2022-23 Annual Report
Sierra Nevada Bighorn Sheep Recovery Program

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***Figure 1**. Remote camera image of Sierra bighorn walking through heavy snows near Shepherd Creek, March 21, 2023.*

Executive Summary

Record snowfall across the western United States during the winter of 2022-23 dramatically reduced ungulate populations in multiple states. Wyoming and Utah experienced extensive die-offs of mule deer, pronghorn, and elk. In California's Sierra Nevada, bighorn sheep suffered severe losses, with approximately 55% of all adult females dying during the winter and a year-over-year decline of about 35% in the ewe population, even after accounting for lamb recruitment into the adult population in late spring and early summer.

Snow water equivalent (SWE) in one southern Sierra snow course exceeded 400% of the April 1 average, while most snow courses ranged between 200% and 300% of normal. Over the past 20 years, only four winters have exceeded 150% of average SWE. Although heavy winters can significantly affect bighorn populations, mortality does not always increase during such years. During the heavy snow winter of 2011, bighorn populations increased overall. Survival is influenced by specific winter characteristics, including the timing of snow onset, the size of individual storms, the duration of breaks between storms, and how long snowpack persists into spring. Winters that generate extreme avalanche conditions are the most detrimental to bighorn survival. The frequency of extreme winters (>150%) is higher in the last ten years than it has been in the last 50, and milder winter conditions may have allowed bighorn populations to recover following big winters historically.

In 2022-23, most bighorn females (N = 43 collared individuals) died directly from snow-related causes, primarily avalanches or starvation. In addition, the extensive and persistent snowpack reduced the availability of snow-free winter ranges, increasing spatial overlap among bighorn, mule deer, and mountain lions and likely elevating predation risk (N = 9 collared females). Mortality was nearly range-wide, with one exception: the southernmost herd at Olancha, where the population increased during this period. Although large avalanches were observed on the flanks of Olancha Peak, this herd unit received significantly less snow than any of the others because it is the farthest south and the lowest elevation.

Despite the severity of the winter, Sierra bighorn demonstrated notable resilience, with herds persisting under extreme environmental conditions.

During this challenging year, the Recovery Program invested substantial effort in locating surviving bighorn, investigating mortalities, and monitoring mountain lions. A total of 72 collared bighorn mortalities were investigated across all 14 herd units. In some herds, all or nearly all collared animals were lost, making ground surveys less efficient and more labor-intensive, particularly when attempting to locate small groups across large herd units. Fifty-six bighorn were captured in October 2022 and March 2023 to support monitoring efforts.

Throughout the year, 32 mountain lions were collared or recollared, increasing our ability to detect predation events. The combination of intensified lion monitoring and increased spatial overlap between bighorn and lions resulted in the highest detection of bighorn killed by mountain lions to date (N = 41, including males and females, collared and uncollared). A comprehensive understanding of the geographic extent and magnitude of lion predation is essential for effective management. Six lions known to prey on bighorn were successfully translocated. Post-translocation survival of lions was equal to or greater than that of non-translocated individuals, demonstrating our capacity to improve translocation outcomes. Reducing predation on Sierra bighorn through targeted lion translocation is an effective strategy that decreases bighorn mortality while minimizing the need for lethal lion management.

The losses of 2022-23 represent a significant setback to Sierra bighorn recovery, effectively returning the population to approximately its 2007 size and reversing some recent distribution gains achieved through reintroductions. However, intensified lion management during 2008-2010 along with the drought conditions of 2011-2015, coincided with the most rapid period of bighorn population growth through 2015. This history suggests that active lion management could again facilitate a rapid population rebound, under suitable climatic conditions. Predation and snow-related mortality remain the leading causes of death for Sierra bighorn. Between 2005 and 2022, 86 collared females died due to lion predation, while 115 died from snow-related causes, primarily avalanches and starvation. Snow-related losses occur predominantly during extreme winters with snowfall exceeding 150% of average and are more likely in herds that rely on high-elevation winter ranges.

Translocation of bighorn remains essential for recovery but presents challenges, particularly given that three of the past six winters have been extreme. Herds reintroduced since 2014 were translocated to west-side ranges of the Sierra crest, where snowpack is deeper and reduced wind limits snow scouring on alpine winter ranges. As a result, low-elevation migration routes must be discovered and established, leading to longer migration distances. These west-side herds are more difficult to reestablish, require larger numbers of translocation animals, and will likely need repeated augmentations.

We employ adaptive management—learning by doing—where scientific monitoring is integrated with management actions to generate knowledge that improves future translocation outcomes. As climate change continues to alter Sierra Nevada landscapes, effective management of Sierra bighorn must remain flexible and responsive to these shifting conditions.

Introduction: Record Snowfall

Snow, snow, and more snow. The 2022-23 winter was both wet and cold resulting in a deep and extensive snowpack (NASA Earth Observatory 2024). The snow water equivalent ranged from 439% of average in the southern Sierra Nevada to 271% of average in the central Sierra Nevada. While interannual snowfall is generally high within the Sierra Nevada varying from 50-200% of average (Halofsky et al. 2021), this was an exceptional winter (Department of Water Resources 2023). All measuring stations within Sierra bighorn habitat showed a clear spike in snow depth and snow water equivalent (Figure 2), with 11 moderate atmospheric rivers documented hitting the Sierra Nevada. Within the Sierra Nevada bighorn range, this snowpack exceeded all previous estimates based on similar methods, except for 1952. Snow survey methods have been updated since 1952, so this may be an imperfect comparison (NASA Earth Observatory 2024). Parts of the central and southern Sierra Nevada recorded >60” of water, which drastically alleviated previous drought conditions and produced a massive snowpack (CW3E 2023).

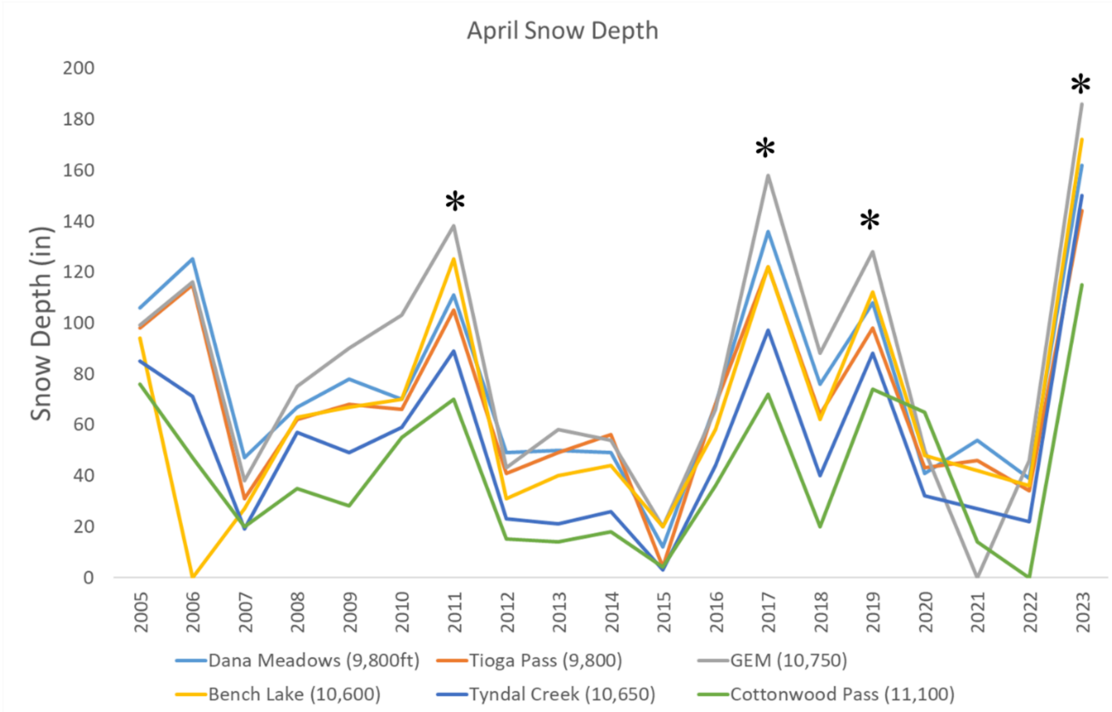

Figure 2*. Snow depth from weather stations near Sierra bighorn populations (http://cdec.water.ca.gov), 2005-2023. * Represents >150% of average values.*

Most western states reported snow water equivalent far above average with a corresponding high ungulate mortality (Hill 2024). Wyoming reported mule deer mortality ~50% in some herds, and Utah projected deer mortality from 30-80% and implemented emergency deer feeding programs (Hill 2024). The incredible snowpack likely contributed to the arrival of a wolverine in the Sierra Nevada that was repeatedly photographed by skiers from Big Pine to Tuolumne in May 2023 (CDFW internal communication). The last time a wolverine was seen in the Sierra Nevada was in 2009-2014 when a lone wolverine established territory near Lake Tahoe, and prior to that none had been documented for 86 years (Moriarty et al. 2009). Sierra bighorn were also documented using novel habitat this winter, likely in response to snowpack that was much deeper and more extensive, notably covering more and persisting at lower east side elevations than typical (Figures 1 and 3). Unfortunately, Sierra bighorn mortality rates were also higher and more extensive (Figure 4, Table 1), similar to ungulate mortality rates documented throughout the west.

Although temperature is predicted to increase, there is considerable uncertainty as to how precipitation will change in the Sierra Nevada (Polade et al. 2017, Dettinger et al. 2018, Halofsky et al. 2021). Marshall et al. (2024) note that snow deluges, like 2022-23, are a 1 in 54 year event, and modeling indicates events of that magnitude will become less likely in the future, although this prediction does not hold for the highest elevations. Other studies have found “the increase in heavy and extreme precipitation is particularly robust over California” (Polade et al. 2017), and that “the amount of precipitation from the largest storms, including atmospheric rivers, is expected to increase by 5 to 30 percent compared to historical period…” (Dettinger et al. 2018), although these large storms may not necessarily increase the overall annual snowpack, and some models show increased precipitation more likely in the northern Sierra Nevada (Halofsky et al. 2021).

***Figure 3**. The snow-covered Mono Lake Valley taken from the air on March 31, 2023, displaying the extensive snowpack that continued into spring in the eastern Sierra. Photo credit Trevor Johnson.*

This report summarizes the activities of the Sierra Nevada Bighorn Sheep Recovery Program (hereafter Recovery Program) from May 1, 2022 - April 30, 2023. Survey and mortality data through the summer of 2023 is included in order to describe the impact of the winter of 2022-23. A brief background on Sierra bighorn and the Recovery Program is provided in Appendix B, along with data analysis methods. Data and summaries in this report are preliminary and subject to change contingent upon further interpretation, analyses and review.

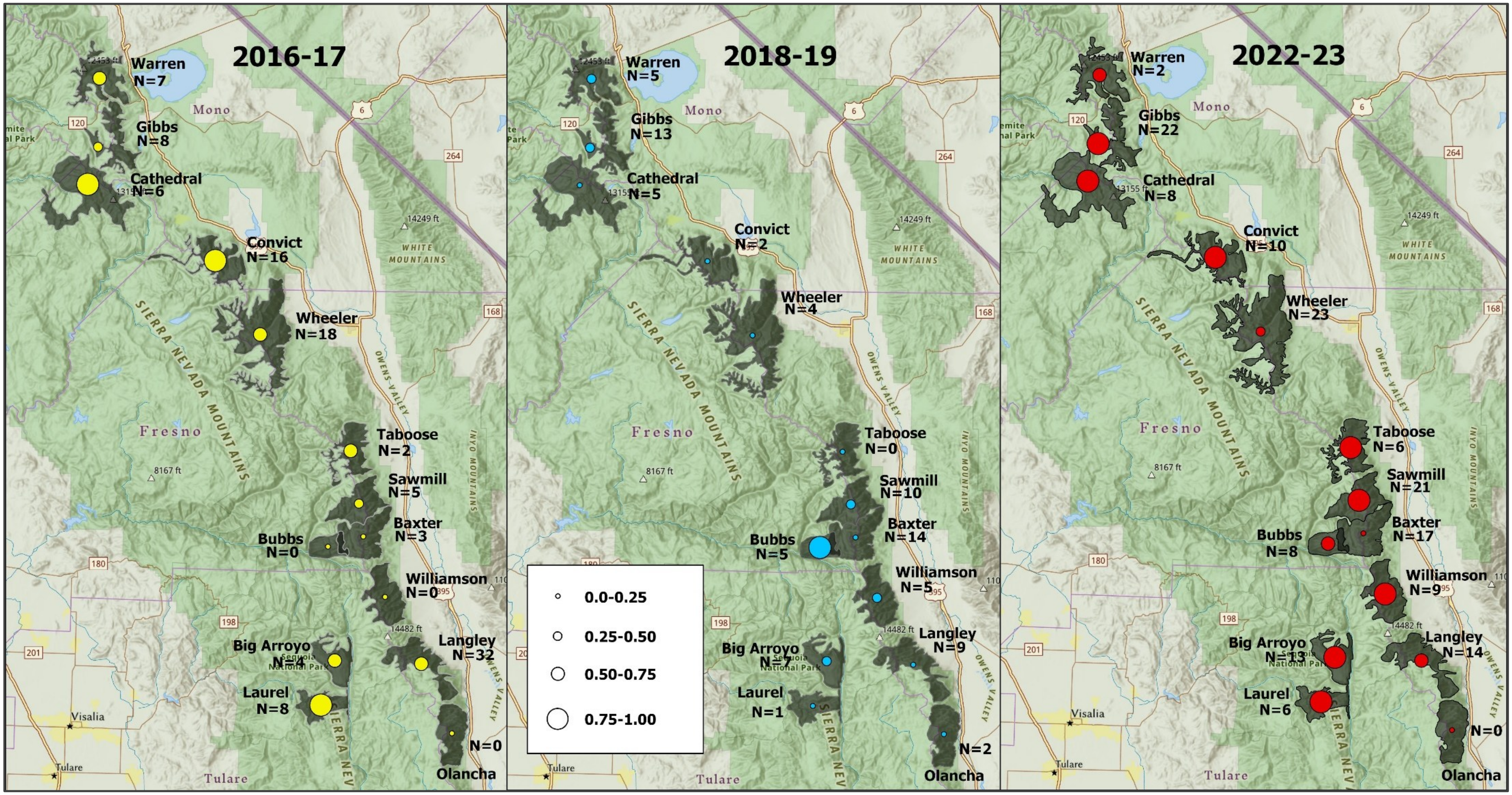

Figure 4. Sierra bighorn herds with numeric losses based on consecutive minimum counts (N=) and proportional losses based on collared females (circle area) for the three most recent snowy winters. This map should not be directly compared to Figure 20 as these symbols represent only collared females with symbol size scaled proportionally.

Population Monitoring and Recovery Goals

Prior to winter, the Sierra bighorn population remained steady following a rebounding trend subsequent to the declines that occurred during the severe winters of 2016-17 and 2018-19 (Table 1a, Appendix A). From summer counts, we estimated there were 585 Sierra bighorn including 272 females, 132 lambs, and a projected 181 males (based on a 2:3 male:female ratio; Appendix B). This is very similar to our count the previous year, which included 277 females and 128 lambs.

However, the 2022-23 winter was the snowiest winter on record causing the highest range-wide mortality recorded for Sierra bighorn. We estimate there were 150 female mortalities, 55% of our minimum count (Table 1 and Table 1b, Appendix A). Based on summer counts in 2023, which include losses from the 2022-23 winter in combination with recruitment from the lamb class, we estimate 346 Sierra bighorn remain, including 173 females, 58 lambs, and 115 males (ratio estimate for males; Table 1b, Appendix A). Counts during 2022 and 2023 indicate that there was a 35% decline in the population of females after new recruitment is incorporated.

Table 1. *Estimates of **female** Sierra bighorn mortality in the winter November 1, 2022 - April 30, 2023. Collar ratio estimates of mortality calculated as [% collared mortality]*[MC pre-winter] summed across herds. Minimum Count (MC) estimates of mortality calculated as: [MC post-winter]-([MC pre-winter])+0.5 * [lambs MC pre-winter]). Herds highlighted in red suffered larger losses, while those highlighted in orange suffered moderate losses.*

Herd	# Collared November 2022	MC pre winter	Lambs MC pre winter	Season Year	Est % collared	# Collared Mortality	% Collared Mortality	Mortality from ratios	Projected Total	MC post winter	Season Year	Mortality from MC	Mortality rate est from MC
Olancha	9	20	16	Spring 2023	0.45	0	0.00	0	28	35	Summer 2023	-7	-0.25
Laurel	4	4	3	Summer 2022	1.00	4	1.00	4	6	0	Summer 2023	6	1.00
Big Arroyo	6	9	7	Summer 2022	0.67	6	1.00	9	13	0	Summer 2023	13	1.00
Langley	5	23	8	Summer 2022	0.22	3	0.60	14	27	13	Summer 2023	14	0.52
Williamson	9	26	10	Summer 2022	0.35	8	0.89	23	15	6	Summer 2023	9	0.60
Baxter	15	50	24	Summer 2022	0.30	2	0.13	7	62	47	Summer 2023	15	0.24
Sawmill	11	37	15	Summer 2022	0.30	9	0.82	30	45	24	Summer 2023	21	0.46
Bubbs	3	12	7	Summer 2022	0.25	2	0.67	8	5	NA	Summer 2023	8	NA
Taboose	3	6	3	2021 Count	0.50	3	1.00	6	3	NA	Summer 2023	6	NA
Wheeler	15	40	19	Summer 2022	0.38	5	0.33	13	50	27	Summer 2023	23	0.45
Convict	4	7	5	Summer 2022	0.57	4	1.00	7	10	1	Summer 2023	9	0.89
Cathedral	2	5	5	Summer 2022	0.40	2	1.00	5	8	0	Summer 2023	8	1.00
Gibbs	8	20	9	Summer 2022	0.40	7	0.88	18	25	3	Summer 2023	22	0.88
Warren	9	13	2	Summer 2022	0.69	5	0.56	7	14	8	Summer 2023	6	0.43
Totals	103	272	133		0.38	60	0.58	**151**	308	164		**150**	0.49

Within the animal year, some herds are counted in summer before winter mortality, and others are counted during the winter after some mortality has occurred. Therefore, we cannot directly compare the population estimate from one animal year to the next to determine the impact from winter. Instead, we use two different methods: one based on the proportion of collared females per herd, and the other based on minimum counts (MC) before and after winter (combining data from multiple years; Table 1). Based on the collar ratio of females in each herd and the known collared female mortality, we calculated 151 females died (Table 1, Mortality from Ratios). Using minimum counts before and after winter, we calculated 150 females died (Table 1, Mortality from MC). Although there is variation between these estimates at the herd level, the range-wide similarity supports an estimate of 150 female mortalities, or 55% of known females (Table 1).

We are still in the process of determining the distributional losses from the winter of 2022-23, but data at this time indicate the Kern Recovery Unit (both Big Arroyo and Laurel herds) suffered major losses, and no females have been observed within these herd units for two years (Table 1), although in 2025 we discovered 6-7 unique individual males (through fecal genotyping) using the Big Arroyo area. Additionally, two females have been observed on the Boreal Plateau between Laurel and Langley on the east side of the Kern River. If these are Laurel animals, they would be descendants of the first Laurel translocation in 2015. All animals translocated into Laurel in 2022 are confirmed dead because they were collared. No females have been observed at Cathedral, although an individual of unidentified sex was caught on camera in February of 2024.

Without collared females in many herds, it is possible that uncollared females remain but have not yet been detected. For example, there were no females detected in Convict or Taboose for the first year after the 2022-23 winter, but some were detected in 2024. It is possible animals emigrated into these herd units, but it is more probable that these uncollared animals went undetected, as finding a small number of uncollared sheep in a large area is challenging.

With the exception of Olancha, all herds declined in the 2022 animal year, and only Baxter has >40 females, a guideline that we use for a herd to be considered a source for translocation. Past source herds Wheeler and Sawmill have <30 females, and Langley has only 13 females. In sharp contrast, Olancha increased in 2022 to 35 females and became the second largest herd (Figure 5). Laurel, Big Arroyo, and Cathedral were reintroduced in 2014 and 2015; Taboose was a natural expansion from Sawmill, and Convict was a natural expansion from Wheeler that was later augmented. All of these small herds had <10 females in 2022. As of 2022, we are below recovery goals for every recovery unit (Figure 6).

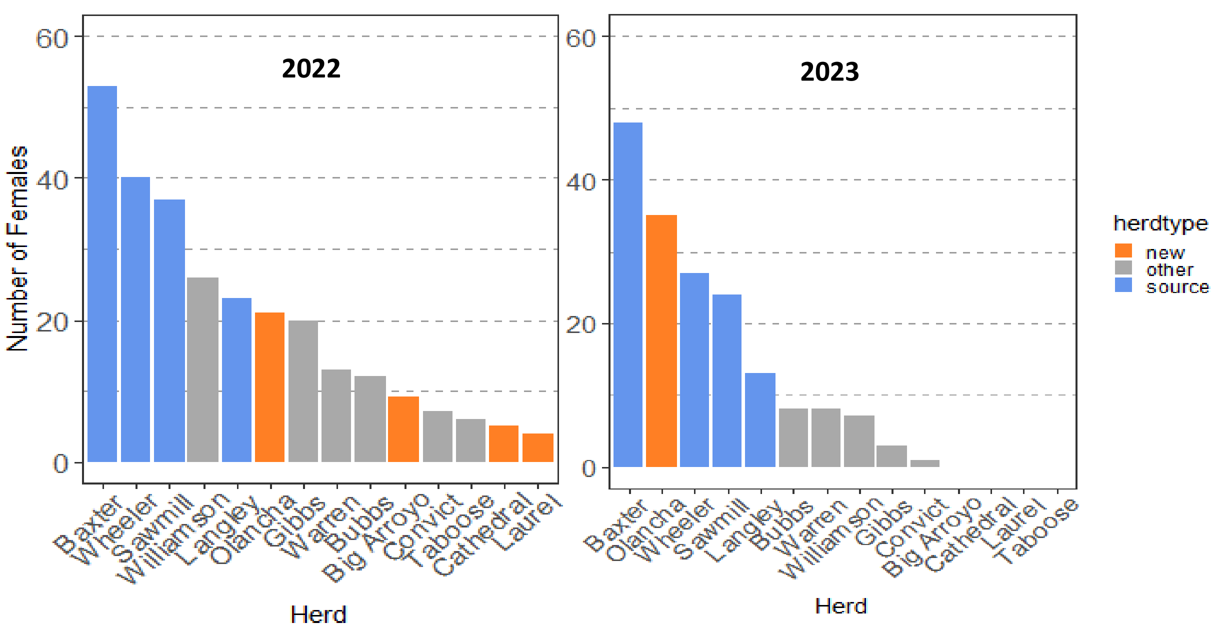

Figure 5. Reconstructed minimum counts of female Sierra bighorn in 2022 (left) and 2023 (right) representing counts before and after the big winter of 2022-23. Herds are arranged from largest to smallest minimum count in both graphs, and herd order changes between the years.

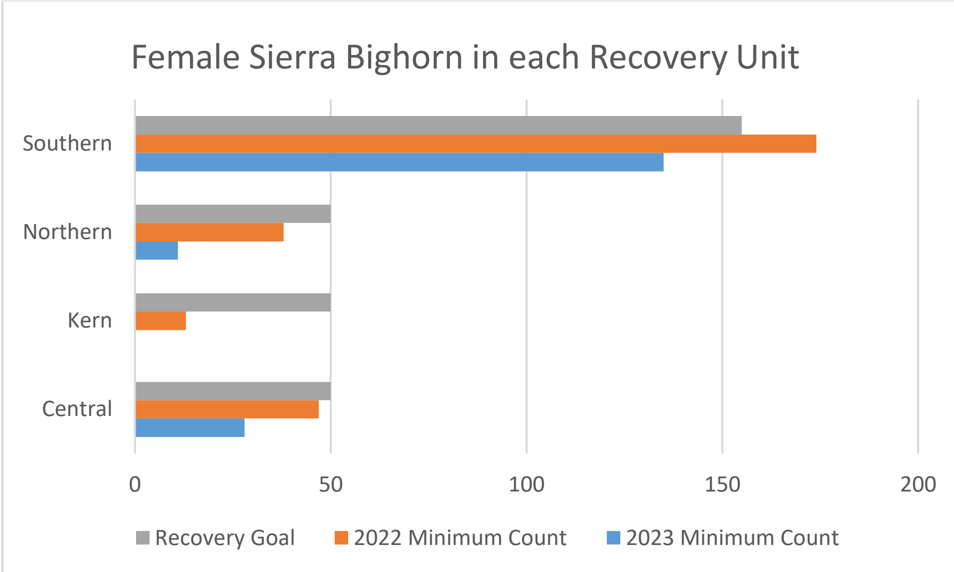

__Figure 6__. Abundance and distribution of female Sierra bighorn across Recovery Units compared to downlisting goals for 2022 and 2023.

2022 Demographic Rates

Unfortunately, the substantial snowfall brought record losses with the biggest numeric and proportional losses the Recovery Program has ever documented; both female (0.46) and lamb (0.27) survival were the lowest observed (Figures 7-9). The Sierra bighorn population experienced a growth rate of 0.67, dropping from 272 to 173 females. We estimate 150 females died, or 55% (Table 1), and the lamb:ewe ratio following the winter was low at 0.42 in the 2023 animal year, but it was within the range previously observed (0.21-0.66).

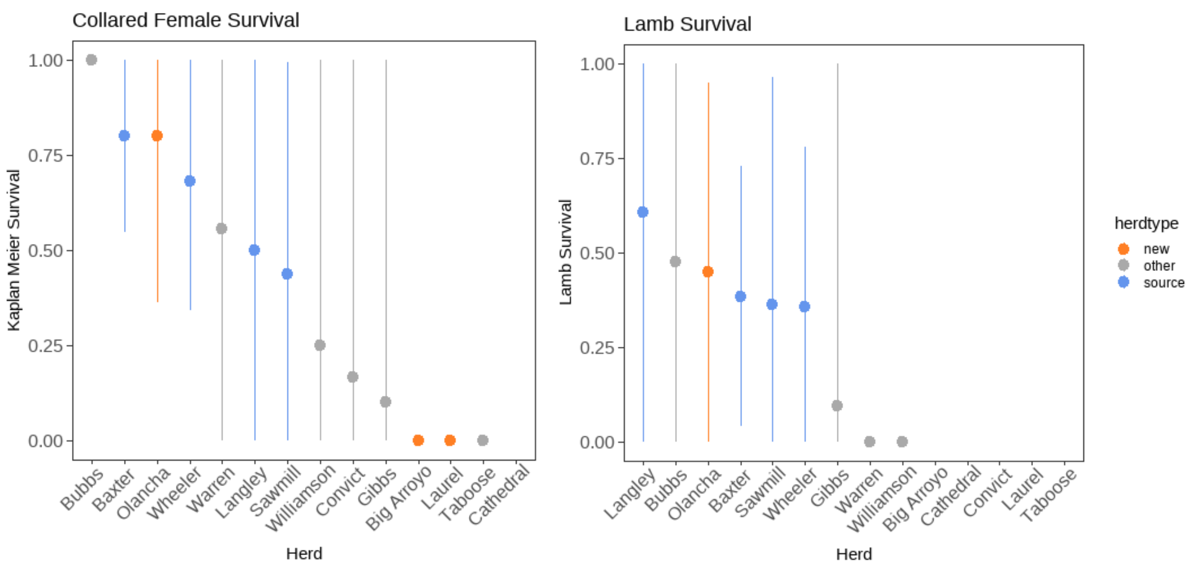

__Figure 7__. Collared Sierra bighorn female and lamb survival with 95% confidence intervals, for herds with at least 3 collared females in 2022. Female survival estimated using Kaplan Meier, and lamb survival estimated using age ratios. Herds are arranged from largest to smallest value in both graphs.

In general, larger herds tended to fare better, while smaller herds were vulnerable to extirpation (Figure 5). Collared female survival ranged from 100% to 0% between herds and lamb survival from 60% to 0%. Bubbs had the highest survival (but this was determined from only 3 females), followed by Baxter and Olancha (Figure 7). The lamb:ewe ratio dropped between 2022 and 2023, partly driven by the loss of four small herds that had high lamb:ewe ratios in 2022 (Figure 10). The yearling:ewe ratio also declined between 2022 and 2023, but the pattern among the herds was less clear (Figure 10).

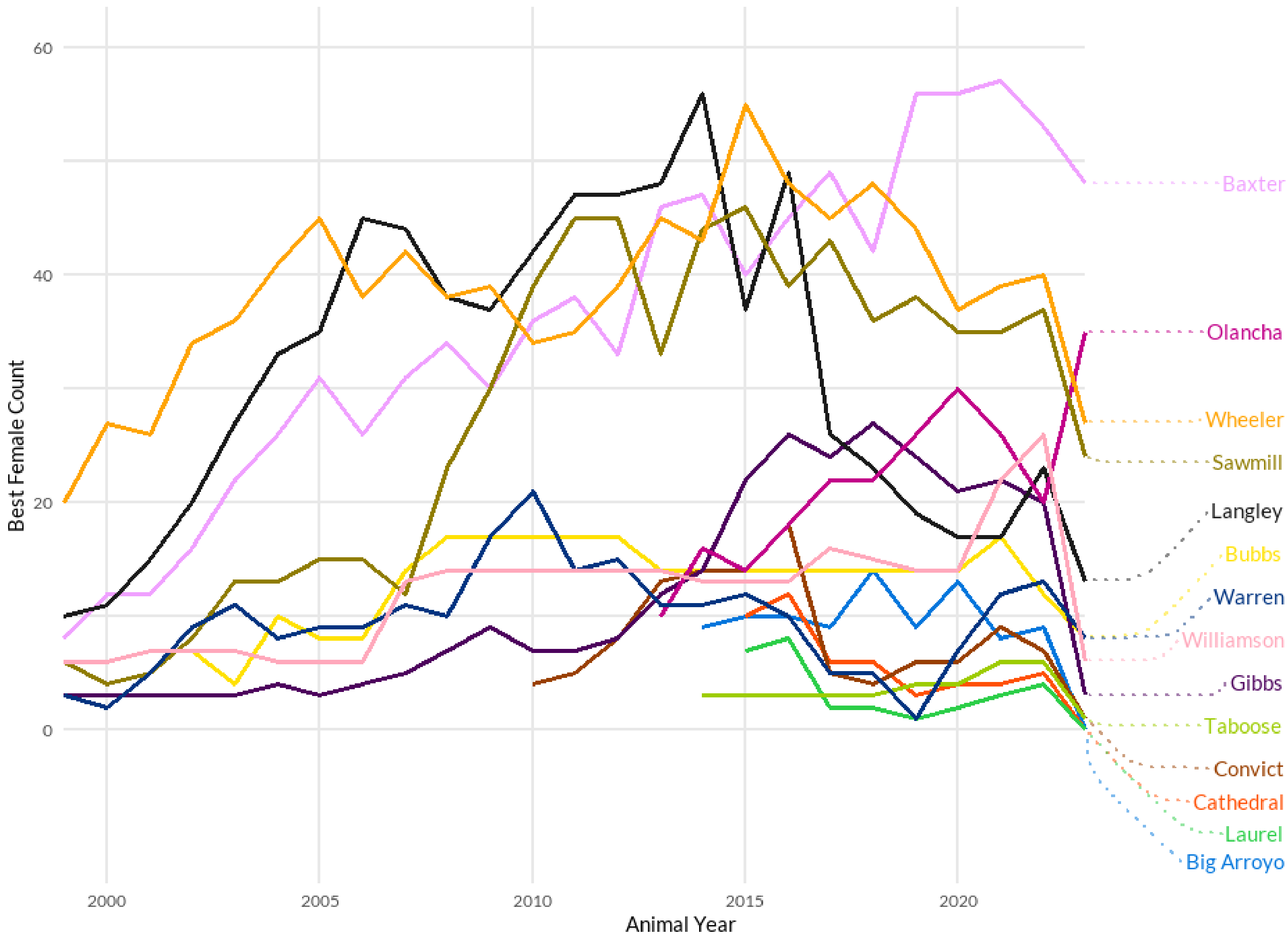

Figure 8. *Minimum counts for female Sierra bighorn 1999-2022. Herd counts do not show the complete impacts of a given winter because some herds are counted in summer (pre-winter impact), and some are counted in spring (post-winter impact). These data include the best count for each herd and animal year.*

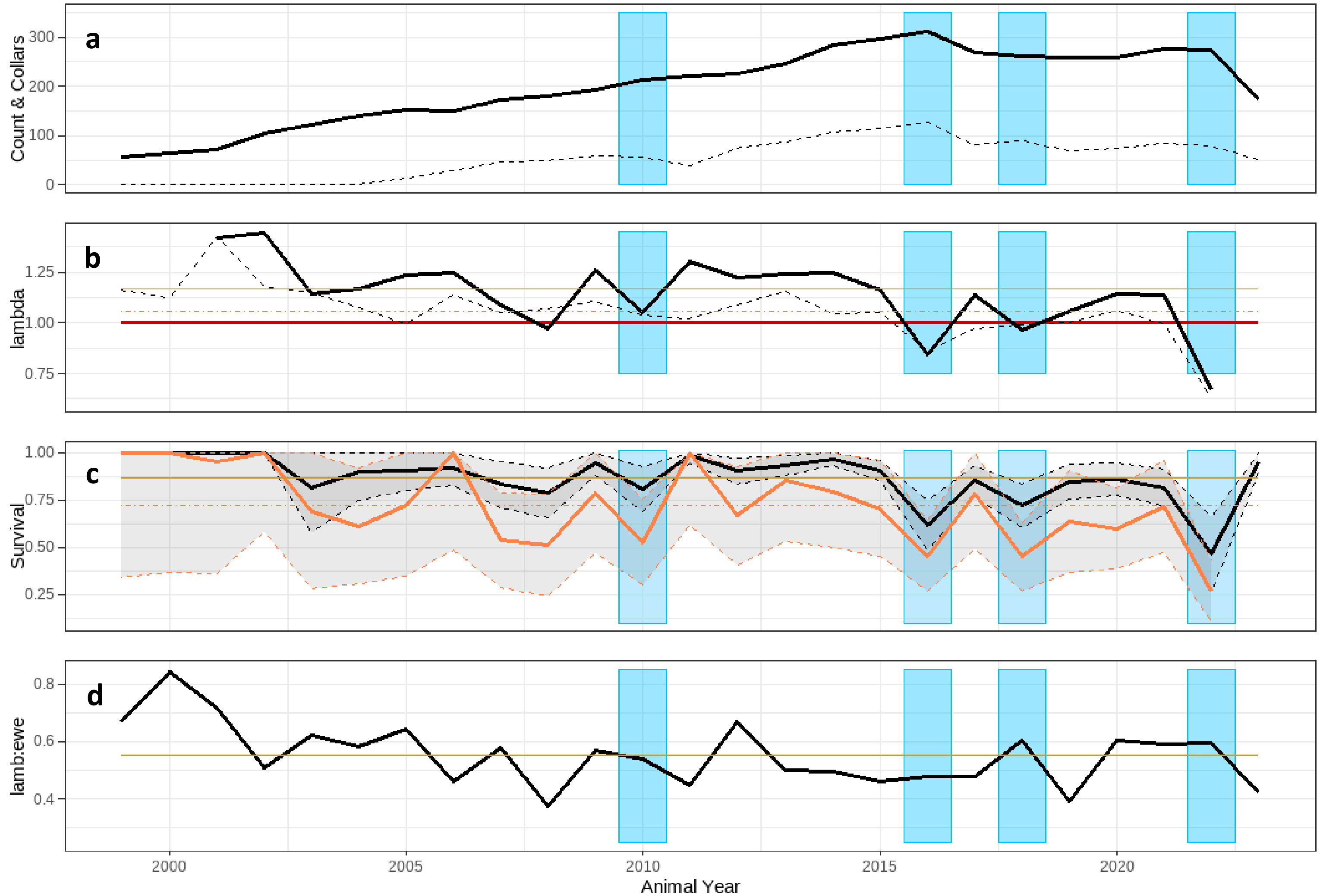

Figure 9*. Long-term and range-wide female Sierra bighorn population estimates and vital rates, 1999-2022; winters with >150% average snow are highlighted in blue.*

- *a) Total female population estimate (solid black line) and collared females (dashed black line).*
- *b) Lambda calculated from eigenvalues derived from vital rates (solid black line) and lambda from minimum counts (dashed black line). Averages shown in yellow and dashed yellow, respectively. 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. Averages in yellow and dotted yellow respectively.*
- *d) Lamb:ewe ratios as a measure of fecundity; long-term average in yellow.*

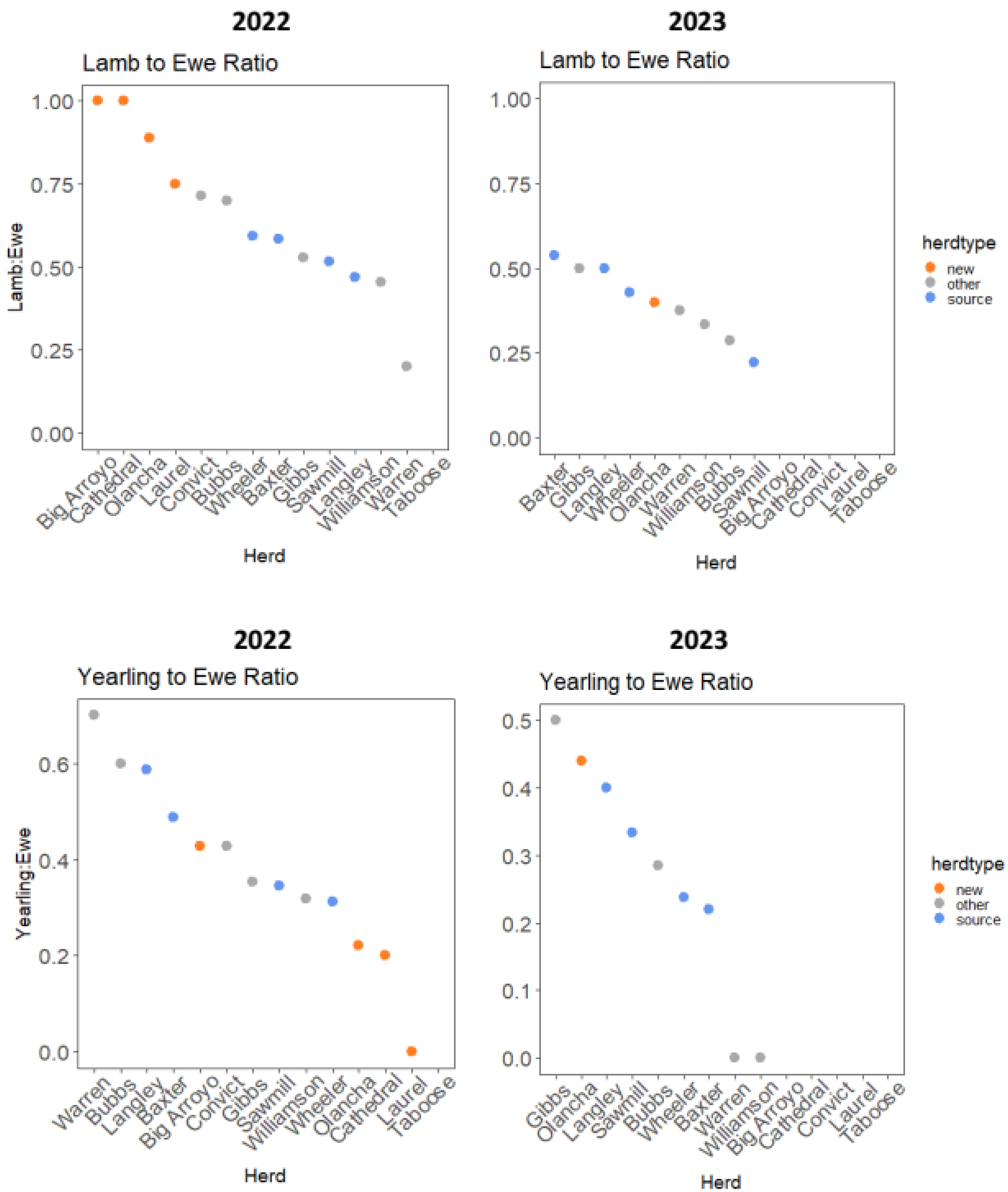

Figure 10. *Observed ratios of Sierra bighorn lambs and yearlings (males and females combined) to adult females by herd in 2022 (left) and 2023 (right). Herds are arranged from largest to smallest value in both graphs, and herd order changes between the years.*

Range-wide Cause-Specific Mortality

The majority (~75%) of collared female mortality during this winter was caused by snow through avalanche or starvation (Figure 11). In this report, "snow" mortality includes animals that died in areas with deep snow from either avalanche or starvation. It is often difficult to distinguish avalanche from starvation mortality because these deaths cannot be investigated until the area is safely accessible, and by that time the carcass is often scavenged or only collars remain. However, with GPS collars and survival flights we can deduce the cause as snow-related when we know the location, time, and snowpack conditions. This year we identified 16 avalanche deaths and 6 starvation deaths, but for 21 additional “snow” deaths, we were unable to distinguish between avalanche or starvation.

Collared females represent our strongest dataset because our captures are designed to target 30% of females in each herd, so these collars represent a high proportion and wide distribution throughout the Sierra. This year 43 collared females died from snow and 9 from lion predation (Figure 11). Additionally, one animal died from physical injury, 2 while giving birth, and 5 from unknown cause. Throughout the year, most animals died in the winter, with some in the fall and spring; mortality was geographically widespread occurring in all 14 herds. Using GPS collar activity data, we were able to pinpoint the time of death for a collar that went on and off mortality this winter (Figure 12). In this case the mortality date for S610F was determined to be March 22, 2023 (pers. comm. Rankins 2025).

We identified a previously undocumented cause of death this year; two females appeared to have died while giving birth. These occurred in May 2022, prior to the severe winter, in Gibbs and Convict, and one female had notably poor body condition. In addition, Convict ewe S526F was found dead on April 19, 2023 with her lamb beside her (Figure 13). We believe the lamb and ewe both died of starvation, indicated by the lack of fat stores and forage available during heavy snowpack. According to her collar, S526F died on March 29, which is very early for a lamb to be born, but the lamb had no umbilicus attached and there were no signs of birthing complications found.

This year a total of 138 mortalities were detected, including 42 lion kills (23 females, 12 males, and 7 unknown sex). Lion clusters from 10 different mountain lions were used to identify 35 of these mortalities, demonstrating the importance of having lions collared that use Sierra bighorn habitat. While collared female mortality is the best metric to determine the proportional importance of different causes of mortality, we also report the total number of animals detected to be killed by mountain lions. This includes all collared (13) and uncollared (29) bighorn mortalities identified. Uncollared bighorn mortalities may be detected through collared lion clusters or opportunistically encountered, often near past lion kill sites, so they tend to overrepresent lion predation. Wheeler experienced the loss of 18 bighorn due to lion predation, making it the second worst loss of predation in a single year following Langley in 2016.

The overall nature of mortality by weather and predation can be characterized as acute for snow mortality and chronic for lion predation. Extreme weather events happen sporadically, while some level of predation is constant, although predation episodes can create high mortality locally. Mortality that is directly related to snow is caused by avalanche and starvation, and these deaths tend to occur when bighorn sheep are using high elevation habitat during winters with heavy snow (although two avalanche mortalities were detected this year at lower elevation, <7,000 ft. in Pine Creek). Predation occurs during most winters but does sometimes take the form of extreme predation episodes, often correlated with lion densities (Gammons et al. 2021). Lion predation has been documented year-round at high elevations (>11,000ft) when these areas were accessible. Severe winters may trigger episodes of high predation by concentrating bighorn sheep and lions on limited snow-free low elevation winter ranges.

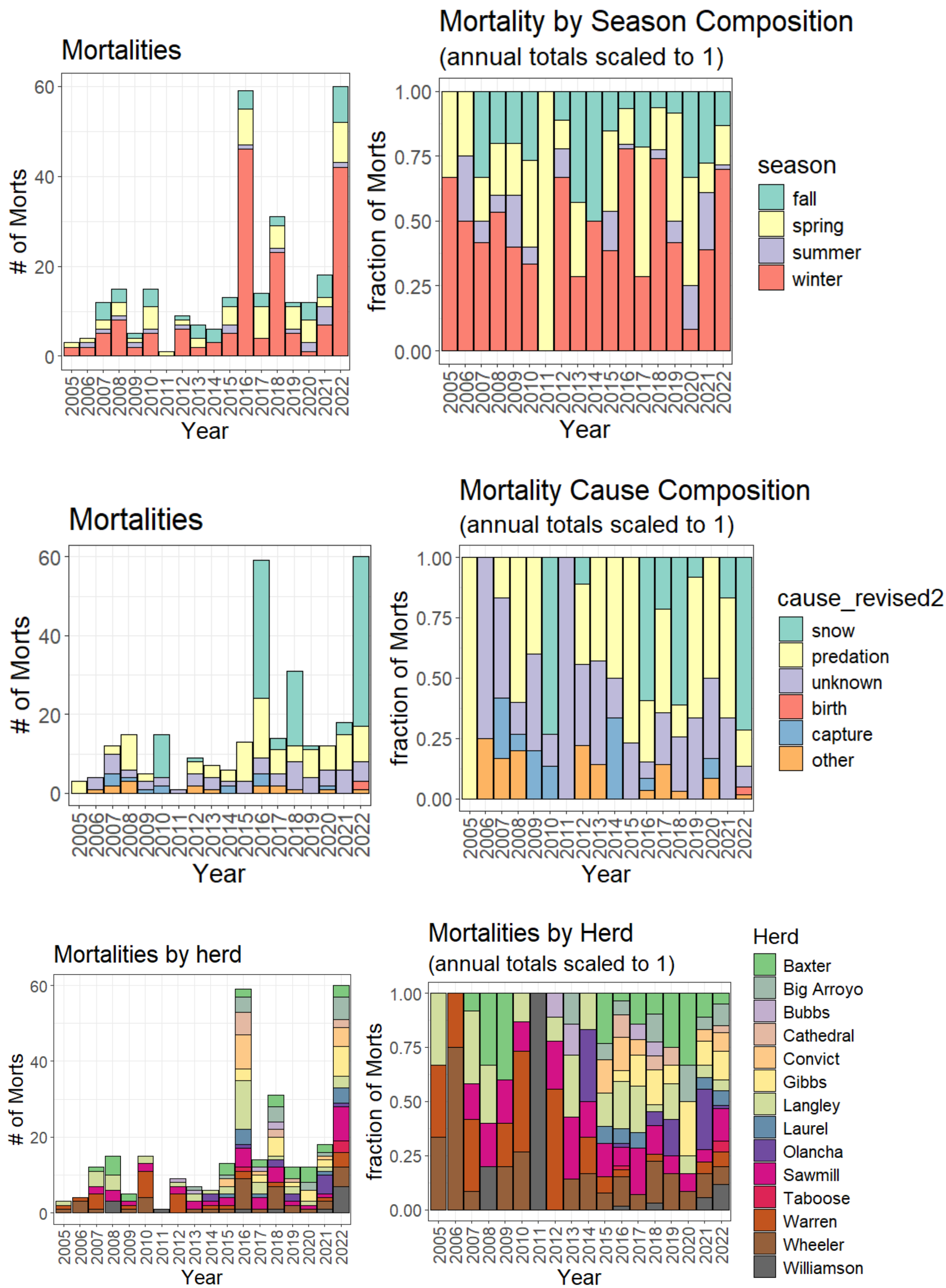

Figure 11. *Collared female Sierra bighorn mortality 2005-2022 by cause of death and herd. The category "snow" includes death by avalanche and starvation during winter and spring. The number of mortalities (left) is influenced by the number of collared females at a given time, which trends with the overall population size. 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).*

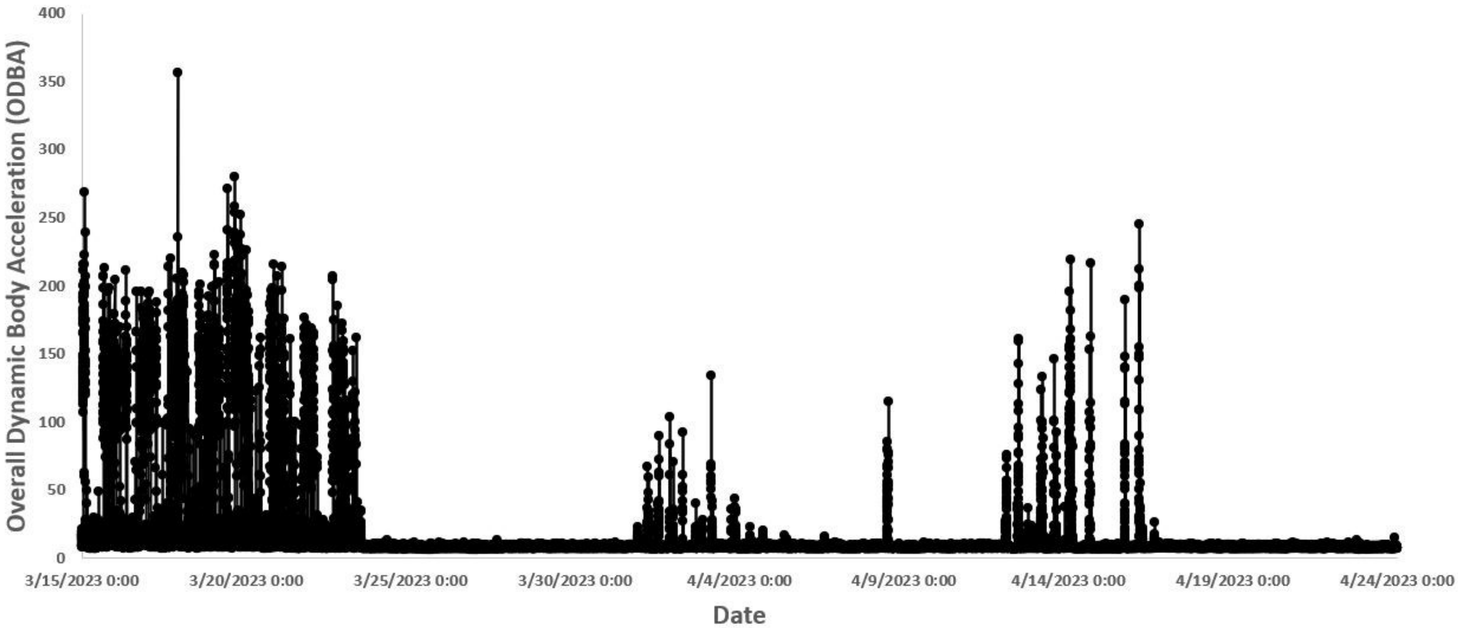

Figure 12. *Activity data from an accelerometer on the collar of Sierra bighorn S610F was used to pinpoint her precise date of death as March 22, 2023. She was killed by mountain lion predation, and movements after her death are likely from scavenging.*

Figure 13. *Starvation associated mortality of Sierra bighorn S526F detected after the big winter of 2022-23 in Convict. S526F died March 29, 2023 and was found with her lamb beside her. We concluded S526F died of starvation, due to her lack of fat stores and the lack of available forage during heavy snowpack. Photo credit Elizabeth Siemion April 19, 2023.*

Snowy Winter Impacts – reviewing 2016-17, 2018-19, and 2022-23

Heavy snow years increase mortality of Sierra bighorn. Snow directly produces avalanches in steep terrain that kills bighorn, and indirectly snow buries forage, delays forage growth, or increases the cost of travel leading to starvation. Furthermore, snow indirectly increases predation by concentrating bighorn sheep on low elevation winter ranges, increasing their vulnerability. Between 2005-2022 we documented 90 collared female mortalities from predation and 115 from snow (Table 2).

***Table 2**. Mortality of collared Sierra bighorn females, May 1, 2005 - April 30, 2022. All snow starvation mortalities occurred in the months between January and April. Capture mortalities and censored animals are not included.*

Cause of Death	Definition		Number Observed
Snow Total	Died of snow-related causes—broken up below		**115**
Snow Unclassified	Died of snow-related causes, including avalanche, starvation, and hypothermia, but unable to differentiate the cause	53	
Snow Avalanche	Died in a snow avalanche	40	
Snow Starvation	Indicated by lack of fat reserves and/or poor bone marrow condition	22	
Lion Predation	Killed by a mountain lion		**86**
Unknown	Cause of death could not be determined		**60**
Injury	Died as a result of physical injury, including falling in steep terrain and rock falls and slides		**16**
Other Predator	Killed by a bobcat or coyote		**4**
Birth	Died while giving birth		**2**
Total			**283**

Although big winters are less frequent than average or dry years, the high range-wide mortality during these years is having a significant impact on the overall population trajectory (Figure 14). The Recovery Program documented large losses including ~150 females or 55% in 2022-23, ~100 females or 33% in 2016-17 and ~75 females or 25% in 2018-19. The majority of the mortality during these winters was snow-related (avalanche and starvation combined), although it also includes predation mortality and notably an extreme predation event at Langley in 2016. Additionally, it is important to consider that lions have been managed through translocation and removal (excluding 2012-2015 when there was a hiatus on lion management) and therefore these documented predation rates are lower than they would be if predators were unmanaged. Unlike many ungulates that tend to have consistent and high survival rates, Sierra bighorn survival swings dramatically from nearly 100% to <50% with snowpack clearly having an impact (Figure 9 panel c). How the snowpack may be affecting recruitment is less clear (Figure 9 panel d), although the lamb:ewe ratio is lower in the year following a severe winter (Figures 9 and 10).

This year, smaller herds were more vulnerable to larger proportional losses and even localized extirpation, while larger herds tended to persist, but some suffered large numeric losses (Table 1, Figures 5 and 8). Some herds showed consistent reductions in survival in response to snowy winters that were either severe (Big Arroyo, Laurel, Cathedral, and Convict) or more moderate (Sawmill and Wheeler). In contrast, Baxter has consistently been robust to snowy winters, and Olancha has thrived during these winters. Baxter is the largest original herd, and Olancha was re-established in 2013. Olancha was the only herd that grew during the 2022 year. Most animals in both of these herds tend to make use of the extensive lower elevation winter habitat available to them, which likely allows them to have higher survival during big winters. Historically, Baxter has periodically suffered high predation episodes, but these do not always coincide with heavy winters (e.g., 2008-09) and did not occur this year. Olancha experienced a mild level of predation during the summer and fall in 2022 but did not experience any winter mortality. It could be that deer and bighorn overlap is not as extensive at Olancha in winter; this would be worth looking into as it could explain the lower levels of lion predation there. However, it is likely only a matter of time, now that Olancha is of significant size, that a lion or lions will cue in on it. Effective predator monitoring and quick management has been crucial for Baxter, and the same will be true at Olancha to limit predation impacts.

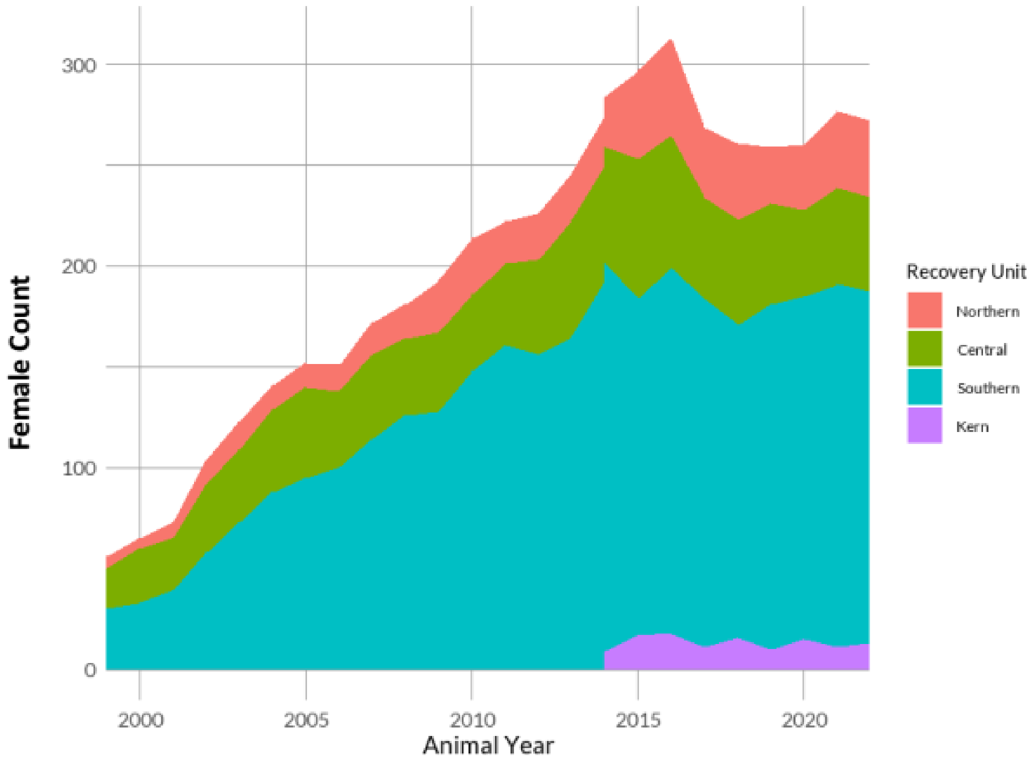

***Figure 14**. Range-wide female Sierra bighorn population abundance 1999-2022. Range-wide numbers are calculated using annual herd values based on reconstructed minimum counts and Mark-Resight estimates, as well as the most recent survey results for herds not surveyed annually. Herd counts are combined 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.*

Some herds have had an inconsistent pattern to snowy winters. For example, Gibbs showed a mild to moderate response to the 2016-17 and 2018-19 winters, but was subsequently nearly extirpated by 2022-23, largely driven by snow-related mortality. Langley, in contrast, had a moderate response to the recent winter of 2022-23, but suffered large losses in 2016-17, driven primarily by lion predation. Warren was generally sensitive to winter conditions with some variation; the female population suffered the greatest loss during the 2018-19 winter and the least during the 2022-23 winter. For some of the smaller herds, we lack substantial longitudinal data to be able to determine much about their response to snow (Taboose, Williamson, and Bubbs).

Capture, Collaring, and Translocation

During October 25-31, 2022, we captured 45 animals (31 females, 14 males) across nine herds: 4 at Big Arroyo, 5 at Bubbs, 7 at Gibbs, 6 at Langley, 6 at Warren, 4 at Williamson, 8 at Olancha, and 5 at Wheeler. An additional 11 animals (9 females, 2 males) were captured on March 20, 2023 from lower elevations at Sawmill to assist with detecting lion kill mortalities. There were no capture mortalities, although one animal, S648F, was killed by a lion 4 days after spring capture. 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 (47/55) were equipped with both a VHF and GPS collar, while 9 had VHF collars only.

Sierra Bighorn Movements

Owens Valley Tour

One of the most notable movements during this winter was documented both by GPS collar and ground observation. Starting on January 20, 2023, Sawmill adult female S543F moved down into the Owens Valley (elevation 4,400 ft.; Figure 15). This unusual movement was immediately uploaded online from her GPS collar, so staff went to observe her in the field and found a group of three: S543F with a yearling female and an adult male. These animals resided on some cinder cones adjacent to the Sierra at ~5,500 ft. Based on the GPS collar, S543F, and presumably the group, continued to occupy low elevation until moving back into the mountains on April 20, 2023.

Figure 15. Novel habitat use during the severe winter of 2022-23. Sierra bighorn ewe S543F and two additional bighorn visited a cinder cone east of the Sierra Nevada in the Owens Valley between January 19, 2023 and April 20, 2023. Photo credit Phil Johnston April 9, 2023.

The Kern Recovery Unit

At this time, our data indicate the Kern Recovery Unit, both Laurel and Big Arroyo herds, were extirpated of females during the 2022-23 winter. Several mortalities were found together in groups of two or three, indicating they may have been caught in an avalanche or hunkered down and starved together. In Big Arroyo, mortalities clustered around lower elevation habitat within the Big Arroyo near the Kern River or along the Kern River between Funston and Red Spur Creeks (Figure 16).

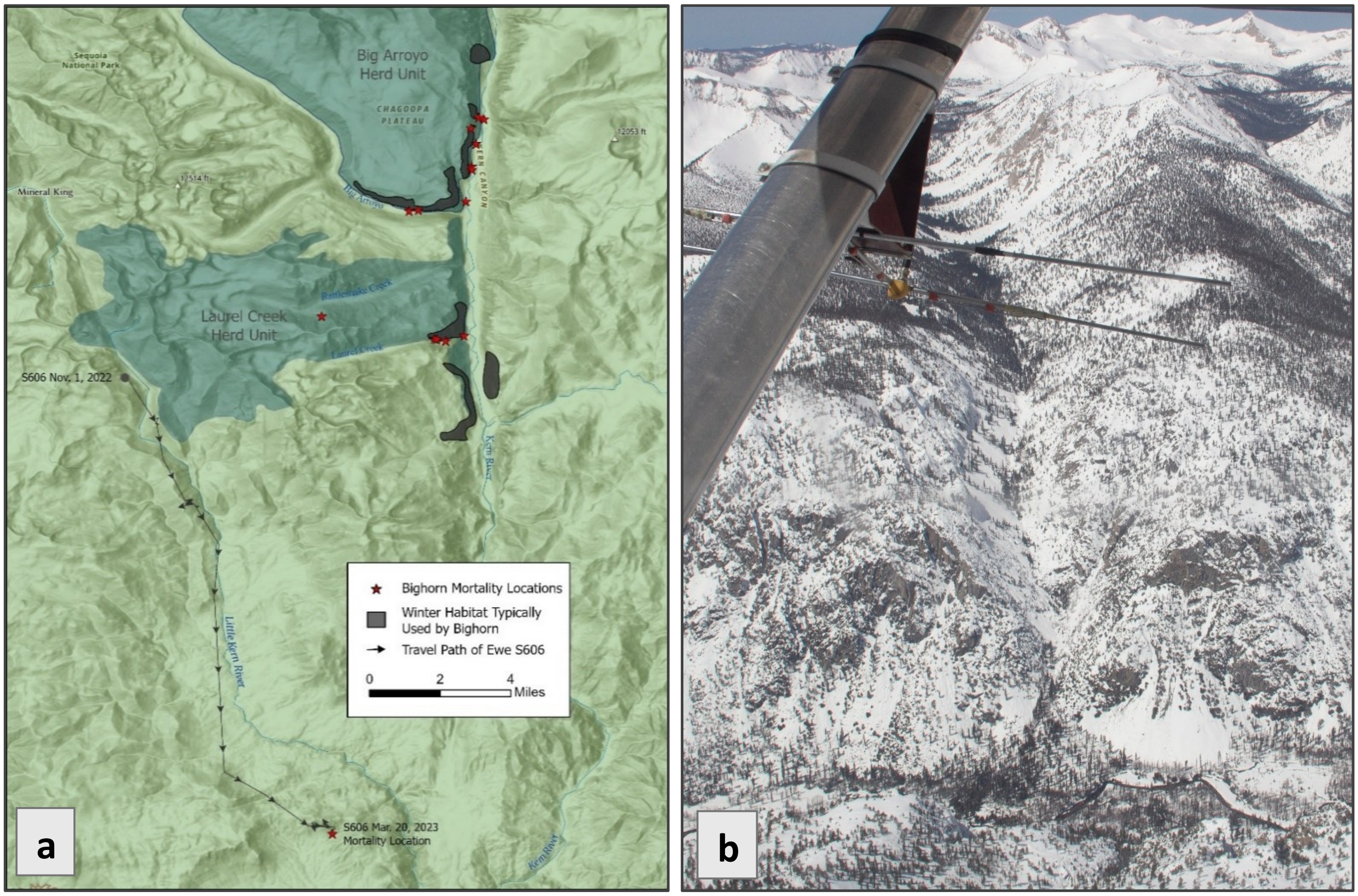

***Figure 16**. **a)** All collared Sierra bighorn in Big Arroyo and Laurel perished during the severe winter of 2022-23. Mortalities were investigated during the summer, and collars were frequently found at low elevations in groups together, sometimes alongside uncollared mortalities. Most carcasses were scavenged by bears, and it was not always clear if animals died from avalanche or starvation.*
***b)** Full snow-coverage at the confluence of Laurel Creek with Kern River (river at bottom) taken from the air on April 1, 2023. Most Laurel mortalities were found within 1 mile of the confluence. Photo credit Trevor Johnson.*

Laurel animals from the prior winter (S600M, S604F, S599M, S603F, S605F) died between January 9 and February 16, within close proximity to each other in a region of frequent use near the junction of Laurel Creek and the Kern River (Figure 16). A single male (S602M) died in nearby Rattlesnake Canyon on April 1, 2023. And most dramatically, Laurel female S606F died on March 20, 2023 after moving more than 12 miles (straight-line distance) south through steep, forested terrain (Figure 16). It is possible that some Laurel animals from an earlier translocation moved over to the Boreal Plateau, a region between Laurel and Langley where 2 females and a lamb were documented in 2023. Currently these are considered Langley animals.

Exploratory Bighorn Who Died This Year

S242F stands out in the category of exploratory bighorn; she was a Wheeler ewe who summered well to the west of Wheeler Ridge and varied in her winter range preferences (Figure 17). Her behavior indicated that she was risk averse to lions, but she was killed by a lion on the eastern escarpment of Wheeler this year. The heavy snow likely forced her to winter at lower elevation than she usually selected. Exploratory ewes like S242F are important in establishing new migration routes and range expansions. Consequently, predation by lions not only has an immediate demographic effect but also reduces the potential for restoration of lost patterns of habitat use that are essential to recovery.

S522F was another female who persisted through years when the Warren herd experienced high mortality. She was the last remaining female to have used Camiaca Peak in prior years. More recently, she exhibited plasticity in her movements throughout the Warren herd (Figure 17). She died in an avalanche this winter.

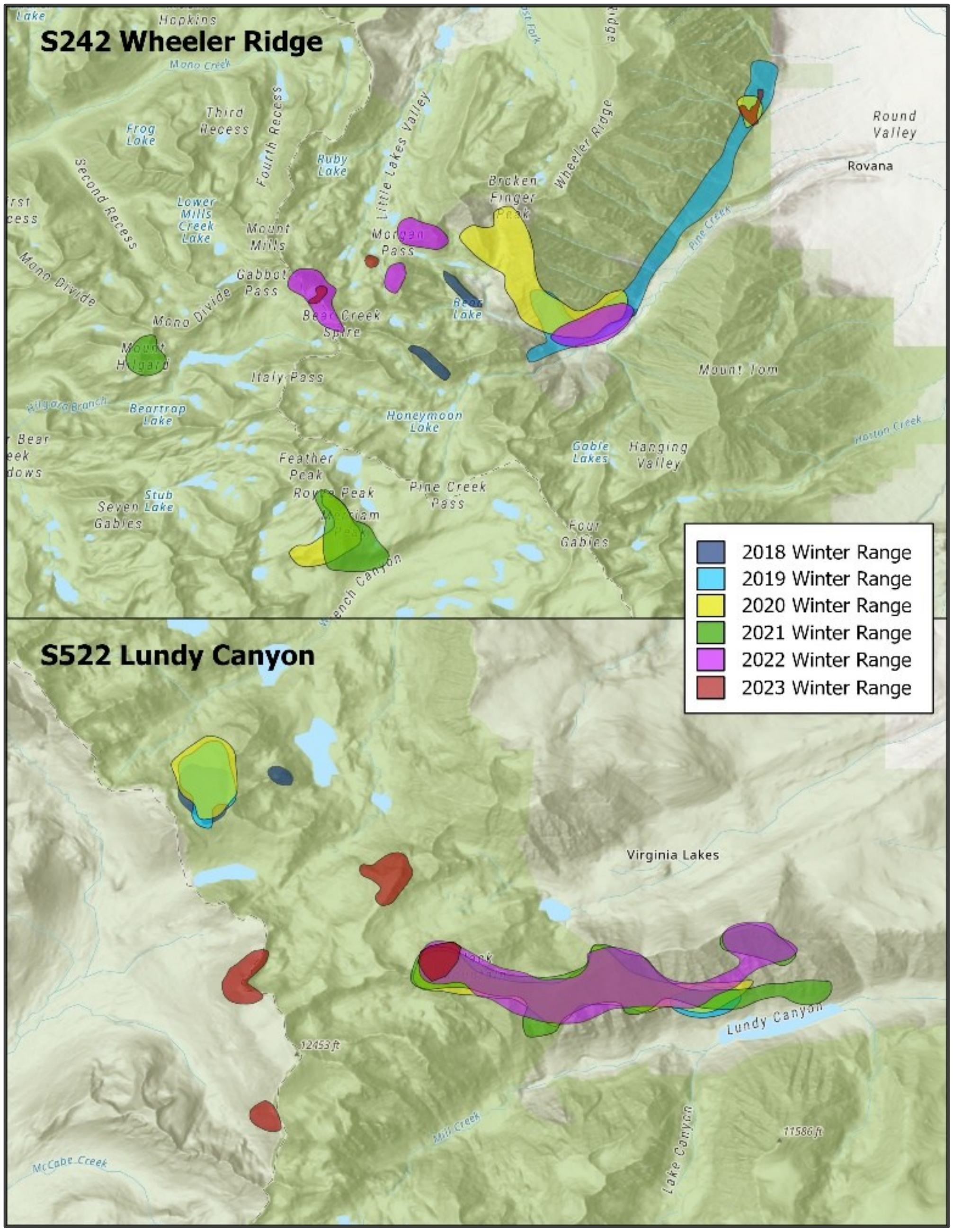

Figure 17. Habitat use patterns of two Sierra bighorn females that died during the severe winter of 2022-23. Polygons were created in ArcGIS Pro around clusters of GPS location data during the winters of 2018-2023.

Mountain Lion Monitoring and Management

Minimum Counts

In the 2022 lion count year we documented a minimum of 84 lions in the eastern Sierra population: 27 adult females, 16 adult males, and 41 subadults. This count exceeds last year's count of 56 individual lions and is the highest count the program has ever estimated. In large part this high count is due to increased monitoring effort, especially on reproductive females and their offspring. Twenty-three of the 41 subadults detected were juveniles detected either at den visits or feeding sites, and it is unknown whether these subadults survived to dispersal age. The remaining 18 subadults were either captured and collared before dispersal or as independent dispersing subadults. The 23 juveniles whose fates are unknown will henceforth be excluded from zone tallies and survival analyses, leaving us with a functional total of 61 lions.

Figure 18. *Mountain lion tracks in snow in Round Valley, Mt. Tom in background, January 12, 2023. Photo credit Phil Johnston.*

Eighteen lions were detected in the central count zone, 12 in the northern count zone, 18 in the southern count zone, 6 in the Olancha count zone, and 9 lions were detected in the eastern Sierra but not inside any count zone (see Appendix B for an explanation of lion count zones and methods). Minimum counts summed across zones will exceed the total minimum count for the eastern Sierra because individual lions detected in multiple count zones are added to the tally for each zone but are only counted once for the total minimum count of 61 lions.

Forty-seven of the 61 lions detected were tracked with functional GPS collars for at least part of the count year. The 14 lions that were not tracked with functional collars during the count year were identified by physical evidence including unique markings, unique tracks, photographs, visual observations, age of dependent young, and applied marks, such as ear tags and non-functional collars. Six of the 14 uncollared lions were adults (4 females, 2 males) and the remaining 8 were either subadults who were captured after the monitoring period, or adults whose collars were non-functional during the 2022 animal year.

Captures

We captured 32 individual lions including 14 adult females, 8 adult males, and 10 subadults, which is slightly higher than the 27 individuals captured during the 2021 animal year.

Predation on Sierra Bighorn

The severe winter of 2022-23 had compounded detrimental effects by directly killing many bighorn and also concentrating bighorn on the areas of winter range where they overlap with mule deer and are most vulnerable to lion predation. We documented 42 bighorn killed by 11 different lions in 7 herds in the 2022 animal year (Figure 20). Lion L230F alone killed 11 Sawmill bighorn (6 ewes, 4 rams, 1 unknown sex) between January 24 and April 17, 2023, demonstrating the heightened predation risk posed by adult females that concentrate their movements on pockets of high prey density and exhibit accelerated kill-rates while raising offspring (Figure 19). Importantly, only two of the 11 bighorn killed by L230F were detected through mortality alerts from GPS-collared bighorn, highlighting the importance of GPS-collaring lions for detecting predation.

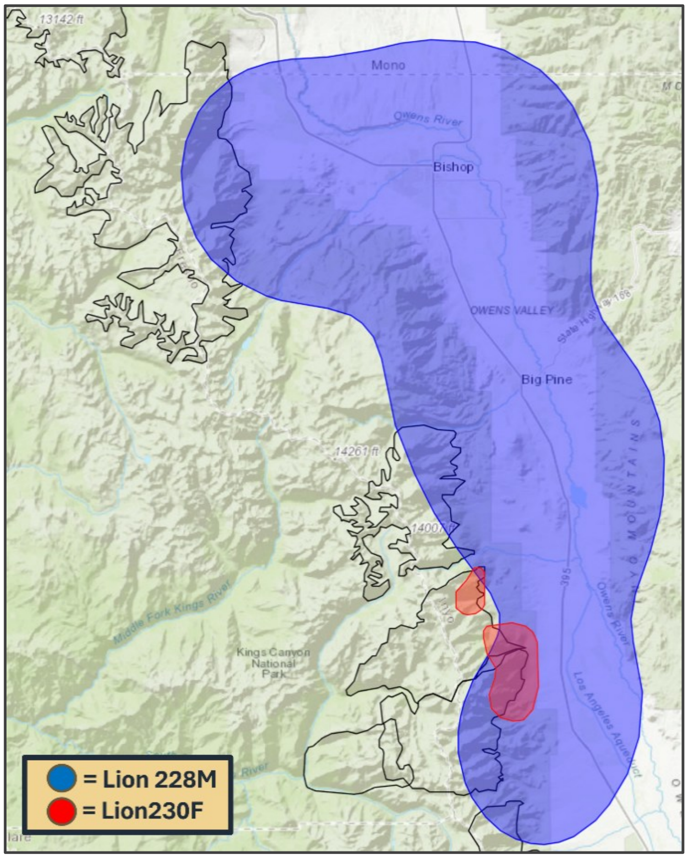

Figure 19. *Different space-use between sympatric male and female Sierra bighorn-predating lions, showing the concentrated movements, and thus increased predation risk, posed by female lions. Movement data covering January 24 - April 17, 2023.*

The Wheeler herd was hit especially hard and lost 18 bighorn (10 ewes, 5 rams, and 3 unknown sex) to lion predation attributed to 7 lions (Figure 21), 4 of which were subsequently translocated. The Sawmill herd lost 9 bighorn (6 ewes, 1 ram, and 2 unknown sex) to predation attributed to two lions, 1 of which was subsequently translocated. Baxter lost 5 bighorn (4 rams, 1 ewe) to two lions; Williamson lost 4 bighorn (1 ewe, 1 ram, 2 unknown) to L214F; Olancha lost 3 ewes to two lions; Langley lost 2 bighorn (1 ram and 1 ewe) to two lions, and Convict lost 1 ewe to L212M (Figure 21). Six of the 11 adult lions responsible for these bighorn predations were subsequently translocated. See Figures 21 and 22 for a summary of lion predation distributed across Sierra bighorn herds and recovery units.

Importantly, only 4 of the 42 documented instances of lion predation on Sierra bighorn were attributed to uncollared lions, which suggests that we are likely documenting a very high proportion of the predation that is occurring. This is a great improvement over the previous year's predation detection, when 13 of 20 bighorn killed by lions were attributed to uncollared lions. Increased capture effort beginning in January 2022 identified several lions of advanced age (L229F, L230F, L214F, L213M, and L211F) preying on Sierra bighorn and raising offspring within herd unit boundaries, suggesting that these lions have been impacting herds for numerous years prior to their capture (Figure 23). Noting the ages of lions when they are collared and recognizing the age at which lions establish a home range provides insight into the duration of predation that may have occurred prior to collaring (Figure 23). Since 2017, 41.6% of lion predation on Sierra bighorn has been detected only through feeding clusters observed in GPS data from collared lions, or conversely 58.4% of known lion predation is detected through other means, including collared bighorn mortality signals and opportunistic investigations. This demonstrates that significant levels of predation by uncollared lions can go partially or entirely undetected. In 2022 only 9% of documented lion predation on Sierra bighorn (n=42) was attributed to uncollared lions, but from 2017 through 2021, 52.5% of lion predation (n=78) was attributed to uncollared lions. Having a low proportion of lions collared is of particular concern in herds when there are also a lower proportion of female bighorn collared than desired (i.e., <30%), because the predation rate is likely underestimated. In 2022, 78.6% of all documented lion predation on Sierra bighorn was detected only through GPS data from collared lions, meaning that only 21.4% of these predation events would have been detected through collared sheep mortality alerts and other means. These facts underline the importance of maintaining a high proportion of collared lions within the recovery area to get a census on lion-killed bighorn.

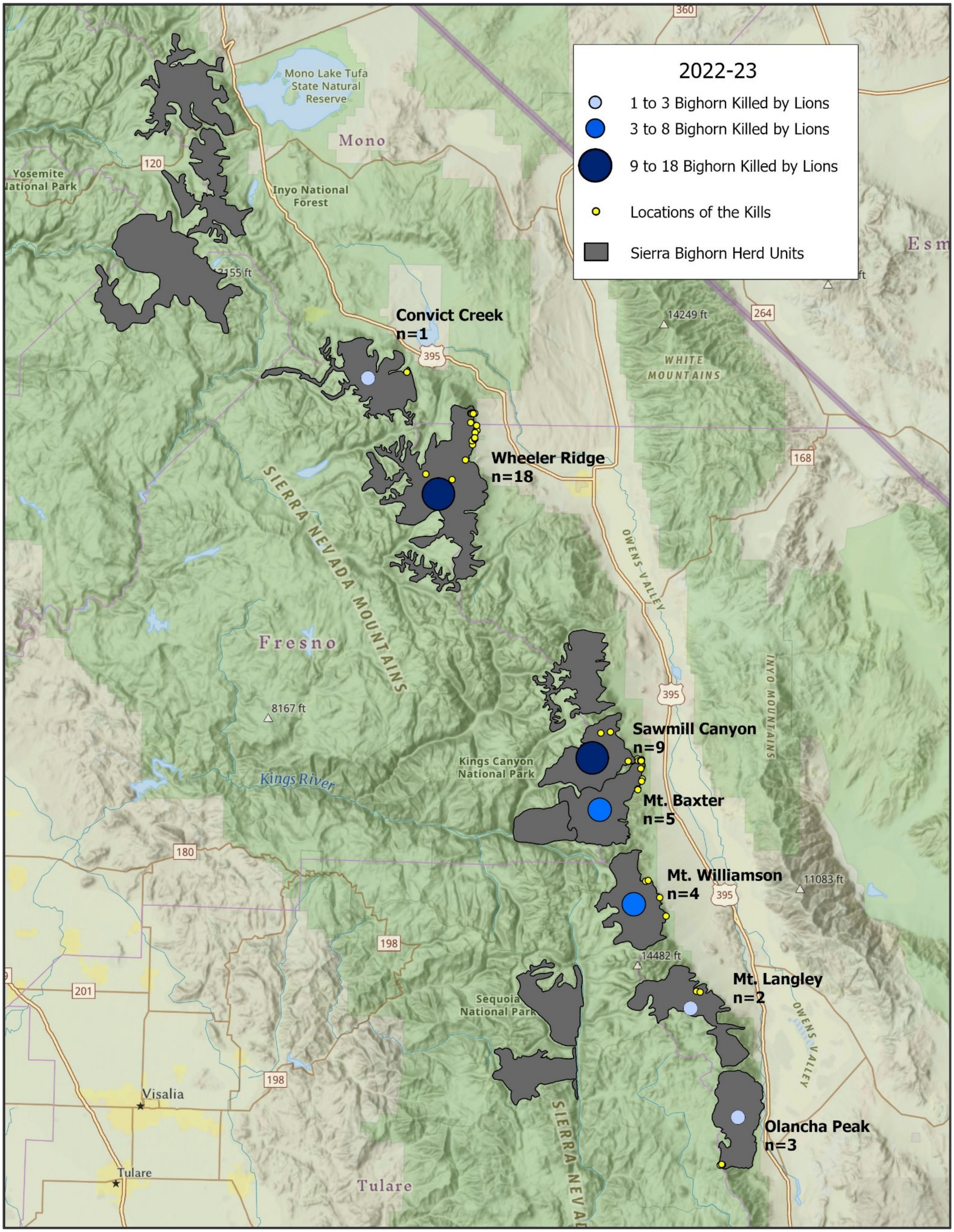

Figure 20. Distribution of mountain lion kills detected in the Sierra Nevada in the 2022 animal year. Circles represent the number of male and female Sierra bighorn killed by lions, including uncollared bighorn. This map should not be directly compared to Figure 4 as the circles represent different data, scaled numerically.

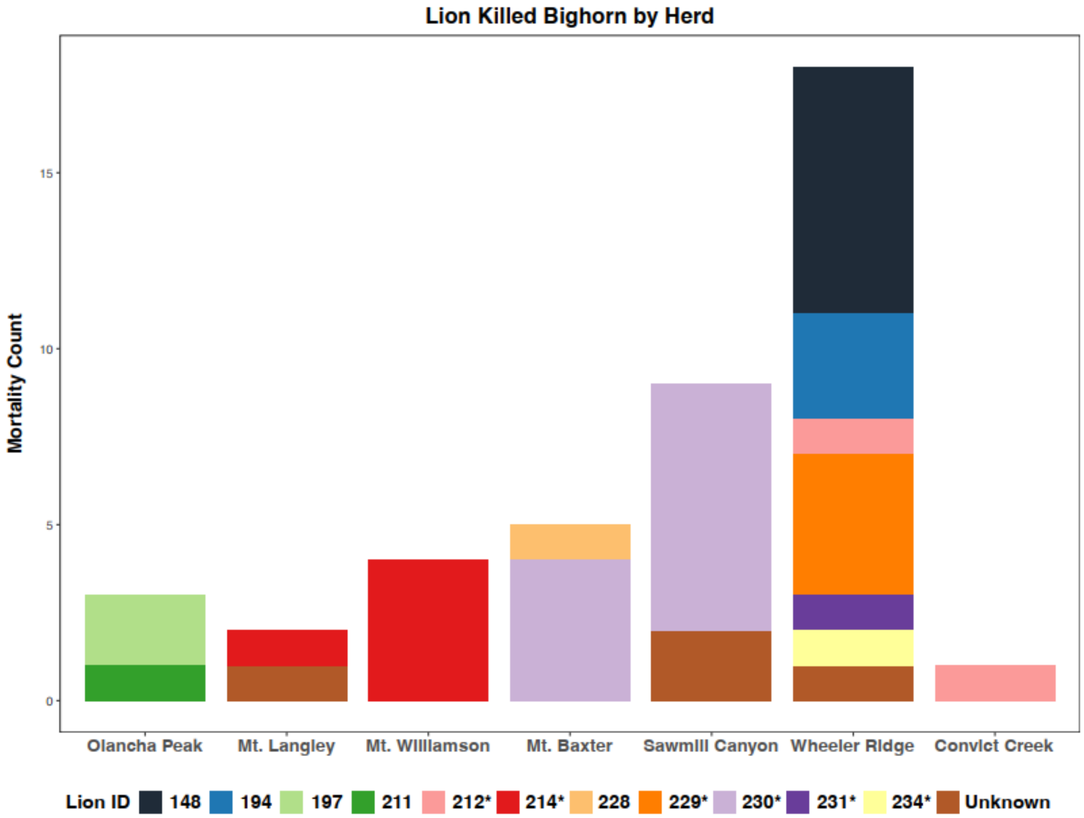

__Figure 21__. Lion predation on Sierra bighorn from May 1, 2022 - April 30, 2023 by herd and individual lion. Lions denoted with an asterisk were removed for Sierra bighorn protection during this time period.

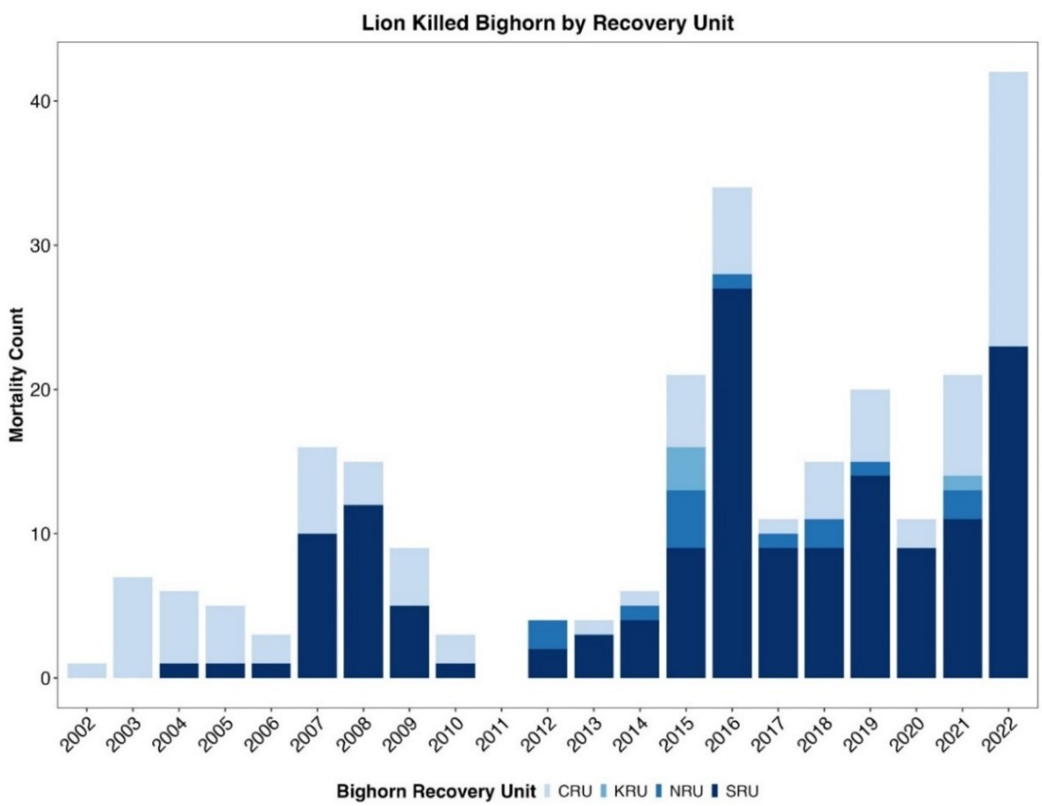

__Figure 22__. Lion predation on Sierra bighorn by year and recovery unit. Lion monitoring effort and Sierra bighorn population sizes were not consistent across this time period.

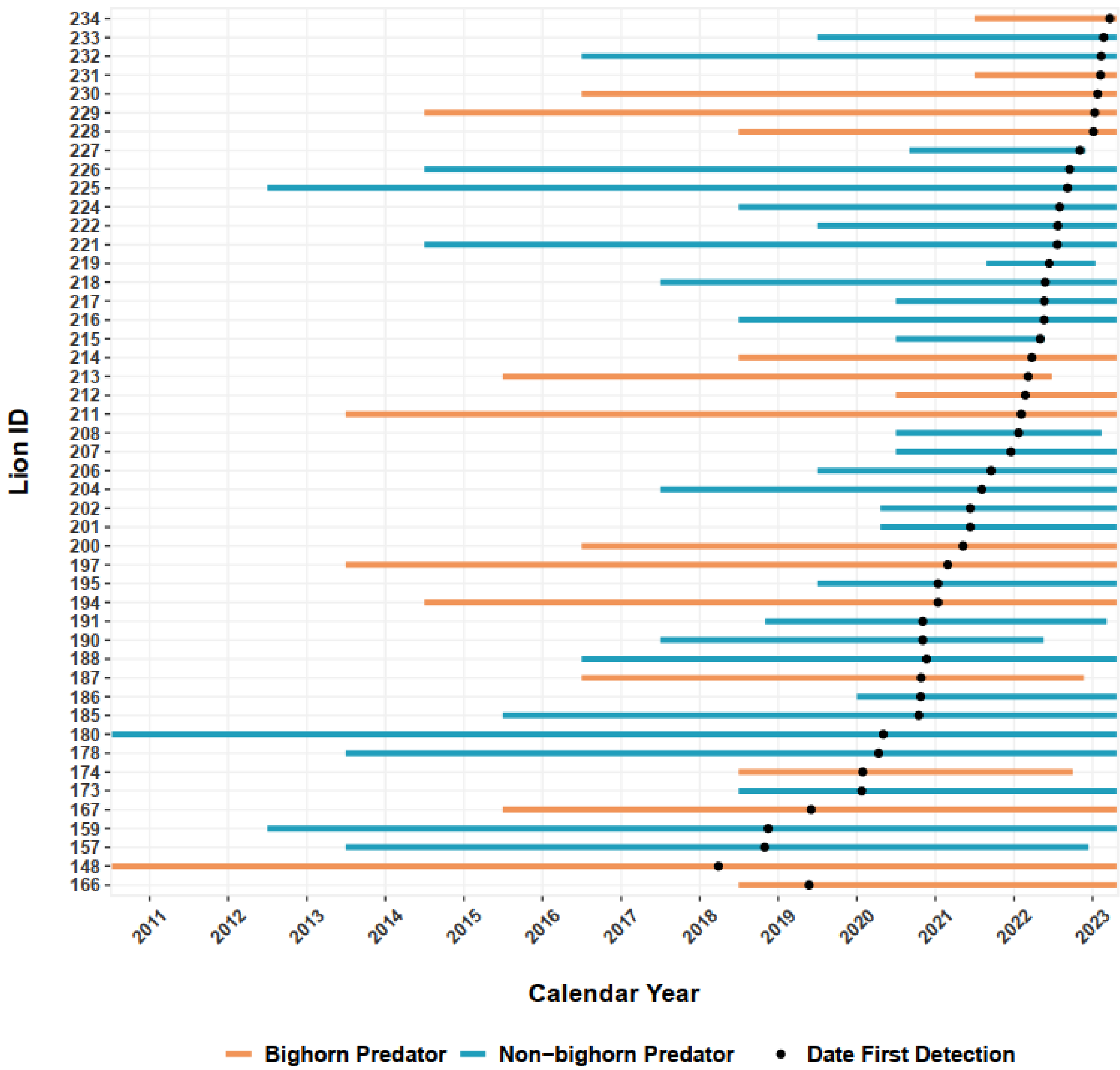

Figure 23. *Temporal presence of collared mountain lions in the eastern Sierra and their known status as bighorn predators. Birth year is based on estimated age from gum recession and tooth wear at capture compared to first capture date (detection). The graph includes all collared lions that were alive during the 2022 animal year. We suspect that individual lions maintain the same predatory preferences before and after capture, after they have established a home range.*

Reproduction

We documented 27 adult females, and 16 of them were confirmed to have a minimum of 1 offspring for a total of 23 juveniles detected whose fates are unknown.

Predation Management – Lion Translocations

In the previous year we translocated a family group of bighorn-predating lions (L200F, L209F, and L210F), all of which established new home-ranges and were monitored for over one-year post-translocation. The success of translocations in 2021 demonstrated the effectiveness of translocation as a predation mitigation strategy, and we redoubled our predation management efforts in 2022 during the severe winter.

Of the 11 bighorn-predating lions, 6 were translocated in the 2022 animal year, comprised of 3 adult females and 3 independent dispersing subadults (Figure 24). An additional 2 dependent juveniles (6-months-old) were translocated with their mother but were not counted toward the total of 11 bighorn-predating lions because they were not directly responsible for predation. The 5 bighorn-predating lions who were not translocated were comprised of 3 adult males and 2 adult females, whose diets primarily consisted of deer or other prey.

***Figure 24**. Mountain lion L230F was translocated with her subadults from Sawmill to San Gabriel on April 17, 2023. L230F was responsible for killing at least 11 Sierra bighorn. Photo credit Phil Johnston.*

As of April 30, 2023, we have monitored 12 translocated lions with an average annual survival probability of 0.67 (±0.20 SE), which is similar to the annual survival of non-translocated lions in 2022 of 0.72 (±0.10 SE). However, since adapting our translocation strategy in 2022, survival of translocated lions (0.88 ±0.13 SE, n=8) has greatly improved and was higher than that of non-translocated lions (0.72 ±0.10 SE, n=42).

Lion Survival and Mortality

The estimated annual survival rate for the 47 collared lions in the eastern Sierra was 0.89 (±0.08 SE) for adult females, 0.60 (±0.20 SE) for adult males, and 0.45 (±0.46 SE) for subadults. Among the 68 lions detected in the eastern Sierra this year we documented 17 mortalities. Mortality causes were as follows: depredation (n=4), intraspecific killing (n=4), poaching (n=1), vehicle collision (n=4), unknown cause (n=1), and, of note, Highly Pathogenic Avian Influenza (HPAI; n=2). These HPAI mortalities occurred within a family group on the shore of Mono Lake where waterfowl congregate in the winter, and we presume that the lions contracted the virus by preying on infected waterfowl. These mortalities were the first documented cases of HPAI in any species of wildlife in Mono County.

Sierra Bighorn: Future Management

During the winter of 2022-23, Sierra bighorn experienced a substantial loss of females due to predation and severe winter conditions. Recovery from this setback will likely require considerable time, particularly because bighorn typically produce only a single lamb per year. Future management will rely on a combination of actions. In the near-term, continued intensive predator monitoring, coupled with appropriate predator management—including translocations and occasional removals—will remain essential. Additionally, identifying and evaluating new low-elevation winter ranges for herds that currently lack such habitat should be considered. Low elevation winter ranges provide abundant forage and refuge from deep snow, but Sierra bighorn may not know the migration routes needed to access those winter ranges. We now have a greater understanding of the variation of threats that Sierra bighorn experience and their effects on population performance. Over the long-term, a more informed translocation strategy will be critical for population restoration.

As a species approaches extinction, population size declines, genetic diversity decreases, and behavioral knowledge is lost. In particular, migratory knowledge within populations may disappear, including memories of established migration routes. Consequently, it is far more difficult for migration routes to be reestablished than for them to persist within stable populations. Considerable trial and error will likely be necessary before reintroduced bighorn sheep reestablish optimal migration routes. Achieving this objective will require an adequate supply of translocation stock from within the Sierra Nevada, as well as patience and persistence from agencies, stakeholders, and other supporters of recovery.

Recovery efforts must also recognize key principles of conservation biology and restoration ecology relevant to endangered species management. Recovery goals are established based on what is necessary to ensure long-term population viability, rather than on what can be easily achieved. Population viability is commonly described in terms of the “3 Rs”: representation, redundancy, and resiliency (Shaffer and Stein 2000). Representation refers to the restoration of populations across the species’ geographic range and across diverse habitats; for example, recovery objectives include occupancy across a substantial proportion of the historical range. Redundancy requires the establishment of multiple populations to ensure persistence despite localized threats. Resiliency emphasizes the capacity of populations to recover from disturbances such as disease outbreaks, habitat loss, and climate change. These principles underpin conservation decisions for Sierra bighorn. In an increasingly variable environment, maintaining a broad geographic distribution will help ensure persistence through droughts, extreme snowfall, and other environmental stressors.

Recent translocation efforts have produced mixed outcomes, largely due to the effects of extreme winter conditions. Translocation decisions were guided by recovery objectives and population modeling based on more than a decade of demographic data. Limited availability of translocation stock required that newly established herds begin relatively small, with the expectation that repeated augmentations would be necessary. Since restoration efforts for Sierra bighorn began in the 1970s, population growth following reintroductions has often required decades to become evident. Similarly, translocation efforts for Sierra Nevada mountain yellow-legged frogs required multiple attempts and decades of monitoring before success was realized (Knapp et al. 2024).

Ongoing monitoring and analysis of both established and reintroduced herds will continue to inform future management decisions. Future population models will incorporate a broader range of variables, including climate effects, predation risk, and their influence on demographic processes and habitat selection. As noted earlier, stochastic individual behavior—such as the exploratory movements of S242F and S543F—can have important consequences for the restoration and persistence of migratory behavior.

Literature Cited

CW3E 2023. CW3E 2022-23 Winter (Dec-Feb) Recap. San Diego. <https://cw3e.ucsd.edu/cw3e-winter-2022-23-recap/>.

Department of Water Resources. 2023. Water Year 2023: Weather Whiplash, From Drought To Deluge.

Dettinger, M., H. Alpert, J. Battles, J. Kusel, H. Safford, D. Fougeres, C. Knight, L. Miller, and S. Sawyer. 2018. Sierra Nevada Summary Report. California’s Fourth Climate Change Assessment SUM-CCCA4-2018-004.

Gammons, D. J., J. L. Davis, D. W. German, K. Denryter, J. D. Wehausen, and T. R. Stephenson. 2021. Predation impedes recovery of Sierra Nevada bighorn sheep. California Fish and Wildlife Journal 444-470.

Halofsky, J. E., D. L. Peterson, L. Y. Buluç, and J. M. Ko. 2021. Climate change vulnerability and adaptation for infrastructure and recreation in the Sierra Nevada. Gen. Tech. Rep. PSW-GTR-272. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 275 p. 272.

Hill, K. 2024. Brutal Winter Causing Huge Losses in Western Big Game Herds. Outdoor Life. <https://www.outdoorlife.com/conservation/brutal-winter-killing-western-big-g>.

Knapp, R. A., T. C. Smith, M. Q. Wilber, R. L. Grasso, and M. B. Joseph. 2024. Reintroduction of resistant frogs facilitates landscape-scale recovery in the presence of a lethal fungal disease. Nature Communications. Springer US. <http://dx.doi.org/10.1038/s41467-024-53608-4>.

Marshall, A. M., J. T. Abatzoglou, S. Rahimi, D. P. Lettenmaier, and A. Hall. 2024. California’s 2023 snow deluge: Contextualizing an extreme snow year against future climate change. Proceedings of the National Academy of Sciences 121:e2320600121. <http://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2216830120/-/DCSupplemental.https://doi.org/10.1073/pnas.2216830120>.

Moriarty, K. M., W. J. Zielinski, A. G. Gonzales, T. E. Dawson, K. M. Boatner, C. A. Wilson, F. V. Schlexer, K. L. Pilgrim, J. P.

Copeland, and M. K. Schwartz. 2009. Wolverine confirmation in California after nearly a century: native or long distant migrant. Northwest Science 83:154-162.

NASA Earth Observatory. 2024. A Boom Year for Sierra Nevada Snow. https://earthobservatory.nasa.gov/images/151232/a-boom-year-for-sierra-nevada-snow.

Polade, S. D., A. Gershunov, D. R. Cayan, M. D. Dettinger, and D. W. Pierce. 2017. Precipitation in a warming world: Assessing projected hydro-climate changes in California and other Mediterranean climate regions. Scientific Reports 7:1-10. Springer US. <http://dx.doi.org/10.1038/s41598-017-11285-y>.

Shaffer, M. L. and B. A. Stein. 2000. Safeguarding our precious heritage. Pages 301-321 in B. Stein, L. S. Kutner, and J. S. Adams, eds. Precious heritage: the status of biodiversity in the United States. Oxford University Press, Oxford, England.

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.

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This report is available at: https://wildlife.ca.gov/Conservation/Mammals/Bighorn-Sheep/Sierra-Nevada/Recovery-Program/Literature

Appendix A: 2022 Population Count Details

Minimum counts for each herd are included in Tables 1a and 1b, below. Table 1a displays counts that occurred primarily before the big winter, and Table 1b reveals the losses that occurred during that winter by showing 2023 animal year minimum counts.

***Table 1a**. Reconstructed minimum counts (MC) of Sierra bighorn during the **2022** animal year: May 1, 2022 - April 30, 2023. Most counts occurred prior to the heavy winter of 2022-23. 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. However, all minimum counts are underestimates. Year-end population is reduced by all known mortality that occurred after the survey. Counts are from summer surveys, except where indicated.*

Herd	Female Adult	Female Yrlng	Female Total	Lambs	Male Adult	Male Yrlng	Male Total	MC	Year End Females	Female Mortality post survey	Notes
Olancha[C]	19	2	**21**	16	14	2	16	**53**	20	M203	Lamb count from spring
Laurel	4	0	**4**	3	3	0	3	**10**	0	All	All adults previously collared and known dead. Lamb remains not found, presumed dead
Big Arroyo	8	1	**9**	7	1	2	3	**19**	0	All	4 additional uncollared morts found for a mort total of 7AF, 3AM, 1 unk sex
Langley	18	5	**23**	8	8	5	13	**44**	21	S613 & S478	
Williamson	22	4	**26**	10	6	3	9	**47**	19	S561, S633, M218, S560, S635, S590, S588, S481	Total count includes 2 yearlings, unknown sex
Baxter[C]	41	9	**53**	24	24	7	31	**110-115**	49	S307, S299, M222, S544	Count includes 3 unclassified females and 2-7 unclassified animals from summer count. Males counted in winter
Sawmill	31	7	**38**	16	5	4	9	**66**	28	S396, S542, S538, M208, S515, S541, S648, S514, M242, S513	Count includes 3 unclassified animals
Bubbs	10	2	**12**	7	9	4	13	**32**	12	none	One Baxter male (S596M) seen but not included
Taboose	1	0	**1**	1	1	0	1	**3**	2	none	Single November observation
Wheeler	33	7	**40**	19	10	3	13	**72**	27	M251, S550, M211, S574, M217, M219, M229, S554, M228, M242, M231, M235, M237	
Convict	7	0	**7**	5	5	3	8	**20**	1	M248, M247, S569, S570, S571, S526	Single female seen in April 2024
Cathedral	5	0	**5**	5	1	1	2	**12**	3	S365, S607	All known collared females died
Gibbs	17	3	**20**	9	18	3	21	**50**	13	S617, S619, S618, S614, S500, S324, S568	All snow-related mortality
Warren	10	3	**13**	2	1	4	5	**20**	9	S536, S522, S533, S621	All snow-related mortality
Totals	**226**	**43**	**272**	**132**	**106**	**41**	**147**	**551**			

C = data combined from winter and summer surveys

***Table 1b**. Reconstructed minimum counts (MC) of Sierra bighorn during summer **2023**, after the effects of the 2022-23 winter. Lambs 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 surveys routes are designed to detect females. However, all minimum counts are underestimates.*

Herd	Female Adult	Female Yrlng	Female Total	Lambs	Male Adult	Male Yrlng	Male Total	MC	Notes
Olancha	27	7	**35**	10	9	4	13	**58**	Includes 1 female unknown age
Laurel	0	0	**0**	0	0	0	0	**0**	No animals or sign found. All adults previously collared and known dead. 2F, 6M seen on Boreal Plateau could possibly be Laurel animals but presumed to be Langley at this time.
Big Arroyo	0	0	**0**	0	1*	0	0	**1**	* 1-2 males on camera in 2023
Langley	11	2	**13**	5	10	2	12	**30**	
Williamson	7	0	**7**	2	4	0	4	**12**	Assumed S632F is alive with low battery GPS and dropped VHF collar. Tracks indicated 1AF and lamb in northern deme not seen.
Baxter[C]	44	4	**48**	22	40	2	42	**112**	Females from summer, males from winter
Sawmill	19	5	**24**	4	3	1	4	**32**	Poor count. Previous April observation had 22AF, 3YF, and 10 lambs. 11 lambs seen in winter 2024.
Bubbs	7	1	**8**	2	1	1	2	**12**	Status of S631F unknown
Taboose	*	*	*	*	0	0	0	**0**	* Not seen during year but 1AF, 1YF captured in fall 2024
Wheeler	22	5	**27**	9	16	0	16	**53**	Added 1 animal of unknown sex and age. 1 unidentified male seen with black collar, possibly S410 (last seen 2016).
Convict	*	*	*	*	5	0	5	**5**	* 1AF found in April 2024. 3AF, 1YF, and 1 lamb seen in Feb. 2025. Some of these animals were likely present but undetected since winter 2022-23.
Cathedral	*	*	*	0	4	0	4	**4**	* 1 animal of unknown sex seen on camera in 2024
Gibbs	2	1	**3**	1	9	0	9	**13**	
Warren	8	0	**8**	3	3	0	3	**14**	
Totals	**147**	**25**	**173**	**58**	**105**	**10**	**115**	**346**	

C = data combined from winter and summer surveys

HERD UNIT SUMMARIES

Olancha

The highest minimum count at Olancha included a total of 53 animals and combined counts from summer and spring: 19 adult females, 2 yearling females, 16 lambs, 14 adult males, and 2 yearling males. Three of the four collared females were seen. The one collared female not seen (S494F) had a functional GPS collar and was within the survey area at mid-elevation in Olancha Canyon during the September survey. This canyon is notoriously convoluted and difficult to survey. Only 8 lambs were counted in September, but 16 lambs were counted on April 6th. However, the September 28-30 survey had the highest count for all other sex and age classes, indicating neither was a complete survey.

At the end of October, eight bighorn were captured including 3 recaptures (2 females, 1 male) and 5 previously unmarked (4 females, 1 male) animals. Two lions (L211F, and L197M) killed three bighorn (M205F, S559F, and M203F), all on the south plateau; 2 of these bighorn were killed during the September survey window.

We counted fewer females than projected from 2021 indicating either a poor count or high female mortality. With documented lion predation and a known incomplete count, it is hard to differentiate between these two possibilities at this time.

Unlike any other herd, Olancha suffered no winter mortality and was the only herd to increase between 2022 and 2023. Large avalanches were easily observed from Highway 395 on both the north and south shoulders of Olancha Peak during the winter of 2023, but no collared animals were detected to have died. The subsequent summer count (post big winter) was the highest ever recorded for Olancha. Despite some obvious avalanche danger, Olancha has the least snow of any herd units because it is both the farthest south and is at the lowest elevations. Additionally, although there is a deer herd that overlaps with Olancha in the summer and fall, during the winter there seems to be minimal overlap between deer and bighorn, which may result in lower predation rates. This should be investigated further.

Laurel

In March 2022, seven animals were translocated into Laurel including 4 females and 3 males. All of these animals were seen during an August survey, along with three lambs. Additionally, previously used habitat on the east side of the Kern River was surveyed but no sheep sign was observed.

Last year, a group of 5 Laurel animals was seen on the east side of the Kern in June 2021 near the Window Cliffs. This group included one collared animal, S382F, whose GPS collar stopped working in November 2018. In September S382F died from unknown cause, but the whereabouts of the other animals in this group are unknown. Surveyors walked through this region, but it is vast and convoluted, and it would be easy to miss a small group of bighorn, particularly since habitat use in this area is not well understood.

All collared animals died in early 2023 from snow-related causes. These were not able to be accessed or investigated until the following summer, but the timing and location of mortalities was known from their GPS collars. We also have photos of the snow conditions indicating this area was completely blanketed in deep snow. One male and one female were identified as having died specifically from avalanche, but for the others we were unable to differentiate avalanche from starvation. None of the three lambs seen during the previous summer were found dead or alive, but they are presumed to have died and been scavenged, as was the state of the other Laurel animals investigated.

Most Laurel animals died near the junction of Laurel Creek and the Kern River. However, S606F made an unusual and substantial movement prior to mortality, traveling 12 miles (direct line) south down the little Kern River in deep snow before dying on March 20th. It is not known if she had her lamb with her. When her mortality was investigated in November, only her collars remained, and she was found on a south-facing slope in oak woodland. She was not in avalanche terrain.

Big Arroyo

In June, we accounted for 19 animals in Big Arroyo: 8 adult females, 1 yearling female, 7 lambs, 1 adult male, and 2 yearling males. This count includes a collared female (S499F) and a collared male (S498M) that were not seen. Although the other three collared females were seen, we expect this is probably an undercount as S499F was seen last year with a group of three (1 lamb and 1 yearling male). S499F is notorious for being separated from the other collared females and using a vast region of very convoluted terrain from Red Spur down to the Kern River. During the survey, her GPS collar was not sending updated locations making it difficult to locate her. In the fall, we captured four animals and outfitted them with new GPS collars, including recaptures of S583F and S498M.

During the following winter all seven collared animals at Big Arroyo died from snow-related causes between January and April. Aerial photographs of the region during the winter showed very limited snow-free habitat—the snow seemed to be sticking to near vertical walls as well as coating areas that in other years were blown free and scoured of snow. We were unable to investigate these mortalities until the following summer due to deep snow. When the 7 collared mortalities were investigated the following August, an additional four uncollared mortalities were found. The cause of death for most animals was identified as snow-related because it was difficult to differentiate avalanche mortalities from starvation as most carcasses had been scavenged. We did determine that at least two animals likely died in an avalanche on March 2 (S499F and S637F) because they were located within obvious avalanche debris. Additionally, one animal (S498M) likely died of starvation as he was found relatively intact on a perch ~1500 ft above the Kern River. Six animals were found at the base of the western wall of the Kern south of the Kern Bridge: a group of two (S582F with an uncollared 6-year-old male M254M) found together, a group of three (S497F, uncollared female M256F and an uncollared animal of unknown sex M255) were found slightly down canyon but also in close proximity, and finally a single collared female (S583F). Two additional animals were located on the north side of the Big Arroyo drainage near the junction with the Kern River (S636F and uncollared male M257M). It seems probable the latter two animals died in different events. All Big Arroyo mortalities were within or very near avalanche terrain, but with heavy scavenging by bear, coyote, and lion it was not clear if these animals were caught in avalanches together or if they hunkered down together and starved while waiting out the winter. There were no noteworthy movements made by Big Arroyo animals prior to their deaths.

Langley

Langley was surveyed on August 30th, and we accounted for a total of 44 animals: 18 adult females, 5 yearling females, 8 lambs, 8 adult males, and 5 yearling males. We saw 3 of the 4 collared females and there are no collared males at Langley. The adult female count was two animals above the projection from 2021, indicating that animals were missed in 2021.

Capture in the fall included 7 animals (2 previously uncollared females, 2 recaptured females, and 3 previously uncollared males). Three mortalities were detected: S613F died from snow on Christmas day; L214F consumed bighorn S478F on March 18th, and an uncollared lion killed S610M on March 22. L214F was captured while feeding on S478F and was later translocated (see below). Compared to most other herds, Langley had notably high survival during the record winter of 2022-23.

Likely influenced by the incredible snowpack, GPS collars indicated some novel habitat use low in Inyo Creek and below and on the ridge separating Lone Pine Lake from the Meysan drainage, as well as lower in the western Rock Creek drainage than previous use (~10,600ft.).

Williamson

We accounted for 47 animals in Williamson during a summer survey: 22 adult females, 4 yearling females, 10 lambs, 6 adult males, 3 yearling males, and 2 yearlings of unknown sex. This included observations in both the northern Williamson deme (13 adult females, 1 yearling female) and the southern Barnard deme (9 adult females, 3 yearling females). This is the highest Williamson count on record. All 6 collared females were seen during this count.

Four new animals were captured in the fall, including 3 females and 1 male. Fourteen mortalities were detected over winter. The first occurred the day after capture activities on October 30 but was not investigated until the following summer. By that time, S561F had been scavenged, and a specific cause of death was not able to be determined using the limited remains found below a boulder in a steep gully. The other mortalities included 9 collared animals (9 females) and 5 uncollared animals (1 female). All other collared animals died from snow (5) or avalanche (3). Four of the uncollared animals were killed by lion L214F between January 1 and February 17th. The other uncollared male was killed in an avalanche and encountered opportunistically while investigating one of the collared female mortalities.

After killing three sheep, L214F moved away from the Williamson area. However, in March, she killed a sheep in Diaz Creek within the Langley herd. On March 24, she was recaptured in Lubkin Creek and translocated to the middle fork of Lytle Creek in the San Gabriels.

Likely influenced by the incredible snowpack, GPS collars indicated some novel habitat use north of Georges Creek at low elevations (~6500ft.). Also, GPS-collared male S598M utilized northern areas, particularly east of the crest in the vicinity of Mt. Bradley and Mt. Keith, as well as dropping into lower Center Basin, an area which was used by Baxter female S167F in 2013. Historically, S167F moved between Baxter and Williamson.

Baxter

This year we accounted for 114-119 animals: 41 adult females, 9 yearling females, 3 females of unknown age, 2-7 unclassified animals, 24 lambs, 24 adult males, and 11 yearling males. We report a range because a group of 10-15 was seen very briefly and only partially classified. Females, lambs and yearlings (both sexes) were counted during a summer survey in July, and adult males were counted during February.

No animals were captured in Baxter this year. We detected 12 mortalities, including 4 females, 7 males, and one of unknown sex. The mortality of unknown sex was a lamb skull encountered opportunistically and neither the sex nor the cause of death could be identified. L230F killed 4 Baxter animals (3 males and 1 female) and L228M killed one male. L230F was first captured and collared on January 24, 2023 and proceeded to kill 9 bighorn (3 from Baxter, 6 from Sawmill) before being recaptured on April 17, 2023 and translocated from Sawmill to the San Gabriels. Four animals died in four different avalanches, including 2 collared females and 1 collared and 1 uncollared male found opportunistically. The cause of death for collared S307F was not able to be determined, but it was not predation. Considering the record winter and the large losses in many of the other herds, Baxter had only moderate mortality. There was no noteworthy or new habitat use detected from GPS collars.

Sawmill

During the summer survey, we accounted for 66 animals: 31 adult females, 7 yearling females, 16 lambs, 3 unclassified animals, 5 adult males, and 4 yearling males. Ten out of eleven collared females were seen; there were no collared males at Sawmill during the survey window. This survey included data from a passive wildlife camera set near Taboose pass (adding 1 adult female, 1 lamb, and 1 yearling male). Cameras also helped determine that S542F had lost her VHF collar. Unusually, S461F was also discovered to have lost her VHF collar so at this time she only has an ear tag. This survey included animals from all three Sawmill demes: core, Goodale, and Acrodectes.

We detected 19 mortalities in Sawmill, including 11 females (10 with collars), as well as 2 uncollared males, and 6 unknown sex animals without collars. Nine were killed by lions, including 8 by L230F. L230F was first captured and collared on January 24, 2023 on a bighorn kill at Sawmill, and proceeded to kill 9 additional bighorn (3 from Baxter, 6 from Sawmill) before being recaptured on April 17, 2023 and translocated to the San Gabriels. In May, an unknown lion killed S540F. Additionally, 8 bighorn were killed from snow-related causes: 4 from avalanche including three in a single early avalanche in Taboose Canyon, 1 from starvation, and 3 were identified as snow-related but the specific mechanism could not be identified. Additionally, one animal died from physical injury and one from unknown cause.

On March 20, eleven animals were captured and collared, all previously uncollared (9 females and 2 males). These animals were captured from low elevation habitat where lion predation was a concern. Within four days of capture, one of the newly collared females was killed by L230F.

One of the most noteworthy bighorn movements associated with the big winter of 2022-23 was female S543F who moved down and out into the lava flows of the Owens Valley in the vicinity of Taboose Creek, moving as low as 4200ft. and nearly 4 miles from the steeper Sierra escarpment in January and February. She was viewed several times in a group of 3, which included an adult male and a female with stubby horns that was believed to be a yearling. Additionally, S652M and S653M used novel habitat on the southern edge of Shingle Mill Bench in April along with S543F.

Bubbs

On July 15, we counted 32 animals: 10 adult females, 2 yearling females, 7 lambs, 9 adult males, and 4 yearling males. The majority of these animals were seen crossing high on the southeast shoulder of Mt. Gardiner moving south out of Gardiner Basin. Additionally, a group of seven rams was seen by a hiker the same day in the vicinity of Fin Dome in 60 Lakes Basin. Baxter male S596M was seen in the ram group but not included in the count, as he is counted in the Baxter herd. With the exception of S596M, no other animals were collared in the Bubbs region.

In October, we got lucky and captured 5 Bubbs animals including 3 females and 2 males. Prior to this capture, we had tried to get collars in Bubbs for years, but with no collars to help lead in the capture crew since 2019, we had not been successful. Unfortunately, one of the newly collared males died two days after capture from capture-related causes. By the following summer, at the start of the 2023 animal year, three additional mortalities were detected including a female and male that died in May and June respectively, but the cause was not able to be determined. Additionally female S631F has been heard intermittently on mortality since March 31, 2023 and has not been seen since capture. That leaves us with a single collared female, S630F. GPS collar data indicates animals used slightly lower habitat within Bubbs Creek, but otherwise no outstanding habitat use was detected.

Taboose

On November 13, 2022, a group of 3 animals were observed wallowing in 3 feet of snow on the north face of Kid Mountain. This is the only observation from Taboose this year; it is unknown if these animals survived the winter. This is also a known undercount because subsequently, we detected 6 mortalities later in the winter and spring, four of which were uncollared animals encountered opportunistically, and three were reported by skiers. In October, S412F died of unknown cause high on a ridge between Kid and Birch mountains. The other five mortalities were snow-related, including a female that died in an avalanche in a western gully of Kid Mountain above the south fork of Big Pine Creek and an uncollared male that was found intact nearby but not clearly in an avalanche path that was identified as a snow-related mortality. S512F was found dead with a lamb of unknown sex at the base of a cliff in Tinemaha Creek, and both mortalities were identified as snow-related.

Before dying in an avalanche in March above the south fork of Big Pine Creek, S578F traveled below the middle Palisade Glacier and also visited the north side of Kid Mountain, two areas that have not seen much use historically. Also, it appears that animals are traveling across the crest in the fall just south of the Thumb.

Wheeler

We accounted for 72 animals at Wheeler during a summer survey: 33 adult females, 7 yearling females, 19 lambs, 10 adult males, and 3 yearling males. All but one of the 12 collared females were seen and 50% (2/4) of the collared males were seen. Females were observed in all three demes: Granite Park (14), Morgan (9), and Hellcat (16).

In October, five Wheeler animals (3 females and 2 males) were captured including 1 male and 1 female recapture. We detected 25 mortalities at Wheeler this year including 17 uncollared animals; most of these were identified from GPS-collared lion clusters. Six GPS-collared lions killed 18 bighorn: L148M killed 7 bighorn including 3 males, 2 females, and 2 of unknown sex from Pine Creek Canyon along the face to Hellcat; L194F killed 3 uncollared females in Hellcat; L212M killed one collared female at 11,600ft. above Finch Lake in May; L229F killed 2 females and 1 male on the Wheeler face between Mayfield and Boundary canyons and also visited other kills sites and scavenged a bighorn that died from avalanche; L234F killed an uncollared male below Rabbit Ears and also visited two other kill sites, and one unknown sex lamb was killed in Hellcat Canyon by an unknown lion. Additionally, 5 bighorn (3 females, 2 males) died from avalanche including two at very low elevation (<6600ft.) in Pine Creek. One collared male died of snow-related causes in January, and a hiker found a female skull near Chicken Foot Lake which likely died during the winter of 2022-23, but the time and cause of death could not be identified.

We detected no novel or notable habitat use in winter. S242F used habitat near Mt. Hilgard in September including a visit to the summit of Mt. Gabb. GPS collars also detected Granite Park animals visiting Merriam, Feather, and Royce Peaks, and the Bear Lakes Basin in September.

Convict

On August 7, we counted 20 animals in Convict in Esha Canyon: 7 adult females, 5 lambs, 5 adult males, and 3 yearling males. This is slightly down from our highest count last year (9 females), but we know of 3 female mortalities between these two surveys, which indicates there may have been 10 females in 2021, or perhaps an individual emigrated into Convict.

We detected 9 mortalities in Convict: in May one female died from lion predation, and one died due to birthing complications, and the other 7 (6 females, 1 male) died of snow-related causes during winter. Three of these were starvation, 1 was avalanche, and we were not able to differentiate the specific cause beyond snow-related for the other two.

If our count was a census and given these mortalities, we would expect there may be only one single uncollared female remaining in Convict. In November, several animals visited the western shoulder of McGee Mountain, which had not been known to be used before.

Gibbs

By combining various observations throughout the summer, we were able to account for 50 animals at Gibbs: 17 adult females, 3 yearling females, 9 lambs, 18 adult males, and 3 yearling males. This included observations of 4/4 collared females and 3/4 collared males. Females were found in both the Gibbs (13) and Algers (7) demes.

We detected 16 mortalities at Gibbs (8 of each sex). Most of these occurred during the winter, apart from S339F who appeared to have died while giving birth in May. This is one of two birth-related mortalities identified in 2022 and the only two birth-related mortalities ever detected. In the winter, 13 bighorn died of snow-related causes, and two individuals died of unknown causes. Within the snow-related mortalities, 2 died from two different avalanches, and 3 died from starvation at different high elevation locations; the more specific cause (avalanche vs. starvation) of the other snow-related mortalities was not able to be determined. No noteworthy or unusual habitat use was detected from GPS collars.

Warren

By combining observations from June and July, we were able to account for 20 animals at Warren: 10 adult females, 3 yearling females, 2 lambs, 1 adult male, and 4 yearling males. All six collared females were observed and there are no collared males at Warren at this time. In the fall, 6 animals were captured including two recaptured females and 4 new captures (3 females, 1 male).

During the winter, we detected seven mortalities, all snow-related, with 3 identified as avalanche and 1 identified as starvation. Mortalities included 4 females, 1 male, and 2 animals of unknown sex.

GPS collars detected no use near Camiaca Peak; it seems this deme may be entirely lost. We detected some use of lower habitat between Dunderberg Peak and Kavanaugh Ridge and the east fork of Green Creek.

Cathedral

On July 20th, we counted 12 animals at Cathedral: 5 adult females, 5 lambs, 1 adult male, and 1 yearling male, and we believe this is a census. This would mean the two unidentified yearlings from last year were male and female. All three collared animals were seen (2 females, 1 male). In the winter the two collared females died, one from avalanche and the other was snow-related, both near Parsons Plateau. We believe that the other females also died, but we do know that at least 4 males survived. No novel or unusual habitat use was detected from GPS collars.

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. For bighorn, we use ‘2022’ to represent the animal year May 1, 2022 - April 30, 2023, beginning with lambing season and including the winter of 22-23. In contrast, climatologists refer to water year 2022 as October 2021 - September 2022, which is most clearly associated with bighorn year 2021. “Source” herds (Wheeler, Sawmill, Baxter, and Langley) have contributed to recent reintroductions (starting 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 Eigenvalue Lambda Estimation

We estimate the annual population growth rate 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, 2022 - April 30, 2023.

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.

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.

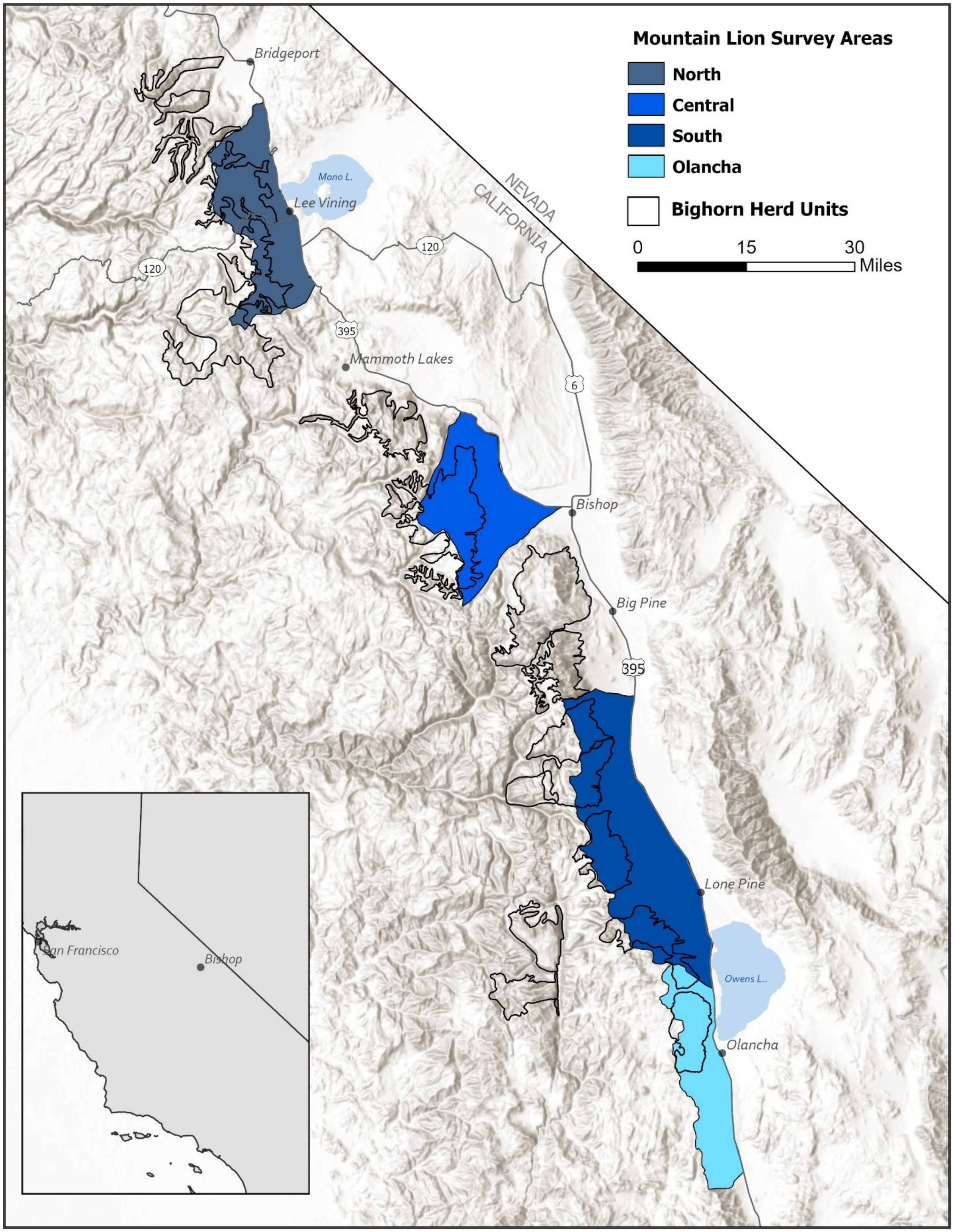

Figure App. 1. Mountain lion count zones in the eastern Sierra Nevada, with Sierra bighorn herd units for reference.

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.

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.

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.