Wheeler. Granite Park bighorn S553F traveled through Seven Gables Lakes in October. This is not the first time bighorn have traveled in this region, but it does not happen every year.

Convict

During the summer only males were observed at Convict, but on April 1, 2024, we saw 5 adult males including the 2 collared males and 1 uncollared adult female. This could be a census as our last female count in 2022 included 7 females, and we subsequently documented 6 female mortalities. Various attempts were made in 2023 to see sheep including a group survey on July 11, a hike up Esha Canyon on September 5, and a hike to Davis Lake chasing the signal of S527M on September 6. In the fall a single uncollared male was captured and collared, which brought the total collars in Convict to 2 males.

Gibbs

Much effort was put into surveys at Gibbs, and the final count was a total of 13 animals: 2 adult females, 1 yearling female, 1 lamb, and 9 adult males. Both collared animals (male and female) were seen many times. No females were seen in the Algers deme. Survey effort included a tour starting July 8 from Bloody Canyon to Parker Plateau, over Koip Pass, and out Silver Lake, as well as a survey July 18-20 from Mono Pass to Kuna Bowl, over Blacktop Peak, down Crest Creek to Alger Lakes, and out Silver Lake. No fresh sign was seen on Blacktop Peak. Additionally, August 31 - September 1, Wehausen spent time on Mt. Wood, Parker Plateau, and Gibbs meadow with no sheep seen. On September 6, no sheep were seen glassing from Parker Lake. In the fall a single uncollared male was captured and collared.

Warren

By combining observations from June and July, we accounted for a total of 14 bighorn: 8 adult females, 3 lambs, and 3 adult males. All four collared females were seen and there are no collared males at Warren. We recorded 5 mortalities at Warren, all females. S537F died from unknown cause in June prior to the survey; S534F was killed by unknown cause, not predation, and 3 animals were killed by unknown lion(s) in March and April 2024 (S622F, S659F, and S532F). We believe the lion responsible was L267M, who was later captured and translocated.

In the fall, a previously uncollared male and female were captured and collared. Bighorn continued to use low elevation habitat between Kavanaugh Ridge and the east fork of Green Creek.

Cathedral

During a spring ski survey, we detected 4 males at Cathedral including the one remaining collared animal S608M. There was no fresh sign on Parson's Plateau, and this may be all that remains of the Cathedral herd. In the fall, S608M was recaptured and recollared.

Appendix B: Background and Methods

BACKGROUND

Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) are a unique subspecies native to the Sierra Nevada in California (Grinnell 1912, Wehausen and Ramey II 2000, Wehausen et al. 2005). They have distinctly wide splayed horns and have been genetically isolated from other bighorn sheep subspecies for roughly 100-300,0000 years (Buchalski et al. 2016). Conservation management has included hunting regulations beginning in 1878, as well as a series of translocations beginning in 1979 (Bleich et al. 1990). The early translocations established the Warren, Wheeler, and Langley herds, and also unintentionally created Gibbs. Despite these efforts, the range-wide population was estimated to be only ~100 individuals in 1995 (U.S. Fish and Wildlife Service 2007).

In 1999, Sierra bighorn were placed on the federal endangered species list, and the California Department of Fish and Wildlife was selected to be the lead agency in the implementation of recovery efforts. Recent bighorn die-offs throughout the west have been associated with the bacterium *Mycoplasma ovipneumoniae* (*M. ovi*), and it is thought that respiratory disease likely drove earlier declines in the distribution and abundance in Sierra bighorn (Wehausen et al. 2011). Fortunately, *M. ovi* has not been detected in the Sierra Nevada based on testing from 2001, and we have observed no clinical signs of respiratory disease, such as coughing or lung lesions, since monitoring began in 1974. Sierra bighorn population dynamics appear to be largely driven by adult female survival (Johnson 2010), and over the last twenty years, the top two causes of mortality are predation by mountain lion (*Puma concolor*) and snow-related death in the form of starvation or avalanche.

The Recovery Program monitors Sierra bighorn abundance, demography, and habitat use to inform management decisions regarding translocation, predator management, and disease risk. We monitor mountain lion abundance, demography, and habitat use because they are the main predator and largest known cause of mortality for Sierra bighorn. Monitoring of Sierra bighorn and lions requires the capture and collaring of animals, ground counts, and the investigation of mortalities and mountain lion kills. Our two main conservation activities are translocation and predator management. Additionally, we work to reduce the potential for disease transmission between Sierra bighorn and domestic sheep, and we promote bighorn recovery through public outreach. We also support and direct academic research.

For brevity we refer to herd units using single word names, for example 'Olancha' for the Olancha Peak herd unit. We refer to Sierra Nevada bighorn sheep as 'bighorn' or 'Sierra bighorn' and mountain lions as 'lions'. Each animal ID number has a prefix: "S" for collared Sierra bighorn, "M" for uncollared Sierra bighorn, and "L" for mountain lion. Each animal ID number has a prefix: "S" for collared Sierra bighorn, "M" for uncollared Sierra bighorn, and "L" for mountain lion. Postscripts "F", "M", and "U", represent sex of the animal, with "U" for unknown. We use '2023' to represent the animal year May 1, 2023 – April 30, 2024, beginning with lambing season and including the winter of 2023-24. In contrast, climatologists refer to water year 2023 as October 2022 - September 2023, which is most clearly associated with bighorn year 2022. "Source" herds (Wheeler, Sawmill, Baxter, and Langley) have contributed to recent reintroductions (beginning in 2013) that have supplied animals for "new" herds (Cathedral, Big Arroyo, Laurel, and Olancha).

METHODS

Capture

Capturing Sierra bighorn provides the opportunity to determine body condition, pregnancy status, test for disease, measure genetic diversity, and deploy collars. Body fat and pregnancy are determined using ultrasonography (Stephenson et al. 2020). Capturing bighorn is critical for translocations, and collaring bighorn enables us to monitor habitat use, disease risk, vital rates, and estimate herd size. Capture is done with a net-gun fired from a helicopter (Jessup et al. 1988). Power analyses indicate we need to maintain collars on 35% of the female population in order to detect 10% change in survival per year over 5 years using a known fate survival analysis (German 2010). Functional collars have proven essential for tracking survival and cause-specific mortality. Collared bighorn and collared lions provide complimentary information on predation by mountain lions and one or the other has proven essential in cases where keeping both species collared in any given herd is challenging. We try to maintain this ratio for source herds with >20 females and in newly established herds. We focus capture and collaring efforts on females, as they tend to drive population dynamics. However, collared males can help identify patterns of habitat use and identify and quantify disease risk from contact with domestic sheep, so we also try to maintain some collars on males, particularly in herds near domestic sheep (e.g., Warren, Convict, and Wheeler).

Sierra Bighorn Population Estimation

Although minimum counts are not technically a statistical estimation with confidence intervals, we consider them an "estimate" of the population size. Without confidence intervals it is not possible to know if a low count is indicative of a shrinking population or simply a bad or incomplete count. For this reason, we also developed our own metric of minimum count quality based on the proportion of females that have marks and the proportion of marks seen. "Census" minimum counts are where we think, based on the previous year's count and our familiarity with the herd, as well as known mortalities and recruitment, that we have accounted for every female and lamb in the herd. "Good" minimum counts have at least 20% of females collared and at least 80% of collared females seen. "Poor" minimum counts either have <20% of females collared or <80% of collared females seen during the survey. It is possible that a poor survey may be accurate, particularly in the case of a herd with few marks but in which all of the bighorn were seen. However, these categories allow us to be more confident that a population trend is real if the minimum counts are consistently at the "census" or "good" level.

Minimum counts are "reconstructed" to include bighorn that were not seen during the survey but subsequently determined to have been present based on additional information. All reconstructions are carefully tracked. The most common way minimum counts are reconstructed is to add collared individuals known to be alive but not seen during the survey. A collared animal is censored after two years without visual, GPS collar, or radio telemetry observation; censor date is one month after the last detection. In addition, for herds with near census counts, a count from a given year can often indicate that there must have been more bighorn present in the previous year than were counted. In this case, additional bighorn may be added to a previous year's count. Even with reconstructions, minimum counts tend to underestimate true abundance, particularly in herds with >20 individuals, as it becomes more difficult to locate every individual.

Mark-resight (MR) estimates were calculated for females using Bowden's estimator (McClintock et al. 2009). Within a season, we evaluated each survey individually and also considered combining multiple surveys to identify the MR estimate with the lowest CV. We only report MR estimates with a coefficient of variation (CV) < 0.15.

Our range-wide abundance represents our best estimate of female population size and is compiled from herd unit survey data. However, these range-wide counts are somewhat confounded by seasonal differences in herd surveys. To prevent double-counting translocated bighorn, we only include translocated bighorn in summer counts of receiving herds and remove them from winter counts of source herds. Wheeler and Baxter tend to be surveyed after most winter mortality has occurred, but before lambing. Therefore, the total female count for these herds includes winter impacts on adult and yearling survival but does not include the addition of recruiting lambs or their survival (lamb to yearling). Most other herds are surveyed in summer, prior to any winter mortality. For these herds, the total count of females does not include the impact of winter. Because of this, more complex vital rate analyses based on count data requires separating the data based on survey timing, or alternatively, focusing on data not associated with count data, such as collar survival (e.g., Conner et al. 2018).

We generally estimate that there are 2 males for every 3 females based on past counts in the Sierra Nevada (Wehausen 1980) and various studies on bighorn sheep (e.g., Valdez and Krausman 1999). We believe this ratio is more accurate than our male minimum count because we have so few males collared, and survey effort is focused on finding females. Our collaring efforts focus on females because they tend to drive population dynamics, but we have enough males collared to know that male survival tends to be lower than female survival (Conner et al. 2018). Our more recent ground counts target female home ranges and therefore produce low counts of males because males tend to use different habitat (Schroeder et al. 2010).

Sierra Bighorn Survival Estimation

We estimate herd-specific annual survival rates using the Kaplan Meier staggered-entry estimator (Pollock et al. 1989). Survival rates are based on collared individuals and only use herds with >3 collars. Survival estimates from herds with few collars may show large changes that do not necessarily reflect the underlying population, as well as higher levels of uncertainty caused by stochastic variation among collared bighorn, rather than correctly representing survival of the underlying population.

Sierra Bighorn Lamb Survival

We estimate lamb survival using the age ratio approach (White et al. 1996). We modified this approach using Kaplan Meier estimates of survival from collared females instead of measuring adult survival from carcasses on winter range. The age ratio approach assumes that the proportion of lambs counted in a given survey relative to the proportion of adults counted is constant across all surveys. In other words, the likelihood of seeing a lamb is the same as the likelihood of seeing a female. This seems reasonable for Sierra bighorn survey observations. We bounded adult and lamb survival at 0 and 1. Similar to the variances calculated by White (1996) we used sequential applications of the delta method to calculate the variance of the ratios. Since our adult survival is not based on a ratio calculation, but on the Kaplan Meier method, our calculations are expected to have a somewhat lower variance for similar survey effort.

Sierra Bighorn Pregnancy Rates

Pregnancy rate was determined from ultrasound during spring capture. Proportion of pregnant females observed with lambs was estimated using the range-wide pregnancy rates for adults (85%) and yearlings (55%) combined with the average proportion of yearling females (21%).

Sierra Bighorn Lambda Estimation from Minimum Counts

We estimate the annual population growth rate λ from minimum counts for herds that are consistently counted annually; this includes 11 herds: Cathedral, Warren, Gibbs, Convict, Wheeler, Sawmill, Baxter, Langley, Big Arroyo, Laurel, and Olancha. Bubbs, Taboose, and Williamson are excluded because we have consistently had a difficult time obtaining quality counts annually from these herds.

Sierra Bighorn Eigenvalue Lambda Estimation

We estimate the annual population growth rate lambda (λ) by constructing a three stage (lamb, yearling, adult) matrix model to describe the population dynamics of Sierra bighorn of the following form (Johnson 2010, Johnson et al. 2010, Cahn et al. 2011). Equations are formulated based on the timing of the annual population survey:

Summer survey equation matrix Fecundity = lamb/ewe ratio (Jul-Aug)

$$N(t+1) = \begin{vmatrix} N_L(t+1) \\ N_Y(t+1) \\ N_A(t+1) \end{vmatrix} = \begin{bmatrix} 0 & S_A F(0.5) & S_A F \\ S_Y & 0 & 0 \\ 0 & S_A & S_A p \end{bmatrix} \begin{vmatrix} N_L(t) \\ N_Y(t) \\ N_A(t) \end{vmatrix}$$

Winter survey equation matrix Recruitment = lamb/ewe ratio (Mar-Apr)

$$N(t+1) = \begin{bmatrix} 0 & R(0.5) & R \\ S_Y & 0 & 0 \\ 0 & S_A & S_A p \end{bmatrix} \begin{vmatrix} N_L(t) \\ N_Y(t) \\ N_A(t) \end{vmatrix}$$

Where N = number of individuals, F = fecundity, S = survival, R = recruitment, p = 1% senescent

We then solve this linear series of simultaneous equations using eigenvectors and eigenvalues to get the ratio of N(t+1)/N(t), or λ, the annual population growth rate.

MOUNTAIN LION POPULATION ESTIMATION

We monitor mountain lions throughout the range of Sierra bighorn to understand which herds may be experiencing impacts from predation and the degree to which these impacts may hinder recovery. We use all available evidence to create minimum counts of mountain lions in each count zone, following techniques described in McBride et al. (2008). Minimum counts encompass the total number of individual collared animals, the number of uncollared mortalities documented, and the number of distinct unmarked animals that can be identified. Minimum counts are conducted within four separate count zones; the northern, central, southern, and Olancha count zones (Figure App. 1). We also create a minimum count for mountain lions in the eastern Sierra outside of the count zones, but within the count zones we attempt to count every animal present when possible. Lion minimum counts in this report reflect animals counted May 1, 2023 – April 30, 2024.

We used GPS locations from collared lions in conjunction with remote cameras to count the minimum number of collared and uncollared lions in the study area. Our cameras were placed with two goals: 1) capturing photographs of every lion in the study area, and 2) obtaining photos of proper angle and quality to discern unique marks on individual lions. Cameras were not placed in accordance with a grid or any other sampling scheme. We used scent-lure and/or naturally occurring mountain lion scent at scrape sites as an attractant for the purpose of enticing lions to linger in front of the camera and offer multiple angles of view as they turn their heads and bodies to investigate the scent, as described by McBride and Sensor (2015).

Lions in photographs were identified as individuals by 1) GPS collar location data, 2) unique collar features, 3) unique ear shapes due to healed lacerations, and 4) age of dependent subadults. GPS-collared animals were identified by GPS locations placing animals in proximity to cameras at the time of camera detections, and by unique features of collars such as model, color, unit symmetry, and spacer modifications. Collared lions were classified as adults if they were greater than 24 months of age and traveling independently of their mother and siblings. A detection was defined by a lion visiting a camera site yielding any number of photos. A new detection was counted if any one of the following criteria were met: 1) greater than two hours elapsed between photos, 2) different individual lions sequentially triggered a camera regardless of elapsed time, and 3) different camera sites triggered by lion regardless of elapsed time or distance between cameras. Detections of adult females with dependent subadults were classified as one detection of a family group rather than multiple detections for the individual lions.

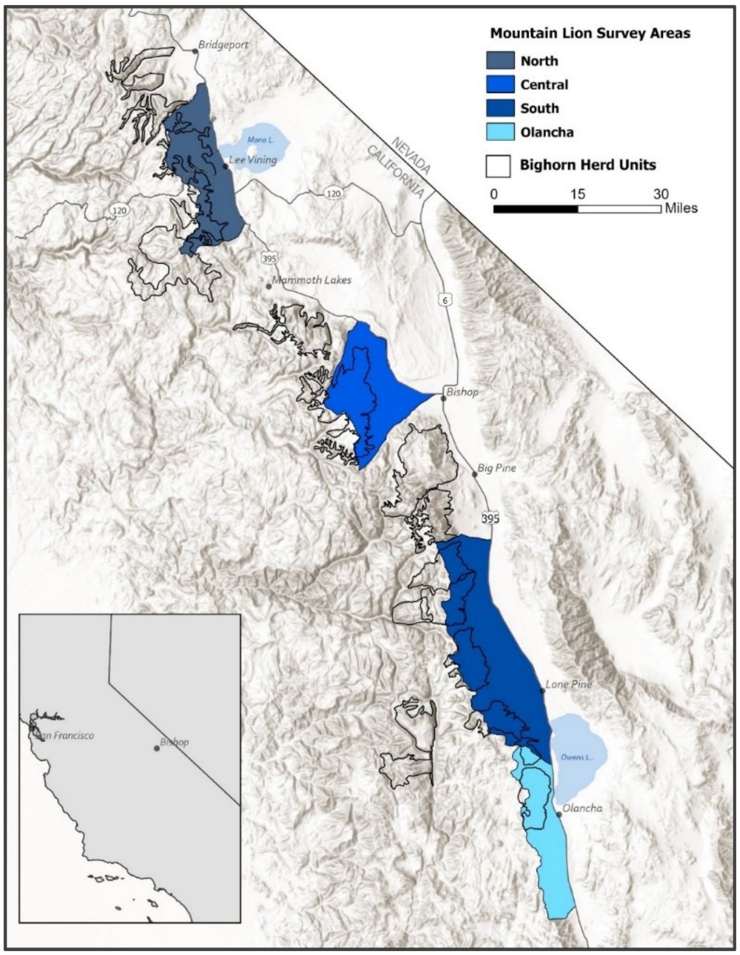

Figure App. 1. Mountain lion count zones in the eastern Sierra Nevada, with Sierra bighorn herd units for reference.

Identification of uncollared lions was based on unique scar patterns on ears and age of subadults. Uncollared lions were also distinguished based on simultaneous detections separated by sufficient distance such that it would have been impossible for one lion to trigger the two distant cameras within the timespan between detections. Tears, notches, holes, and missing parts of ears are common in mountain lions, and while the bleeding edges will heal, they do not regrow missing flesh. A lion may accumulate these scars as time goes on, but they do not lose them. If a lion passes a remote camera in January with no ear scars, then a lion passes the same camera in February with many ear scars this is counted as one lion because the scars could have been accumulated between the detections. However, if a lion passes a camera in January with many ear scars, then a lion passes the same camera in February with no ear scars, these photographs represent two individual lions. All lions within a gender with no ear scars are counted as one individual. Female lions with no ear scars or other unique marks can be identified by the age of their dependent young that appear in photos with them. For example, if a camera detects a female lion with a group of 4-month-old subadults and the following week the same camera detects a female lion with a group of 12-month-old subadults than that would yield a count of two adult females.

Uncollared subadult lions were classified as individuals by the adult female which they were photographed with, by the number of animals visible in a single frame, and by the gender of those animals. Subadults photographed by themselves with no adult female present were counted as one of the known subadults belonging to a known adult female unless the age of the unknown animal was not consistent with that of the known animals.

Uncollared lions were classified as adults if they were photographed with dependent young, or if they met all of the following criteria: 1) had no juvenile pelage or morphological characteristics, 2) had unique ear notches which distinguished them from all known lions, and 3) were photographed repeatedly over a period of months indicating residency. Collared and uncollared lions that could not be identified as individuals by the methods described above were classified as unknown.

Mountain Lion Survival Analysis

Mountain lion annual survival probabilities were calculated with a standard Kaplan-Meier survival analysis for each age and sex class individually. This analysis allows for censoring of animals whose collars failed as well as for staggered time entry of animals who were captured for the first time during the monitoring period. This yields survival probability estimates for individuals of a given age and sex class based on observed mortalities within those groups. Uncollared mountain lions were not included in the analysis.

LITERATURE CITED APPENDIX

Bleich, V. C., J. D. Wehausen, K. R. Jones, and R. A. Weaver. 1990. Status of bighorn sheep in California, 1989 and translocations from 1971 through 1989. Desert Bighorn Council Transactions.

Buchalski, M. R., B. N. Sacks, D. A. Gille, M. C. T. Penedo, H. B. Ernest, S. A. Morrison, and W. M. Boyce. 2016. Phylogeographic and population genetic structure of bighorn sheep (*Ovis canadensis*) in North American deserts. Journal of Mammalogy 1-16.

Cahn, M. L., M. M. Conner, O. J. Schmitz, T. R. Stephenson, J. D. Wehausen, and H. E. Johnson. 2011. Disease, population viability, and recovery of endangered Sierra Nevada bighorn sheep. Journal of Wildlife Management 75:1753-1766.

Conner, M. M., T. R. Stephenson, D. W. German, K. L. Monteith, A. P. Few, and E. H. Bair. 2018. Survival analysis: Informing recovery of Sierra Nevada bighorn sheep. Journal of Wildlife Management 82:1442-1458.

German, D. W. 2010. Sample sizes for estimation of population size, recruitment, and adult female survival of Sierra Nevada bighorn sheep. California Department of Fish and Wildlife Memo.

Greene, L. E. 2023. Sierra Nevada bighorn sheep mortality reclassification. California Department of Fish and Wildlife Memo.

Greene, L. E., P. Johnston, C. P. Massing, D. W. German, E. A. Siemion, K. Anderson, and T. R. Stephenson. 2023. Sierra Nevada Bighorn Sheep Recovery Program Annual Report 2022-23.

Jessup, D. A., R. K. Clark, R. A. Weaver, and M. D. Kock. 1988. The safety and cost-effectiveness of net-gun capture of desert bighorn sheep (*Ovis canadensis nelsoni*). The Journal of Zoo Animal Medicine 19:208.

Johnson, H. E. 2010. Escaping the extinction vortex: Identifying factors affecting population performance and recovery in endangered Sierra Nevada bighorn sheep. University of Montana.

Johnson, H. E., L. S. Mills, T. R. Stephenson, and J. D. Wehausen. 2010. Population-specific vital rate contributions influence management of an endangered ungulate. Ecological Applications 20:1753-1765.

McClintock, B. T., G. C. White, M. F. Antolin, and D. W. Tripp. 2009. Estimating abundance using mark-resight when sampling is with replacement or the number of marked individuals is unknown. Biometrics 65:237-246.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Schroeder, C. A., R. T. Bowyer, V. C. Bleich, and T. R. Stephenson. 2010. Sexual segregation in Sierra Nevada bighorn sheep, *Ovis canadensis sierrae*: Ramifications for conservation. Arctic, Antarctic, and Alpine Research 42:476-489.

Stephenson, T. R., D. W. German, E. F. Cassirer, D. P. Walsh, M. E. Blum, M. Cox, K. M. Stewart, and K. L. Monteith. 2020. Linking population performance to nutritional condition in an alpine ungulate. Journal of Mammalogy 101:1244-1256.

U.S. Fish and Wildlife Service. 2007. Recovery Plan for the Sierra Nevada Bighorn Sheep. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=27634 215.

Valdez, R., and P. R. Krausman, editors. 1999. Mountain Sheep of North America. University of Arizona, Tucson.

Wehausen, J. D. 1980. Sierra Nevada bighorn sheep: History and population ecology. University of Michigan.

Wehausen, J. D., V. C. Bleich, and R. R. Ramey II. 2005. Correct nomenclature for Sierra Nevada bighorn sheep. California Department of Fish and Game 91:216-218.

Wehausen, J. D., and R. R. Ramey II. 2000. Cranial morphometric and evolutionary relationship in the northern range of *Ovis canadensis*. Journal of Mammalogy 81:145-161.

Wehausen, J., S. Kelley, and R. Ramey II. 2011. Domestic sheep , bighorn sheep , and respiratory disease : a review of the experimental evidence. California Fish and Game 97:7-24.

White, G. C., A. F. Reeve, F. G. Lindzey, and K. P. Burnham. 1996. Estimation of mule deer winter mortality from age ratios. The Journal of Wildlife Management 60:37-44.